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ICPI

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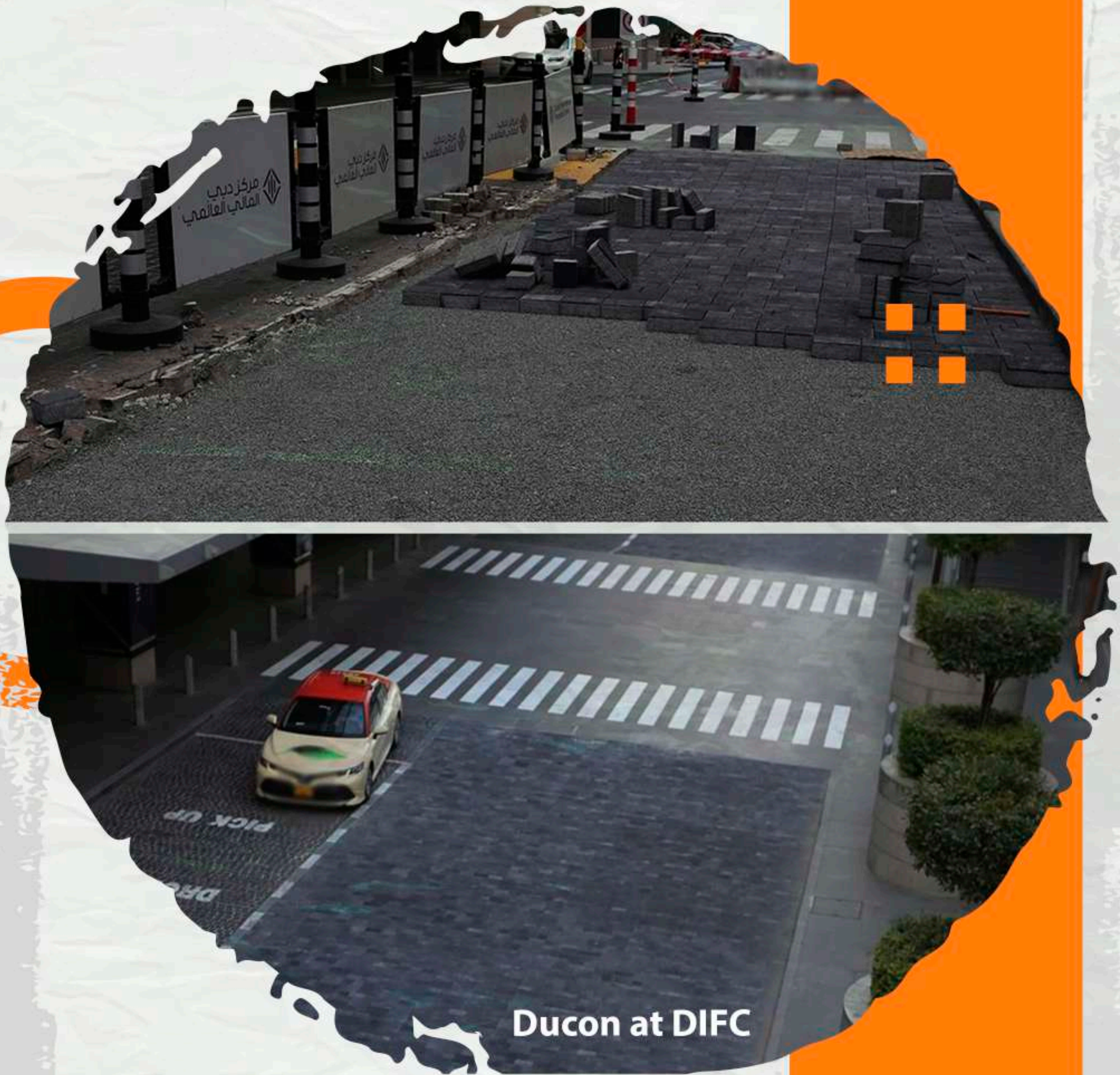

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أنصحك
ANSA7K
1- CHECK DESIGN SUITABILITY
2- CONTRACTOR COMPATIBILITY AND ETHICS
3- SITE READYNESS TO START
4- ROADBASE MATERIAL AND LEVEL CHECK
5- INSTALLATION ADVISE AND WASTE MANAGEMENT
6- AS BUILT DESIGN CHANGES

DUCON
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MANUAL

DUCON
OUTDOOR LIVING

Introduction
[CPI01]

Student Manual
ICPI Concrete Paver Installer Course

icpi
Interlocking Concrete
Pavement Institute®

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Interlocking Concrete Pavement Institute
14801 Murdock Street, Suite 230
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Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Every effort has been made to present accurate information. However, the recommendations herein are guidelines only and will vary according to local conditions. Professional assistance should be obtained in the design, specifications and construction with regard to a particular project.

Table of Contents

Introduction

Thousands of companies throughout North America build interlocking concrete pavement. The role of paving activities within these companies falls into one of three categories.

First, there are companies that emphasize segmental concrete pavement as the main business of their company. These companies are few in number and they install concrete pavers more than other materials. The larger and more mature ones have developed marketing and business skills. They actively promote their services to project owners, general contractors, developers, and design professionals.

Figure 1-1: Example of a well-planned, highly functional paved walkway and pool deck

Second, there are companies that have a division or group that does segmental paving. These companies can be asphalt and concrete pavement contractors or landscape contractors who also install pavers and segmental concrete retaining walls (SRWs). These are often called hardscape contractors. A smaller group within North America are mason contractors who may have a division that installs concrete pavers, typically using crews with skills for installing mostly commercial applications.

Characteristics of hardscape contractors in the second category are separate crews and management, and sometimes separate companies installing pavers and SRWs. They represent the majority of the companies that place interlocking pavement. Some companies separate their paving and SRW operations from other services and often run it as an incorporated profit center.

The third group are companies who install pavers when the opportunity presents itself. They do not actively promote or seek paver jobs, but take them when they come along. Some landscape contractors and some masons fall into this category.

These three contractor categories present a unique mix of backgrounds, technical, business and marketing skills. Due to these diverse approaches, there are differences in knowledge and in the quality of paving jobs. The most influential person in determining the quality of a job is the site foreman, or job supervisor, whose degree of knowledge and crew management skills ultimately determines the quality and efficiency of installations. In smaller companies this person can be the owner.

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Section 1 Part A:
The Course: Objectives, Prerequisites, and Benefits

Objectives

Video Supplement Introduction

In order to establish and maintain installation knowledge among contractors, the Interlocking Concrete Pavement Institute (ICPI) created a certification course on the installation of interlocking concrete pavement. Since 1996 over 30,000 have taken this course and about 2,500 maintain ICPI certification. The objectives of the certification are:

1. Learn how to meet or exceed industry established guidelines for paver installers. Topics include site planning, base, bedding sand and paver installation, use of labor saving specialty tools, and documenting job costs for job estimating.

2. Broaden, evaluate, and recognize knowledge through certification of individuals that have successfully completed the course and passed an exam, and have installation experience. Receiving certification is a way to gain recognition in a career.

3. Provide credible promotion by the individual contractor and by the ICPI. This is accomplished by ICPI promoting certification through its technical literature, guide specifications, and marketing literature, as well as by ICPI producer members and installation companies with certified installers. Additional contractor credibility can come from the number of years in the contracting business, written job references, a project portfolio, membership in local business associations and with ICPI.

4. Benefit design professionals and the general public by creating and contributing to a perception of value and quality. Certification identifies a higher level of desire to excel in the career of interlocking concrete pavement. This can be important to homeowners, architects, landscape architects, engineers and general contractors as they influence the selection of interlocking concrete pavement contractors.

Certification Renewal and Continuing Education

This course is designed for residential and small commercial contractors. Participants who take the course and score 75% or higher on the exam will receive a Record of Completion. Upon meeting the minimum installation experience requirements for certification, a participant will receive an ICPI Concrete Paver Installer certification document with a certification term of two years. Continuing education credits must be earned within each certification term in order to renew certification. Visit the Education section of the ICPI website (www.icpi.org) to learn about approved continuing education programs.

Promotion of Contractor Certification by ICPI

The ICPI consists of members who represent the majority of concrete paver production in North America. The Institute also represents a growing number of contractors. Promotion of ICPI concrete paver installer certification by ICPI and its members is to homeowners and design professionals---architects, landscape architects and engineers. This is done through a variety of publications:

Choosing the Best Pavement and the Best Installer
This brochure answers homeowner questions about interlocking concrete pavement and guidance on how to select a certified installer/contractor, and provides a project checklist.

Building a Pavement to Last a Lifetime
This brochure provides homeowners an overview of what to expect during construction of a new paver patio, walkway, driveway, pool deck or entryway.

Peak Performance from Concrete Pavers
This brochure provides tips on preventing stains, weeds, ants and efflorescence, and explains the causes of efflorescence and remedies.

ICPI Website
The ICPI website provides homeowners and commercial customers with important information about products, systems, and selecting qualified contractors. Visit www.icpi.org.

Interlock Design Pavement Magazine
The magazine features paver projects and industry news. It circulates to thousands of design professionals in the U.S. and Canada, as well as to contractors and suppliers. This is a key avenue for communicating the ICPI certification program.

Press Releases and e-Newsletters
Press releases and a biweekly e-newsletter called "Paver Express," in which ICPI continues to educate design professionals about the certification program, are read by thousands of design professionals.

All of these avenues create an awareness of the certification program and the need for specifiers to include certified installers in construction specifications. In short, the ICPI supports installers who obtain certification!

Prerequisite Skills and Knowledge

To be proficient in this course, the student should have:

- Ability to read English, understand spoken English and perform basic math calculations (addition, subtraction, multiplication and division)
- Some knowledge of industry terminology, materials and tools
- Recommend at least one year of experience installing interlocking concrete pavements

Section 1 Part B:
Registration and Course Procedures

Participation in ICPI Concrete Paver Installer Certification follows these steps:

1. A local sponsor contacts ICPI with a date and location for a class. The sponsor must be an ICPI member, Government Agency, Municipality, approved Non-Profit Association or Educational Institution. The local sponsor enters into an agreement with ICPI to hold the class. The sponsor may be one or more companies. The sponsor identifies instructors and invites contractors to attend a class in their local area. A session coordinator is designated by the sponsor that communicates with ICPI staff on registration, materials, exams and fees.
2. The instructors must have attended ICPI instructor training. Contractor instructor or lead instructor can teach alone, while a technical instructor must be accompanied by either a contractor or lead instructor.
3. The local sponsor will set the class time and date, arrange the meeting place, and provide information on lodging if needed. The sponsor generally pays most meeting expenses. These may include the classroom, coffee, AV equipment, instructor's expenses, etc. Instructors must be ICPI members, staff or licensed design professionals.
4. A completed course application and payment must be submitted by an applicant to the ICPI either on-line at www.icpi.org/educate or fax to ICPI for enrollment in the local class. The application should arrive at ICPI offices no later than 10 days before the class date.
5. Members and non-members of the ICPI may participate as students in the course.
6. The student manual and a class schedule will be distributed at the class. Class attendance is mandatory for both days of class.
7. In order to receive a Record of Completion the course exam is mandatory and must be passed. The exam is given at the end of the last day of the course. The exam is a "closed book" exam. After the course, the instructor will send exams directly to ICPI for grading. Exams with at least 75% correct answers are considered passing. ICPI distributes the exam results and a Record of Completion to those who pass.
8. Upon meeting the minimum installation experience requirements, a participant will be issued an ICPI Concrete Paver Installer certification document. The certification term is two years, and continuing education hours must be earned within each certification term in order to renew.
9. Letters are sent to those who did not pass the exam within 30 days of the receipt of exam grades by ICPI. They can elect to take the course again for a fee. However, the course may be in another location. Appeals may be submitted in writing to the Director of Education and Workforce Development, ICPI, 14801 Murdock Street, Suite 230, Chantilly, VA 20151. The appeal should fully explain the basis of the appeal. ICPI will respond in writing to the appeal within 30 days.

Note: Certification and Membership have separate application and fees in ICPI.

Disclaimer and Understanding

The Interlocking Concrete Pavement Institute ("ICPI") Concrete Paver Installer Programs are intended to communicate industry guidelines to paver installers on estimating, planning and executing residential and commercial projects and to educate individuals in applicable construction and general business practices.

ICPI recognizes only that a Record of Completion awarded to a participant conveys that the participant has completed the required course of instruction and earned a passing grade on the examination administered by ICPI at the conclusion of the course. For a participant obtaining ICPI Concrete Paver Installer certification or designation status, ICPI recognizes only that the certificate holder has earned a Record of Completion and has also met the minimum amount of installation experience required by ICPI. ICPI exercises no control or direction over certified concrete paver installers and does not in any manner endorse, guarantee, or certify the performance or quality of services rendered or products used. ICPI further disclaims any and all liability for injuries or damages to persons or property or for monetary damages arising out of or resulting from the failure of performance of services rendered or products used by an installer holding an ICPI certification or designation.

Section 1 Part C: Concrete Segmental Paving: A Brief History

The concept of tightly fitted paving units on an aggregate base is very old. History records that the first segmental roads were built about 5,000 years ago by the Minoans. With almost free labor and military dominance, the Romans built the first interstate system with segmental pavement over 2,000 years ago. That system was longer than the U.S. interstate highway system. Since then, practically every culture continues to use segmental pavements.

Figure 1-2: The Romans built the first interstate highway system with segmental pavement over 2,000 years ago.

European nations used segmental paving for centuries. Of particular interest are the Dutch, who live on land reclaimed from the ocean and protected by dikes. The ground settles 6 in.–12 in. (150 mm–300 mm) every five to ten years. Settlement is caused by removal of water in the soil that slowly seeps in from the sea. The pavement surface has to be removed during this interval and the underlying base brought up to grade. The need for a pavement that can be removed and reinstated led to a 1,000-year tradition of using segmental paving, most of it made from clay.

After World War II in the midst of rebuilding, the Netherlands experienced a shortage of coal to fire clay bricks for buildings and pavement. All the clay units made went to constructing buildings. There were few available for pavement. Concrete paving units, approximately the same size as clay units, were developed as a substitute. The idea quickly spread to Germany. German and Dutch companies developed high-efficiency concrete paver manufacturing equipment in the 1960s. Production technology spread to England, Europe, Australia, Japan New Zealand, and South Africa in the 1970s. Today, Germany produces over one billion ft.^{2} (100 million m^2) annually.

Brick streets were extensively used throughout the older portions of North American cities in the 1800s and early 1900s. However, North America appears to be the only place where the use of segmental paving greatly diminished. From the 1920s to the 1970s, segmental paving was forgotten, suppressed by rising labor costs and the invention of the automobile with its need for a smooth surface. This era was a minor setback in a seven-thousand year history of segmental paving throughout the world. Unfortunately, several generations of North American architects, engineers, and contractors practiced with almost no working knowledge of this technology during this era. Know-how in segmental paving faded for lack of use and improvement.

Fortunately, this set back has been temporary. In 1973 paver production technology was transferred from Germany to Canada and quickly spread to the United States. The advent of interlocking concrete pavements in the 1970's revived segmental paving in North America. Segmental paving being absent from trades and college education, urban design, civil engineering, and life's daily experiences appears to be over. Interlocking concrete pavements began and continue to lead this revival. Users have recognized that pavers satisfy the need for a safe, cost-effective, easy-to-repair, smooth riding surface for the automobile and the need for convivial, human scale not offered by visually boring conventional pavements.

As of 2017, North American companies sold about 800 million $ft.^2$ (80 million m^2) of concrete pavers. This does not include millions of square feet or square meters of larger paving slabs and grid units. While this represents significant growth over 20 years, it is small in comparison to the other 6 billion $ft.^2$ (500 million m^2) sold globally each year. There is much potential for interlocking concrete pavements in North America and installer certification is a step toward reaching it.

Section 1 Part D: Overview: Components of an Interlocking Concrete Pavement System/ Comparison to Other Pavement Systems

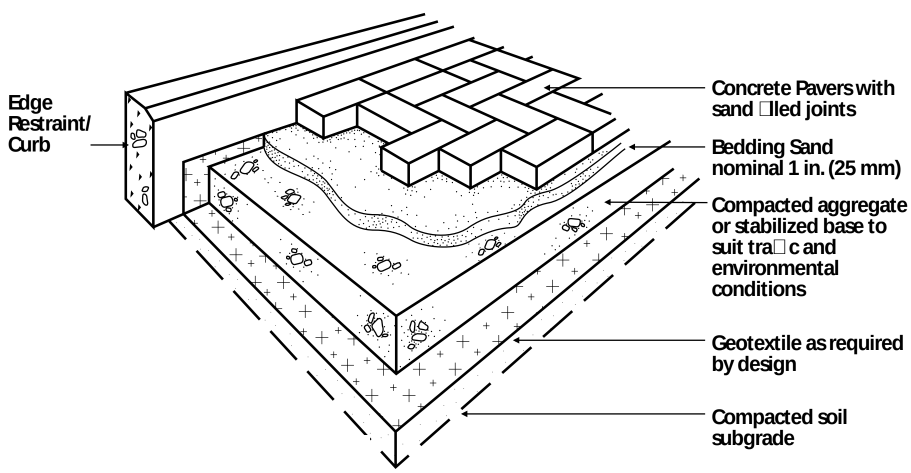

Figure 1-3: Components of interlocking concrete pavement.

Interlocking concrete pavements are flexible pavements. Flexible means that loads are distributed through the base by point-to-point contact and interlock among an aggregate base.The base protects the soil subgrade from deforming under loads. The base moves slightly when a load is applied, returning to its original (or near original) position. The base spreads the loads from a car or truck tire through successively weaker layers of base material. When the load reaches the soil layer, it is distributed across a wide area so that the soil does not deform or rut. As an added benefit, flexible pavements can move slightly from normal movement in the soil and from seasonal changes in the moisture without losing their load-spreading ability.

Interlocking pavers spread loads across the base. They can move with minor movements in the base without cracking. This gives them a distinct advantage over asphalt and poured concrete. These pavements can crack more readily should the base move from loads or settlement. They also crack from expansion and contraction due to temperature changes.

The unique aspect of concrete pavers is that they interlock to help spread loads. There are three kinds of interlock: vertical, rotational, and horizontal. Figure 1-4 illustrates these kinds of interlock that work together.

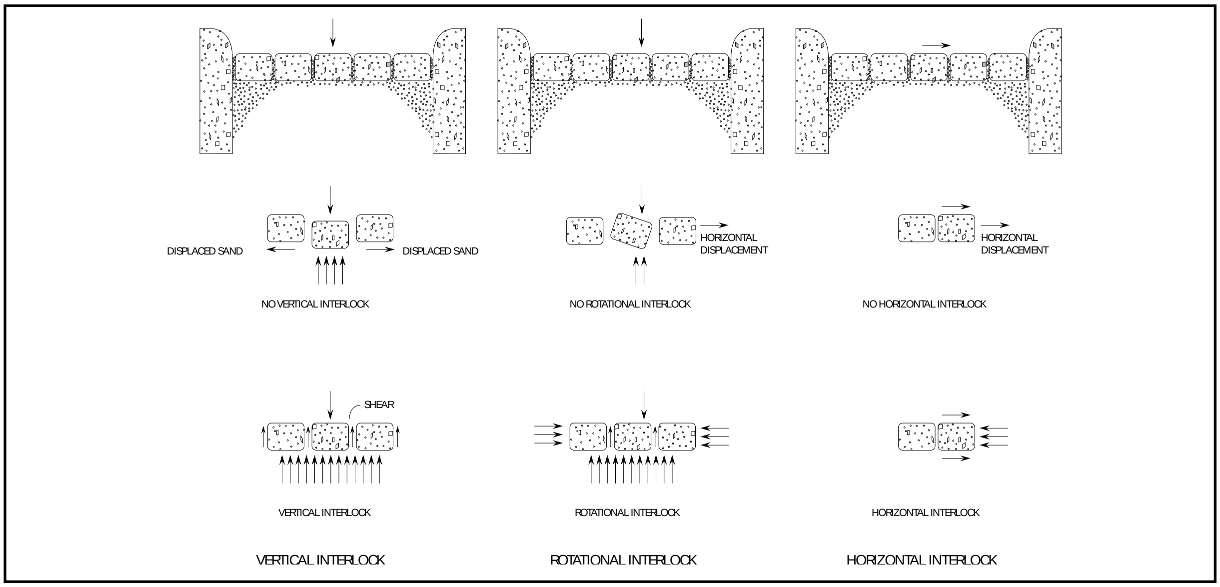

Figure 1-4: There are three kinds of interlock: vertical, rotational, and horizontal. The unique aspect of concrete pavers is that they interlock to help spread loads.

Vertical interlock is achieved by the shear transfer of vertical loads in horizontal paths to surrounding units through the sand in the joints.

Rotational interlock is maintained by the pavers being of sufficient thickness, placed closely together, and restrained by a curb from lateral forces of vehicle tires. Rotational interlock can further be enhanced if there is a slight crown to the pavement cross section. Besides assisting drainage, the crown enables the units to tighten slightly through loads and minor settlement, thereby increasing load bearing capacity.

Horizontal interlock is achieved through the use of laying patterns that disperse forces from braking, turning, and accelerating vehicles. The most effective laying patterns for maintaining interlock are herringbone patterns, and these are recommended in streets. Certain shapes have been shown to contribute to horizontal interlock, offering additional resistance to lateral forces from vehicles. Stable edge restraints, such as curbs, also maintain horizontal interlock, keeping the units together at the edges of the pavement.

In summary, the contractor achieves vertical, rotational and horizontal interlock by the interaction of these factors:
Thickness of the paver– 3 1/8 in. (80 mm) thick pavers typically used in parking lots and streets have a greater interlock than 2 3/8 in. (60 mm) thick pavers.
Laying pattern – Herringbone patterns have greater interlock than bond or parquet patterns.
Joint widths – Consistent sand-filled joint widths in the 1/16 in.-3/16 in. (2 mm–4 mm) range. Wider joints contribute much less.
Crown– Presence of a crown in the cross-section of the pavement. This settles with traffic and stiffens over time. The process is called progressive stiffening or lock up.
Stationary edge restraints– The pavement must be held tightly together at its edges.
Paver shape– Shapes that allow interlocking patterns to be placed (such as Herringbone) offer higher resistance to loads.

Other Pavement Systems

Other flexible pavement systems include asphalt pavements. They distribute wheel loads in a manner similar to interlocking pavement. However, concrete pavers are more durable than asphalt. Therefore, they offer higher resistance to abrasion, freeze-thaw cycles, concentrated loads, and to spilled oils and gasoline.

Rigid pavements include Portland cement concrete (PCC) pavement. Rigid pavements work on the principle of using a horizontal structure, or a layer of concrete, to protect the soil subgrade. Loads are spread by the concrete and bridge soft spots in the soil. While poured concrete is durable, it requires time to cure (usually 3-5 days) before being available for traffic. Poured concrete cracks and deteriorates due to shrinkage, loads, and weather. In contrast, interlocking pavement has joints or “cracks” that contribute to the strength of the pavement. These contribute to its ease of repair with no damage to the surface after reinstatement of the paving units. The pavement is immediately ready for traffic.

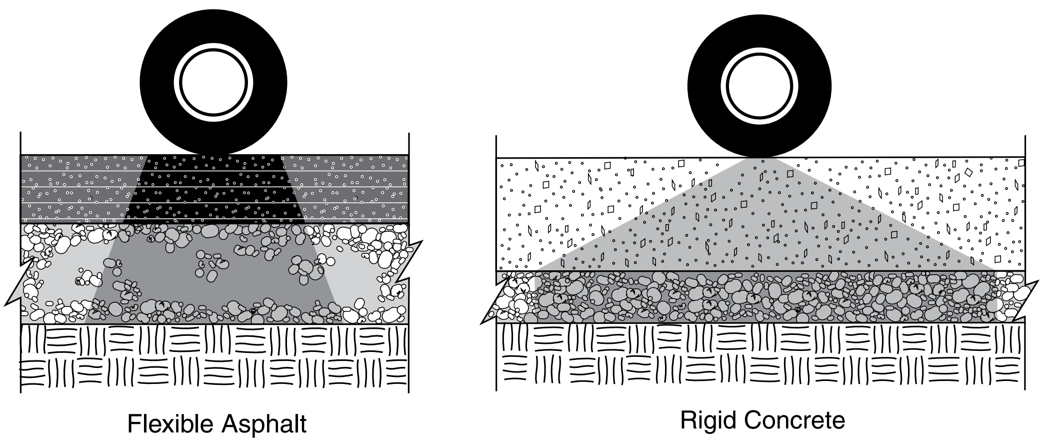

Figure 1-5: Load distribution of pavements

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Safety
[CPI02]

Student Manual
ICPI Concrete Paver Installer Course

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Pavement Institute®

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14801 Murdock Street, Suite 230
Chantilly, VA 20151
Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

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Section 2 Part A: Introduction – The Four-point System

Health and safety can sometimes be viewed as an inconvenience and an unnecessary expense. However, national figures estimate that accident costs amount to 6.5 cents of every construction dollar. Safety program costs, on the other hand, average at only 0.6 cents for every construction dollar. It is easy to see that safety programs can provide a substantial opportunity for a company to save money. The question for many small and medium sized companies is how to implement a safety plan with the already limited resources that they have. One way to get started is the OSHA (Occupational Safety and Health Administration) Four Point Workplace Program.

Introduced in 1989 the Four Point Workplace Program is an introduction to employers and employees for creating a worksite free from occupational hazards. This program is outlined in the OSHA bulletin, 2209-02R 2005 Small Business Handbook . The four point program consists of:

1. Management Commitment and Employee Involvement
2. Worksite Analysis
3. Hazard Prevention and Control, and
4. Training for Employees, Supervisors and Managers

Paver installation companies in Canada or the United States should develop a workplace program that follows these four points. A safety and health plan based on these four elements may not guarantee compliance with OSHA standards, but these voluntary programs are designed to recognize and promote effective safety and health management.

Following this voluntary program will offer several benefits to hardscape installation companies. They can improve a safety program that might already be in place, improve the efficiency of your operations, and ultimately they can reduce insurance claims and other related costs.

The key to the success of a safety and health plan is to view it as a part of your business operation and reflect it in your day-to-day operations. As you implement the plan and incorporate it into your business culture, safety and health awareness will become second nature to you and your employees.

Two important web sites provide resources for employers and employees. The U.S. Department of Labor, Occupational Safety and Health Administration web site can be found at http://www.osha.gov/ and the Canadian Centre for Occupational Health and Safety can be found at http://www.ccohs.ca/.

Section 2 Part B. Implementing a Company Safety Program

The first point in the OSHA four point program, “Management Commitment and Employee Involvement” is key to implementing a successful company safety program. This is an important step for business owners, since employees need to see leadership demonstrating that the owner or manager is interested in preventing employee injury and illness. Some of these actions include:

1. Forming a joint employee-management safety committee
2. Develop a company policy on the importance of worker safety and health and post this in a prominent location
3. Developing health and safety objectives with your employees
4. Staying active on all health and safety initiatives to demonstrate your ongoing commitment
5. Ensure the managers and supervisors follow all safety requirements that the employees must follow
6. Include the employees in the safety inspections and in putting on safety training
7. Include safety as part of every job responsibility
8. Ensure there are adequate resources for your employees to implement safety measures and programs, including money, training, and authority
9. Follow up on the progress regularly and reward those who do well and correct those who do not
10. Review your objectives annually and make necessary adjustments as required
11. Conduct toolbox talks on a regular basis to educate and review job site safety and concerns.

Section 2 Part C. Conducting a Hazard Analysis

Everyone in the company needs to understand “where” and “what” in the work place that can cause injuries. This means conducting a work site analysis and determining a list of common jobsite hazards. This is the first step to Hazard Prevention and Control. The main objectives are eliminating hazards, but where this may not be possible you should set up company procedures to control them. Conducting a Hazard Analysis includes:

1. Identifying and isolating specific tasks related to your operation
2. Identifying the risk of injury from such things as impact, vibration, dust, temperature, electrical, and lifting
3. Determining ways to eliminate the hazard or control the risk of injury
4. Assigning the hazard control to the proper person on the job site and/or management

A simple form can be developed by you to implement your own Hazard Analysis. An example is shown in Figure 2-2. All employees involved in every task, from the general laborer to job site foreman to the owner should be involved in this process.

Information obtained from a job hazard analysis is of no use, however, unless hazard control measures recommended in the analysis are incorporated into the tasks. Managers should recognize that not all hazard controls are equal. Some are more effective than others at reducing the risk. Employees should continually assess the effectiveness of control measures for each situation

OSHA describes the order of precedence and effectiveness of hazard control as follows:

1. Engineering controls.
2. Administrative controls.
3. Personal protective equipment (PPE).

Engineering controls include the following:

- Elimination/minimization of the hazard – Designing the facility, equipment, or process to remove the hazard, or substituting processes, equipment, materials, or other factors to lessen the hazard;
- Enclosure of the hazard using enclosed cabs, enclosures for noisy equipment, or other means;
- Isolation of the hazard with interlocks, machine guards, blast shields, welding curtains, or other means; and
- Removal or redirection of the hazard such as with local and exhaust ventilation.

Administrative controls include the following:

- Written operating procedures, work permits, and safe work practices;
- Exposure time limitations (used most commonly to control temperature extremes and ergonomic hazards);

- Monitoring the use of highly hazardous materials;
- Alarms, signs, and warnings;
- Buddy system; and
- Training.

Personal Protective Equipment is acceptable as a control method in the following circumstances:

- When engineering controls are not feasible or do not totally eliminate the hazard;
- While engineering controls are being developed;
- When safe work practices do not provide sufficient additional protection; and
- During emergencies when engineering controls may not be feasible.

Use of one hazard control method over another higher in the control precedence may be appropriate for providing interim protection until the hazard is abated permanently. In reality, if the hazard cannot be eliminated entirely, the adopted control measures will likely be a combination of all three items instituted simultaneously.

Section 2 Part D. Typical Hazards on a Hardscape Installation Project

In addition to the more common job site hazards, hardscape installation job sites also have some of their own unique hazards. Some of these include:

- Back injuries from lifting heavier segmental concrete products
- Back injuries from repetitive motion of paver installation
- Muscle pulls from digging and lifting
- Finger abrasion from handling concrete products
- Skin rashes or burns from job site chemical spills and splashes
- Eye injuries from saw cutting
- Lung and respiratory injuries from long term exposure to saw cutting dust
- Heat exhaustion
- Impact injuries from moving equipment
- Vibration related injuries from compaction equipment
- Hearing loss injuries from working with high decibel equipment such as saws and compactors
- Knee injuries from repetitive kneeling

Exposure to Respirable Silica

Workers exposed to respirable crystalline silica are at increased risk of developing serious adverse health effects including silicosis, lung cancer, chronic obstructive pulmonary disease and kidney disease. When concrete pavers are cut, equipment should be used that has demonstrated the capacity to reduce the amount of respirable silica exposure to levels below the OSHA specified limits. Examples include wet-cut table saws, dry-cut table saws with a vacuum, power cutters with a water attachment and power cutters with a vacuum attachment.

Certain combinations of site conditions and materials can increase the exposure level. For this reason, ICPI recommends that an N95 dust mask (2 band), half face respirator or a respirator with an assigned protection factor greater than 10 should also be used as part of a voluntary or mandatory safety program. These best practices will not guarantee the silica exposure level will be below OSHA specified limits. Contractors should use onsite monitoring to confirm that respirable silica exposure levels are below OSHA specified limits.

The Occupational Safety and Health Administration has published a guide, "Small Entity Compliance Guide for the Respirable Crystalline Silica Standard for Construction" to help small businesses understand and comply with OSHA's Respirable Crystalline Silica standard for Construction. This guide describes the steps that employers must take to protect employees in construction from the hazards associated with exposure to respirable crystalline silica. This document is available at https://www.osha.gov/Publications/OSHA3902.pdf.

Section 2 Part E. Personal Protection Equipment

Typical personal protection equipment (PPE) includes respirators, hearing protection, protective clothing, safety glasses, hardhats, and workboots. Safety footwear protects paver installers' feet from becoming injured by tools slipping out of their hands, dropping parts, rolling objects, palletized products, etc. A safety footwear program is an important part of bringing contractors into compliance and possibly results in lower insurance premiums. Most safety shoes and boots are also designed with slip-resistant soles. Slips, trips and falls are included in the most frequent causes of workplace injuries. Safety footwear provides the wearer with added slip-resistant protection as well. Other equipment developed especially for paver installers are pictured below.

KneeSeat – A KneeSeat™ is an alternative to traditional knee pads, offering greater comfort and less stress on the knees when kneeling

Finger Tape – Finger tape is used to protect fingers when using rough product or in wet conditions

Knee protection – Knee pads protect workers knees from moisture, cement, cold and sharp rocks

Photos courtesy of PAVE TECH

Figure 2-1: Examples of safety equipment for paver installers.

Dust masks – OSHA requires a minimum of 2 head bands and a bendable steel nose bridge

Hearing Protection – Hearing protection is required around any noise producing activities such as sawing, compacting, or other machine operations

Gloves – Hand protection will protect installers from abrasive injuries; shown are vinyl coated polyester gloves

Safety Glasses – A good pair of safety glasses must protect the front and sides of the eyes. They should not be too dark of a tint and should be worn whenever impacting, striking, cutting or splitting anything.

Figure 2-2:
Sample of a
Job Hazard Analysis

Job Location: Stationary Table Saw on Job Site	Analyst Joe Safety	Date
Task Description: Employee takes marked pavers from pile and uses stationary diamond table saw to cut pavers		
Hazard Description • Employee could cut fingers or hands with saw • Employee could have small pieces of concrete fly into eyes • Employee could ingest dust .		
Hazard Controls: 1. Ensure guard is installed on table saw. 2. Wear eye protection. 3. Wear protective gloves. 4. Wear appropriate dust mask		

Source: http://www.osha.gov/Publications/osha3071.html

Figure 2-3: Sample of a
job function analysis

Job Title:	Job Location:	Analyst	Date
Task #	Task Description:		
Hazard Type:	Hazard Description:		
Consequence:	Hazard Controls:		
Rationale or Comment:			

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Tailgate/Toolbox Topics

California Department of Industrial Relations · CAL OSHA

Division of Occupational Safety and Health
Cal/OSHA Consultation Services Branch

Setting Up a Tailgate/Toolbox Safety Meeting

Jobsite tailgate and toolbox safety meetings are proven methods of preventing accidents, illnesses and on-the-job injuries. The safety meetings can be as brief as 10 or 15 minutes in length, and provide the opportunity to implement your Injury and Illness Prevention Program and improve the safety culture at your jobsite. Tailgate or toolbox safety meetings help employees to recognize and eliminate jobsite hazards.

Why Have Tailgate Safety Meetings?

If you work in the tunneling and construction industries, tailgate safety meetings are required by Title 8, Sections 8406 and 1509 of the California Code of Regulations.

While tunneling and construction are the only industries that specifically require tailgate safety meetings, all California employers must have a safety program that includes employee training in safe work practices (3203).

Tailgate/toolbox safety meetings can be used to address actual problems on the job or in the work area. The supervisors or foremen leading the meeting can draw on workers' own real life experiences, and use those experiences to remind all employees – especially newer ones – of the dangers of working with particular kinds of machinery, tools, equipment and materials.

Title 8, California Code of Regulations, Section 1509(e) states:

Supervisory employees shall conduct "toolbox" or "tailgate" safety meetings, or equivalent, with their crews at least every 10 working days to emphasize safety.

What to Talk About?

Talk about work practices, machinery, tools, equipment, materials, attitudes and anything else that may cause or contribute to a work-related accident or illness. Keep the topic relevant to the job or tasks that workers perform.

To identify safety meeting topics that will help your employees perform their jobs in a safer and more effective manner, you should review:

- OSHA Log 300 records (work-related deaths, injuries, and illnesses that require more than first aid treatment).
- Findings from safety inspections including corrective actions taken.
- Findings from accident investigations and near misses.
- Cal/OSHA Safety Orders (Title 8) at:
  http://www.dir.ca.gov/samples/search/query.htm

In addition to reviewing your records, look for potential safety hazards by carefully observing your workplace and employees' work activities. For example, if you notice that spills are not being cleaned up promptly, hold a tailgate safety meeting to discuss housekeeping policies. If an accident or a near-accident occurred at your jobsite, share the details and corrective actions during a tailgate safety meeting. Try to answer the following questions at the meeting: what happened? Where did it happen? How can it be prevented from happening again? Encourage employees to suggest topics to be discussed. Employees often know where the hazards are and can suggest corrective actions.

An excellent source for construction related topics is the publication Cal/OSHA Pocket Guide for the Construction Industry. Supervisors can choose individual sections or topics from this guide and tailor the information to the specific needs of their jobsites. Supervisors can also use the Tailgate Safety Meeting Topics worksheet for selecting, tracking and recording the tailgate meeting topics.

How to Run an E￿ective Meeting

1. Hold the meeting at the jobsite, preferably where everyone can sit and relax.
2. Hold meetings at the start of a shift or after a break.
3. Choose the topic carefully. Topics should be about health and safety problems on the job. Research the problem before the meeting. For issues with machinery, consult the manufacturer's operations manual. For handling toxic substances, get a copy of the Safety Data Sheet (SDS). Your insurance carrier is another valuable source of information. For Cal/OSHA's educational materials on worksite safety and health, please visit: http://www.dir.ca.gov/dosh/puborder.asp
4. Supervisors should chose topics that directly relate to their projects and job tasks, and remember to be prepared:
   - Explain why the topic is timely and important.
   - Familiarize yourself with the topic before discussing it.
   - Know your company procedures/Code of Safe Practices.
   - Make a short list of key points you want to cover.
   - Include relevant Cal/OSHA regulations and best practices.
   - Pick from the topics listed on the Tailgate Safety Meeting Topics, whenever possible.
   - Determine if the safety meeting material will be presented or distributed
5. Keep the topic specific. Do not choose an overly broad topic.
6. Make it practical. Demonstrate:
   - Safe work practices
   - Proper use of tools and equipment

7. Support employee participation by asking questions on work practices and encouraging discussion on the topics.
8. Talk about personal experiences or have one of the crew tell a story about a near miss, an injury, or a workplace fatality. Personal stories and experiences can dramatically enhance safety messages.
9. Keep the meeting short - usually 10 to 15 minutes.
10. After the meeting, take the time to consider the following:
    - Did the topic fit the jobsite?
    - Did the crew participate?
    - Did someone demonstrate safety equipment or safety practices?
    - Did the meeting lead to changes in work practices?
11. Evaluate the tailgate meeting's impact. Are employees clear on recognizing and correcting hazards? Ask questions, walk the jobsite and observe.
12. Document/record the meeting topic, date, who was in attendance and any actions taken such as recording safe work practices that employees can perform. Also note any other employer actions to be taken to ensure a safe workplace.

Additional Tailgate Meetings Resources

Further assistance on general safety and health training in the workplace, resources for conducting effective tailgate meetings and training/meeting materials may be obtained from the organizations listed below:

California Department of Industrial Relations Division of Occupational Safety and Health (DOSH)

Effective Workplace Training eTool
http://www.dir.ca.gov/dosh/etools/09-002/index.htm

Providing effective on-the-job training contributes greatly to a safer and more healthful work environment. This etool assists employers improve their ability to provide effective trainings. It provides practical information on regulatory requirements and step-by-step guidance for employers to conduct effective safety and health training in the workplace.

Construction Ergonomics
http://www.dir.ca.gov/dosh/PubOrder.asp

A series of ergonomic survival guides (English/ Spanish) are available to assist employers and employees on safety and health in construction. Contractors, foremen, and workers from various trades such as carpenters, electricians, cement masons, and others can benefit from the trade-specific safety tips and safer work practices included.

California Department of Public Health (CDPH) Occupational Health Branch

BuildSafe California Educational Materials and Publications
www.cdph.ca.gov/programs/ohb/Pages/BuildSafe.aspx#conducting

Information is presented as a tailgate meeting kit. The kit consists of a set of Safety Break cards (English/ Spanish) covering 23 construction safety topics. These cards promote a hands-on training approach that involves workers more directly in workplace safety, increased communication, problem solving and injury prevention. Also included are instructions on how to use the cards and a template for designing safety trainings using other topics contained in: Cal/OSHA Pocket Guide for the Construction Industry (Spanish)

California Department of Public Health

California FACE Program - Fall Prevention Tailgate Training Materials
http://www.cdph.ca.gov/programs/ohb-face/Pages/Tailgate.aspx

To prevent falls in the construction and solar industries, the California Fatality Assessment and Control Evaluation (FACE) program developed training cards to be used in conjunction with fatality story videos in tailgate meetings. These cards in English/ Spanish are simple to use, and cover four main fall prevention areas: skylights, roofs, and floor openings; step and extension ladder safety; scaffold safety; and fall restraint/fall arrest systems.

Training materials also include instructions and a template card on how to create your own tailgate meeting using topics contained in: Cal/OSHA Pocket Guide for the Construction Industry (Spanish)

Electronic Library of Construction Occupational Safety and Health (eLCOSH)
http://www.elcosh.org/index.php

This web page contains a wide range of safety and health educational materials employers in construction can use to train their workers. Included are a series of toolbox talks on numerous topics with easy to use trainer's talking points and training cards. Other materials are presented as handouts, factsheets, videos, wallet cards, and posters. Topics range from roofing safety and selection of power tools to ergonomics in construction and how to strengthen the jobsite safety climate. Educational materials are in English, Spanish and other languages.

Contacting Cal/OSHA Consultation Services

Consultation Programs:
http://www.dir.ca.gov/dosh/consultation.html
Toll-free Number: **1-800-963-9424**
Publications: http://www.dir.ca.gov/dosh/puborder.asp
Onsite Assistance Program Area Offices:

Central Valley: 559-454-1295	San Diego/Imperial: 619-767-2060
No. California: 916 263-0704	San Bernardino: 909-383-4567
SF/Bay Area: 510-622-2891	San Fernando Valley: 818-901-5754
La Palma/LA/Orange: 714-562-5525	

***Note**: The information provided is not meant to be either a substitute for or legal interpretation of the occupational safety and health regulations. Readers are cautioned to refer directly to Title 8 of the California Code of Regulations for detailed information regarding the regulation's scope, specifications, and exceptions and for other requirements that may be applicable to their operations.*

November 2015

Weekly Tailgate Topic: Avoiding Heat Stress

The sun and warm weather of summer can also bring special hazards for those working outdoors. The combination of heat, humidity and physical labor can lead to illness. The two most serious forms of heat-related illnesses are heat exhaustion (primarily from dehydration) and heat stroke. Signs of heat exhaustion or heat stroke need immediate attention. Recognizing those warning signs and taking quick action can make a difference in preventing heat illnesses.

The following are guidelines all employees should follow during the warm weather months:

1. Understand what heat stress is and be able to recognize the symptoms. It is a signal that says the body is having difficulty maintaining its narrow temperature range. The heart pumps faster, blood is diverted from internal organs to the skin, breathing rate increases, sweating increases, all in an attempt to transfer more heat to the outside air and cool the skin by evaporation of sweat. If the body can't keep up then the person suffers effects ranging from heat cramps to heat exhaustion, and finally to heat stroke.
2. Symptoms of Heat Exhaustion include headaches, dizziness, lightheadedness or fainting; weakness and moist skin; mood changes such as irritability or confusion; upset stomach or vomiting.
3. Symptoms of Heat Stroke include dry, hot skin with no sweating; mental confusion or loss of consciousness; seizures or convulsions. Seek professional assistance immediately.
4. Dry clothes and skin do not mean that you are not sweating. In dry climates, you might not feel wet or sticky, but you are still sweating. On a very warm day, you can lose as much as two liters of fluid.
5. Beat the Heat. Help Prevent the ill effects of heat stress by:
   - ✓ Drinking water or Gatorade frequently and moderately (about eight ounces every 15 minutes.)
   - ✓ If possible, avoid direct sunlight or other heat sources.
   - ✓ Try to plan your day to tackle more strenuous jobs during the cooler morning hours.
   - ✓ Utilizing the ventilation or fans in enclosed areas.
   - ✓ Rest frequently in cool, shaded areas.
   - ✓ Avoid alcoholic or caffeinated beverages and eat lightly.
   - ✓ Remembering that it takes about one to two weeks for the body to adjust to the heat; this adaptation to heat is quickly lost — so your body will need time to adjust after a vacation or extended absence.
   - ✓ Wearing lightweight, light-colored and loose fitting clothes.
   - ✓ Wear wide brimmed hard hats, neck protectors (Chill-Its) and sunscreen
6. Be prepared to act. In the event you recognize these symptoms in yourself or a co-worker, immediately notify your supervisor and contact emergency professionals. While waiting for First Aid or Medical Aid, you should:
   - ✓ Move the worker to a cool shaded area
   - ✓ Loosen or remove heavy clothing
   - ✓ Provide small sips of cool drinking water
   - ✓ Fan and mist the person with water

Questions to Generate Discussion

For your jobs practices, what are common and practical controls to prevent heat illnesses?

Workers Participating

Supervisor: ______________________________ Date: ______________________

Job Planning and Documentation
[CPI03]

Student Manual

ICPI Concrete Paver Installer Course

Interlocking Concrete Pavement Institute®

ISBN 978-0-9886795-0-4

Published in the United States by:
Interlocking Concrete Pavement Institute
14801 Murdock Street, Suite 230
Chantilly, VA 20151
Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Table of Contents

Job Planning and Documentation

Section 3 Part A: What's in it for me?

This course presents proper documentation. It explains its use beginning with the sale to collecting final payment at the end of the job. It will introduce some tracking, job costing and project management forms and paperwork an owner may use to maintain or grow a business. These forms are not intended to evaluate the performance of the crew but to provide a system that tracks materials used and labor functions of the jobsite.

Most of these forms are to always be kept in the office while some are copied and used in the field to provide essential information needed during a project. The forms presented may be modified by individual companies to their needs, but the system process is essential to success.

Section 3 Part B: Job Jacket Contents

The job jacket or folder is a file folder. It is created when the job is quoted. The folder and its contents stay at the office and never leave it. All originals are photocopied from this folder and copies are used in the field. If any documentation is lost in the field, it can be replaced by copying the original in the job jacket. The cover of the job jacket lists the project name, address, phone/fax/email, contact persons, list of payments made with dates and information specific to the job. The file contents include the items listed below and samples are given on the following pages:

1. Job proposal and drawing – A copy of the signed proposal and signed drawing provide the basis for planning the project. The original signed proposal is not given to the job foreman and remains in the office. A copy of the signed drawing and the signed proposal is given to the foreman to guide layout and construction.

When signed, the job proposal becomes a legally binding contract. The job proposal should include the type of work (walkway, patio, pool deck, driveway, etc.). Excavation and demolition items should be described and quantified. The proposal should also include the paving area, the name and color(s) of concrete pavers, the bedding sand thickness (1 in. or 25 mm) and material name, the thickness of the base and material name, and type of edge restraints. Sources of electricity and water should be on the proposal. These are sometimes supplied by the customer.

If permits are required or homeowner approval, the proposal should state the responsible party (contractor or owner). The same should be stated regarding utility location prior to starting excavation as this determines who is responsible for underground utilities. Utility location companies will not locate underground sprinkler systems. The contract should require the owner to locate and mark these prior to excavation. In addition, contracts should account for unforeseen circumstances such as buried construction debris, rock and roots and high depth to bedrock. The contractor should not pay for removing these items.

Additional works such as seeding or planting as a result of the paving project should be stated in the contract proposal. The contract should have a starting week. While not typical, a starting date can be written into the contract if the contractor does efficient scheduling of crews and has sufficient flexibility to work around bad weather.

The proposal should also reference a drawing or drawings for the project as they are part of the contract. The drawing is easiest to read and estimate quantities from when drawn on graph paper to a convenient scale. The owner/customer should sign the drawing as well as the proposal. The proposal and drawings can be used to clarify the scope of the job if questions arise. It can be useful in keeping the crew or owner from making any unauthorized changes. Changes orders (covered later) are kept in the folder as well.

Note on raised patios : Be sure construction complies with local building codes since the additional load from base material is often supported by the existing house foundation. This load may crack and damage the foundation wall. The existing wall and footer must be of sufficient thickness and strength to withstand additional loads. In some cases, an engineer should review and approve the design to obtain a permit. Prior to starting, the foundation should be inspected inside and outside for cracks and damage. Ask the homeowner about previous damage and leaks through the foundation walls.

2. Maps –A map photocopied from a city map or from the Internet shows the exact location of the job site and environs. Maps should also show where dump sites are located, as well as places for purchasing pavers, base, bedding sand, and other materials required for the job. Copies of these maps should be issued to the foreman and given to drivers going to the job. Besides company employees, drivers can include those hauling away materials, and those delivering base, sand, pavers, and other materials. Some companies are using GPS to find sites plus track vehicle mileage and travel times. GPS will save time and money. Mapquest and Google Maps, free internet map services, are other valuable resources.

3. Job Sheet –This gives essential information for the foreman to organize the job. It includes information on the materials, laying pattern, and edge restraints, plus any special requirements of the job. Samples of job sheets are given on the following pages. The exact format will vary with the preferences of the contractor. These forms can be modified by the contractor to suit particular needs. The foreman uses the job sheet to plan the job.

4. Daily Time Sheets –These are for recording all labor and materials for each day of work on a given job. Each crew member is responsible for completing a job sheet at the end of each day. The foreman completes his and collects the completed sheets from the crew. Each labor operation has a code or number so that the number of hours spent doing each can be tracked. Materials have code numbers as well. There are examples of these forms on the following pages. These codes are essential to tracking job costs if the information is entered into a computer database.

5. Job Quantity Sheets for Materials and Labor –These are provided by the estimator. The Job Quantity Sheets tell the foreman what materials and labor to document during the job. The estimated list of materials, labor functions and hours are provided by the estimator on the sheet. The actual amounts used are written by the foreman. The labor functions, number of hours, and materials used are transferred from the daily time sheets to the Job Quantity Sheets by the foreman. If there are additional labor functions, hours, and materials used, these are entered by the foreman on the Job Quantity Sheets.

The Job Quantity Sheets for Materials and Labor indicate what is expected from the foreman to complete the job. They are not intended to evaluate the performance of the foreman. The completed sheets help tell the estimator how well the job was estimated.

Copies of the items 1–5 listed above should be kept in a clear plastic holder, carried in the foreman's or job superintendent's vehicle. The information should be on the job site at all times until the job is finished. All sheets, i.e., the daily time sheets and job quantity sheets are returned to the job jacket at the office by the foreman at the end of each day. Many companies are utilizing smart phones/ tablets with items 1–5 on job sites rather than paper.

Other items that belong in the office job folder include job cost estimate sheets for labor and materials, the estimate pricing summary sheet, actual vs. estimated job costing sheet, material order forms (company purchase orders), and copies of checks issued as payment for the job.

DECORATIVE PAVING CO

33W518 Fabyan Parkway
West Chicago, Illinois 60185

Telephone: (708)232-9525
(800)448-4110
Fax: (708)232-6370

QUOTATION

PROPOSAL SUBMITTED TO		PHONE	DATE
Mr. & Mrs. Bruce Anderson		358-8314	4/1
STREET 85 Lochleven Ln. (Inverness on the Ponds)		JOB NAME Rear Patio	
CITY, STATE, AND ZIP CODE		JOB LOCATION Inverness	
CUSTOMER NO.	DATE OF PLANS	OTHER	

WE HEREBY SUBMIT SPECIFICATIONS AND ESTIMATE FOR:

Removal & disposal of existing concrete patio

Excavation to (-8 in.) below finished grade.

4 in. aggregate base course.

1 in. sand setting bed.

6 cm cobble pavers, color: Rustic Red, random pattern w/ soldier course.

Plastic edging.

Permits to be obtained by others.

All underground lines to be clearly identified.

Landscaping & finished grading to be by others.

Work to start May 2nd.

WE PROPOSE HEREBY TO FURNISH MATERIAL AND LABOR - COMPLETE IN ACCORDANCE WITH ABOVE SPECIFICATIONS

For the sum of: dollars ($) x,xxx.xx

Payment to be made as follows:
1/3 down payment upon signing; balance due upon completion

All material is guaranteed to be as specified. All work is to be completed in a workmanlike manner according to standard practices. Any alteration or deviation from above specifications involving extra costs will be executed only upon written orders, and will become an extra charge over and above the estimate. All agreements contingent upon strikes, accidents, or delays beyond our control. Owner to carry fire, tornado, and other necessary insurance. Our Workers are fully covered by Workmen's Compensation Insurance. In the event Decorative Paving Company is forced into litigation prompted by non-payment of contract, Decorative Paving Company shall be entitled to full reimbursement of contract plus interest and all reasonable legal expenses.

Authorized Signature Brian L. Jones

Note: This proposal may be withdrawn by us if not accepted within 30 days.

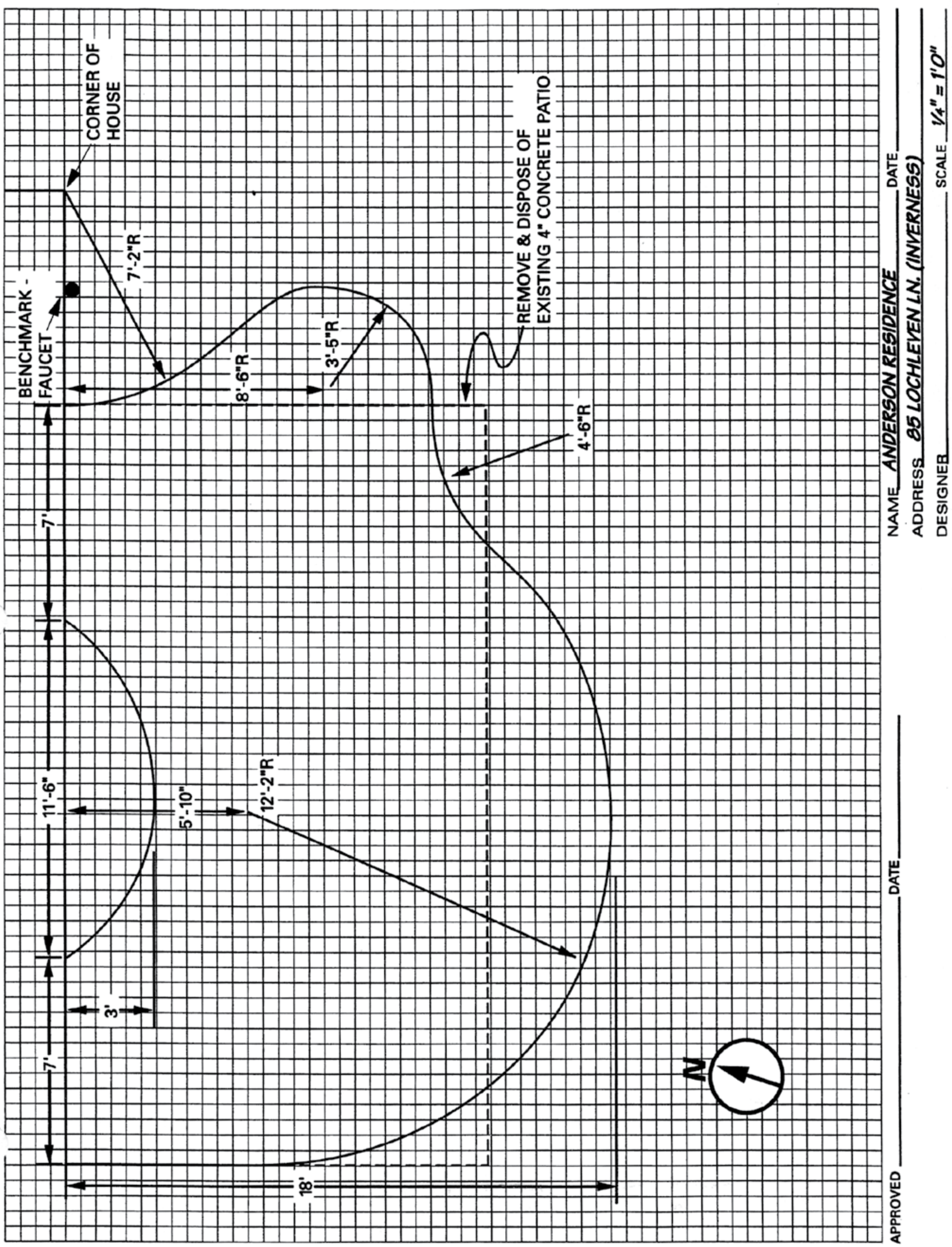
ACCEPTANCE OF PROPOSAL

The above prices, specifications, and conditions are satisfactory and hereby accepted. You are authorized to do work as specified. Payment will be made as outlined above.

Signature: Bruce P. Anderson

Date of Acceptance: 4/20

Signature:


CORNER OF HOUSE
BENCHMARK - FAUCET
7'-2"R
8'-6"R
3'-5"R
REMOVE & DISPOSE OF EXISTING 4" CONCRETE PATIO
4'-6"R
7'
11'-6"
5'-10"
12'-2"R
3'
7'
18'
N
NAME ANDERSON RESIDENCE
DATE
ADDRESS 85 LOCHLEVEN LN. (INVERNESS)
DESIGNER
SCALE 1/4" = 1'0"
APPROVED
DATE

Northwest Hwy
W Dundee Rd
E Dundee Rd
Inverness
14
N Hicks Rd
N Roselle Rd
Inverness Golf Course
85 Lochleven Ln
Palatine
E Palatine Rd
Roselle Rd
IL-53
Euclid Ave
Kirchoff Rd
Algonquin Rd
Algonquin Rd
Course
53
90
65
90
I-90
67
53
mapquest
MAP
59W → 58E
→ Roselle Rd N
(Just past Palatine Rd!)
→ "Inverness on the Pond"
– 85 LOCHLEVEN –

FOREMAN WORKSHEET PAVERS

JOB # D3140

DATE: 4/21 JOB: PATIO

CLIENT NAME: ANDERSON APPROX. INSTALL DATE: 5/2

JOB ADDRESS: 85 LOCHLEVEN PHONE #(OFFICE): ______

(INVERNESS ON THE POND) PHONE #(FIELD): 358-8314

INVERNESS FIELD CONTACT: BRUCE ANDERSON

SUBCONTRACTOR: Y ( ) N (✓) ______ SEE ATTACHED SHEET

TEAR OUT ✓ CONCRETE ✓ ASPHALT ______ OTHER ______

BY HAND ______ MACHINE ______ AIR HAMMER ✓

EXCAVATION DEPTH: ______ LOCATION OF DUMP SITE: "WHEELING" #20 520-185

BASE DEPTH: 4" (NEW) - REGRADE EXISTING # OF TONS: 6 "MEYER"

SAND DEPTH: 1" # OF TONS: 4

PAVER TYPE/CATEGORY CODE	COLOR	# OF CUBES
RECTANGULAR COBBLE	RUSTIC RED	4
SQUARE COBBLE	" "	2

PATTERN TO BE LAID: RANDOM PATTERN DIRECTION: PARALLEL TO HOUSE

SOLDIER COURSE: Y (✓) N ( ) CONTRACT SQ. FT. QUANTITY: 395

EDGING: TYPE: PLASTIC # LIN. FT.: 70

LEXEL ( ) LATICRETE ( ) # LIN. FT.______ # SQ. FT.______ #TUBES ______

#GAL: ______ # BAGS SAKRETE: ______

SOIL SEPARATOR: TYPE: ______ # OF SQ. FT. ______

PLYWOOD PLANKING: Y (✓) N ( ) AMOUNT REQUIRED: ≃ 24 SHEETS

SIGNED CHANGE ORDERS REQUIRED: FIELD ( ) OFFICE ( )

SPECIAL NOTES: ______

LODGING EXPENSES: ______ ROOM NIGHTS AT $______ PER ROOM (PRICE MUST INCLUDE TAXES)

DUCON OUTDOOR LIVING

DAILY TIME SHEET

JOB # D - 3140 FOREMAN DONNY
JOB NAME ANDERSON PATIO DAY TUE.
JOB ADDRESS 85 LOCHLEVEN
INVERNESS
PHONE ______ DATE 5-3
CONDITIONS ______
WEATHER BEAUTIFUL TEMP 75°

COST CODE	LABOR DESCRIPTION	U M	QUANTITY INSTALLED	CLASS	DONNY L-113	PHIL L-114	EFFRIN L-140
					8	8	8
321L	DEMO CONCRETE	SF	350		7	7	7
200L	BASE - ROUGH IN	SF	350		1	1	1

COST CODE	MATERIAL/RENTAL DESCRIPTION	VENDOR	U M	QUANTITY RECEIVED	LOAD TICKET #	# LOADS FREIGHT
B15AA	6CM RECTANGLES - LARGE	ICPI MEMBER	SF	312	031767	
B14AA	6CM SQUARES	ICPI MEMBER	SF	155	031767	
200M	AGG. BASE	MEYER	TN	7	060451	
301M	DUMPING	APTAKISIC	LD	1	028821	
110M	FREIGHT		LD	1		1
341M	JACK HAMMER	R+J RENTAL	PC	1	008812	
310M	PLASTIC EDGING	YARD STOCK	LF	70	N/A	
311M	SPIKES	YARD STOCK	PC	70	N/A	

COST CODE	OUT OF TOWN EXPENSES DESCRIPTION	NO OF ROOMS	ROOM COST

DAILY TIME SHEET

JOB # D-3140 FOREMAN DONNY
JOB NAME ANDERSON PATIO DAY WED.
JOB ADDRESS 85 LOCHLEVEN
INVERNESS
PHONE ______ DATE 5-4
CONDITIONS ______
WEATHER GREAT TEMP 73°

COST CODE	LABOR DESCRIPTION	U M	QUANTITY INSTALLED	CLASS		DONNY L-113	BILLY L-114	EFFRIN L-140	PHIL L-111				
						7	7	7	3				
140L	SAND BED	TN	4			1	1.5	1.5	1				
120L	INSTALL PAVERS	SF	400			4	.5	2.5	2				
121L	SAW CUTTING	LF	70			0	3	0	0				
310L	PLASTIC EDGING	LF	67			1		1					
200L	BASE	SF	400			1	1	1	0				
230L	BASE - FINAL	SF	400			0	1	1	0				

COST CODE	MATERIAL/RENTAL DESCRIPTION	VENDOR	U M	QUANTITY RECEIVED	LOAD TICKET #	# LOADS FREIGHT
301M	DUMPING	SETTLERS HILL		1 LOAD	363222	
140M	SAND	YARD STOCK	TN	4		

COST CODE	OUT OF TOWN EXPENSES DESCRIPTION	NO OF ROOMS	ROOM COST

JOB NAME ANDERSON RESIDENCE - PATIO
DATE 21-Apr

JOB QUANTITY SHEET - MATERIAL

CATG CODE	DESCRIPTION	U M	ESTIMATED QUANTITY	QTY RECEIVED	DATE	QTY RECEIVED	DATE	QTY RECEIVED	DATE
B15AA	OLD GREENWICH (LG. RECT)	SF	312.40						
B14AA	OLD GREENWICH (SQ.)	SF	155.80						
140M	1" SAND SETTING BED	TN	4.00						
110M	FREIGHT	LD	1.00						
200M	4" AGG. BASE	TN	6.00						
	(NEW PLUS REGRADE EXT.)								
301M	DUMPING (ELMHURST-#28)	LD	2.00						
310M	PVC EDGING	LF	70.00						
311M	12" SPIKES	EA	70.00						

JOB NAME ANDERSON RESIDENCE - PATIO
DATE 21-Apr

JOB QUANTITY SHEET - LABOR

CATG CODE	DESCRIPTION	QTY/ HOUR	U M	EST QTY	QTY RECEIVED	DATE	QTY RECEIVED	DATE	QTY RECEIVED	DATE
120L	INTSALL 6CM PAVERS	35.00	SF	11.00						
121L	SAWCUT PAVERS	24.00	LF	3.00						
140L	INSTALL 1" SAND BED	0.80	TN	5.00						
200L	INSTALL 4" AGG. BASE	0.75	TN	3.00						
230L	REGRADE/COMP. AGG BASE	65.00	SF	5.00						
321L	DEMO/HAUL CONCRETE	22.00	SF	16.00						
320L	EXCAVATE/HAUL SOIL	30.00	SF	3.00						
310L	INSTALL PVC EDGING	30.00	LF	2.00						

DUCON OUTDOOR LIVING

JOB# ______________

PAVER JOB INFORMATION SHEET

JOB SITE ADDRESS: ______________________________ Phone # ______________
Scheduled Start Date ____________ Directions ______________________________
____

OWNERS NAME(S): ______________________ Phone # (h) ____________ (w) ____________
GENERAL CONTRACTOR: ______________________ Contact ____________ Phone # ____________
ARCHITECT: ______________________ Contact ____________ Phone # ____________
PLANS: ____________ Specs ____________ Date ____________ # Pages ____________
UTILITY LOCATOR CONFIRMATION #: ______________ Date ________ Call placed by ________
SOIL/BASE TESTING:
Company____________Contact____________Phone #__________Scheduled date(s)____________
TESTS: Soils - classiﬁcation/Standard Proctor density/modiﬁed Proctor density/ nuclear density
Base - gradation/Standard Proctor density/modiﬁed Proctor density/nuclear density Bedding/joint sand - gradation

OTHER CONTRACTORS ON SITE:
Company ______________________ Trade ____________ Phone # ____________
Company ______________________ Trade ____________ Phone # ____________
Company ______________________ Trade ____________ Phone # ____________
ROAD RESTRICTIONS: Location ______________________ Weight ________ Date ________
DEMOLITION: Yes / No Self / Others Company ____________ Contact ________ Phone # ________
Soil ______ Concrete ______ Asphalt ______ Thickness ______ Sq. Ft. ______ Method ________
Dump Site Location: ______________________________
____

EXCAVATING CONTRACTOR:
Company ______________ Contact ______________ Phone # ____________
Excavation Depth ______________ GEOTEXTILE Yes / No Type ________ Sq. ft. ________
Base Depth ________ Tons ____________ Sand Depth ____________ Tons ________
TRUCKING COMPANY: (scheduled Yes / No) When ______________________
Company ______________ Contact ______________ Phone # ____________
BASE MATERIAL SUPPLIER:
Company ______________ Contact ______________ Phone # ____________
SAND MATERIAL SUPPLIER:
Company ______________ Contact ______________ Phone # ____________
PAVER SUPPLIER:
Name ______________ Contact ______________ Phone # ____________
Order # ______________ Delivery Schedule/Equipment ______________
PAVERS:
Pattern(s) to be laid ______________________ Direction of pattern ____________

Type/shape	Size/Height	Color	Qty.

Edge Restraints Linear Ft. ______________________ # of SPIKES ____________
BONDING PAVERS: Lineal ft. ________ Sq. ft. ________ Qty. of Adhesive ________ Type ________
EQUIPMENT RENTAL:
Company ______________ Phone # ____________ Type ________ Pick-Up / Delivery
Company ______________ Phone # ____________ Type ________ Pick-Up / Delivery
ELECTRICAL: Circuit breaker location ______________________
110v/220v In / Out / No Location ______________________
WATER: Yes / No In / Out Location ______________________
TOILET: On / Oﬀ Site Public / Private Location ______________________

PAVER JOB INFORMATION SHEET

DATE ____ /____ /____ FILE NO. ____ APPT. DATE ____ /____ /____

SALESMAN NAME ______________________ APPT. TIME ____ :____ AM PM

I. CUSTOMER INFORMATION:

CUSTOMER NAME ______________________

CUSTOMER NAME ______________________

ADDRESS ______________________

CITY ______________ STATE ______________ ZIP ________

PHONE NO. ____ - ____ - ______ [H] ____ - ____ - ______ [W] ____ - ____ - ______ [O]

PROJECT NAME ______________________

LOCATION ______________________

JOB PHONE ____ - ____ - ______

OWNER NAME ______________________

ADDRESS ______________________

PHONE ____ - ____ - ______

ARCHITECT ______________________

ADDRESS ______________________

PHONE ____ - ____ - ______

DIRECTIONS TO JOB SITE ______________________

____

____

____

SOIL/BASE COMPANY ______________ CONTACT: ________ Phone: ________

TYPE OF PRODUCT ______________________

SCOPE OF WORK ______________________

____

____

____

II. SITE CONDITIONS

CHECK APPROPRIATE BOX

☐ CHECKED ALL GRADES, SLOPES, AND DRAINAGE REQUIREMENTS

☐ GRASS / AMOUNT OF EXCAVATION ________ INCHES

☐ DIRT REMAINS ON SITE ☐ DIRT NEEDS TO BE HAULED AWAY

☐ CONCRETE / THICKNESS ________ INCHES ☐ REMOVE ☐ GO OVER

☐ ASPHALT / THICKNESS ________ INCHES ☐ STONE UNDERNEATH

☐ NO STONE UNDERNEATH

☐ BASE THICKNESS ________ INCHES OF DEPTH 3" BELOW GRADE

☐ BRICK OR PAVERS IN MORTAR

☐ OTHER ______________________

☐ SPECIAL SITE CONDITIONS DRAIN LINES, UTILITIES, ETC. ______________

III. SITE ACCESS

CHECK APPROPRIATE BOX

☐ UNI-LOADER (FIVE FOOT MINIMUM)
☐ BACKHOE (EIGHT FOOT MINIMUM)
☐ DUMP TRUCK
☐ PAVER CART (FOUR FOOT MINIMUM)
☐ STEPS, HILL ETC. EXPLAIN ______________________
____

☐ WATER AVAILABLE
☐ ELEC. AVAILABLE
☐ UNLOAD ON DRIVEWAY PAVERS, STONE, ETC.
☐ DO NOT UNLOAD IN DRIVEWAY
☐ INFORMED CUSTOMER OF DAMAGE TO AREAS USED FOR ACCESS BY EQUIPMENT

SITE SKETCH WITH DIMENSIONS AND DETAILS:

DAILY TIME SHEET

JOB # ______________ FOREMAN ______________
JOB NAME ______________________ DAY ______
JOB ADDRESS ______________________________
____
PHONE ______________ DATE ______________
CONDITIONS ______________________________
WEATHER ______________________ TEMP ______

COST CODE	LABOR DESCRIPTION	U/M	QUANTITY INSTALLED	CLASS												

COST CODE	MATERIAL/RENTAL DESCRIPTION	VENDOR	U/M	QUANTITY RECEIVED	LOAD TICKET #	# LOADS FREIGHT

COST CODE	OUT OF TOWN EXPENSES DESCRIPTION	NO OF ROOMS	ROOM COST

Project Number:

Project Name:

Address:

Date:

Completed by:

JOB QUANTITY SHEET - MATERIAL

CATG CODE	DESCRIPTION	U M	ESTIMATED QUANTITY	QTY RECEIVED	DATE	QTY RECEIVED	DATE	QTY RECEIVED	DATE

Project Number:

Project Name:

Address:

Date:

Completed by:

JOB QUANTITY SHEET - LABOR

CATG CODE	DESCRIPTION	QTY/ HOUR	U M	EST QTY	QTY RECEIVED	DATE	QTY RECEIVED	DATE	QTY RECEIVED	DATE

Job Layout, Planning and Material Flow
[CPI04]

DUCON
OUTDOOR LIVING

Job Layout, Planning and Material Flow

Student Manual

ICPI Concrete Paver Installer Course

icpi
Interlocking Concrete
Pavement Institute®

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14801 Murdock Street, Suite 230
Chantilly, VA 20151
Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Every effort has been made to present accurate information. However, the recommendations herein are guidelines only and will vary according to local conditions. Professional assistance should be obtained in the design, specifications and construction with regard to a particular project.

Table of Contents

Job Layout, Planning and Material Flow

Section 4 Part A: Job Layout For Excavation

Utility Locations –The location of underground utilities must be determined on the job site prior to excavation. This can be the responsibility of the homeowner or contractor, but this must be specified in the signed agreement. Underground utilities can include water lines, sanitary sewer, storm sewer, natural gas, telephone, electrical, and cable television. The drawing should indicate all utilitiy locations. If not done by others, mark underground lines in the project area to see where excavation might interfere with them.

The key to locating underground utilities is never assume anything about where they are placed. Always check and re-check the plans. If utility locations are the contractor's responsiblity, call the utility companies to get the locations marked on the site before digging. Many utilities have a telephone number such as Miss Utility. Call to obtain the exact location of the lines marked with paint on the site.

Staking an Area for Excavation– Identify the area on the drawings to be excavated and mark it on the site with spray paint. Consider the location of the dump truck(s) and loader(s) and where they are going to move on and off the site. Be sure the riding surface under the dump truck can take the load without rutting or getting stuck.

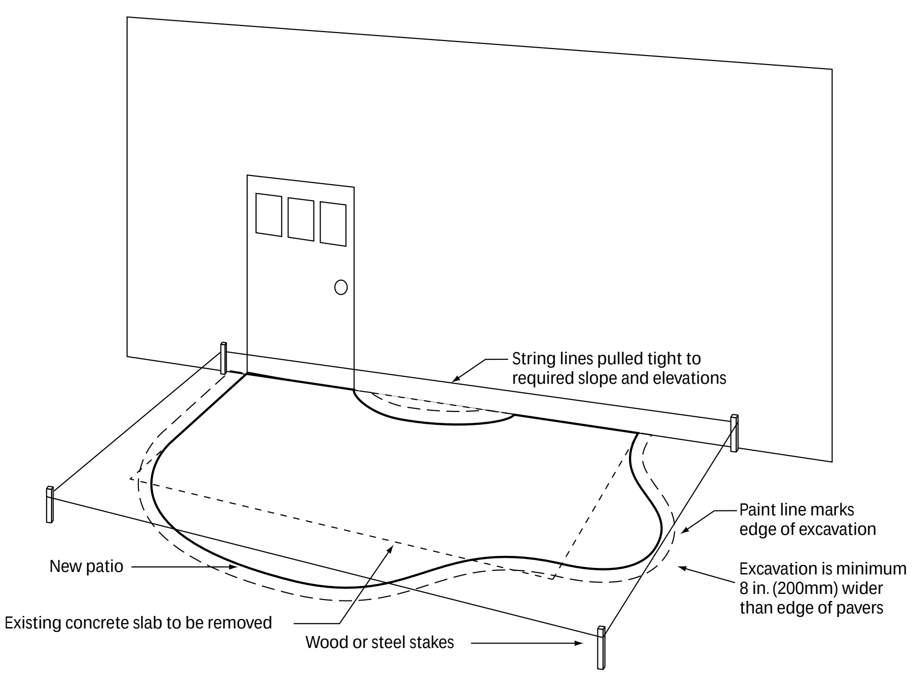


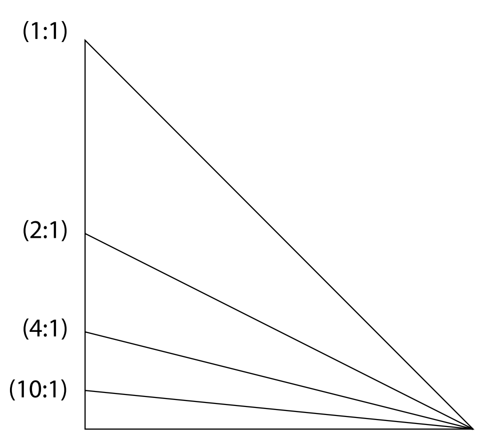
Figure 4-1: Job layout and staking

Place grade stakes with string lines just about 12 in. (30 cm), outside the area to be excavated. Mark the elevations on them so that the depth of excavation can be checked as it progresses. Use nylon mason's line and set it at the finished elevation of the pavement. Measure all excavations and base thickness from these lines. Set the initial elevations and check them at the beginning of each day with a transit. The stakes can be moved at night by mischievous persons.

String lines set at final or finished elevations should be sloped. All lines (and final elevations of the pavement) should slope away from the house or building. The minimum recommended slope is 1.5% or a drop of 3/16 in. for every foot of pavement (15 mm per meter). Many pavements are sloped at 2% or 1/4 in. per every foot of pavement (20 mm per meter) as this will better facilitate drainage. The maximum slope for comfortable walking is 7 degrees or about 12%. Table 1 shows the relationship between slopes, degrees and percent. A laser transit should be used to establish elevations using marks on stakes set around the area to be paved. The transit will save time and money because only one person is needed to operate it.

Table 4-1:
Grades and slopes

SLOPE	DEGREES	PERCENT	INCHES DROP PER FOOT
1:1	45.0	100.0	12
1.5:1	33.7	66.7	8
2:1	26.6	50.0	6
2.5:1	21.8	40.0	4 3/4
3:1	18.3	33.3	4
3.5:1	15.9	28.6	
4:1	14.0	25.0	3
4.5:1	12.5	22.2	
5:1	11.3	20.0	2 1/2
6:1	9.5	16.7	2
7:1	8.1	14.3	
8:1	7.1	12.5	
9:1	6.3	11.1	
10:1	5.7	10.0	1 1/4
11:1	5.1	9.0	
12:1	4.7	8.3	1
13:1	4.3	7.7	
14:1	3.9	7.1	
15:1	3.6	6.6	
16:1	3.4	6.2	3/4
17:1	3.2	5.8	
18:1	3.0	5.5	
19:1	2.8	5.2	
20:1	2.7	5.0	5/8
25:1	2.1	4.0	1/2
33:1	1.5	3.0	3/8
50:1	0.9	2.0	1/4
65:1	0.6	1.5	3/16



Video Supplement
Section 3

Section 4 Part B: Job Planning

The company estimator determines the amount of materials and labor hours required to remove and install materials from the site. Estimates for labor are placed on the Job Quantity Sheet for Materials and the Job Quantity Sheet for Labor presented in the last Section. Estimates are based on documenting labor hours for specific job functions and materials used on past jobs.

The daily time sheets introduced in the previous Section provide essential information on labor hours by job function and materials placed (or removed). Compiling labor and material information, or job costing, for each job is the basis for making accurate estimates.

Quantities are estimated from drawings of the project. Always double check the scale of the drawing and details with a scale. Electronic digitizers can estimate areas and quantities on drawings.

An excavated material is estimated by calculating volume and applying appropriate swell factors. When soil is excavated it gains air, so this has to be considered when figuring how many truck loads will be required to remove all the soil. Soil enlarges by approximately 20%–30% in volume when it is removed and dumped.

Demolition of concrete or asphalt pavements will only use about 50% of the volume in a dump truck. In other words, there will be about 50% air space around the chunks of demolished pavement when placed in a dump truck.

A suitable place must be found to dump the material. Sometimes it can be used as fill elsewhere on the site, or taken to another site nearby. In other cases, the soil, asphalt or concrete will be dumped in a landfill. The travel distance to the dump and the time it takes to load each dump truck, can determine the number of trucks needed for excavation.

Fees to dump soil or construction debris are continually rising due to ever shrinking landfill space. Dump bins left at the job site and removed when full can be a means to save time and money in hauling. The dumping requirements of each job will vary, so before you begin formulate an economical plan that will work best for the job.

Most jobs require cutting of pavers along one or more sides. The amount of cut pavers required for a job is determined by the dimensions of the pavement and whether they conform to the modular dimensions of the pavers. The dimensions shown on the drawings can not be used to determine whether the module of the pavers will fit into an area without cutting. (Remember, the drawing is only a representation of what is to be paved.)

The direction of the paving is the best guide in determining the amount of cutting. In other words the paving sequence, planned before arriving on the site, indicates starting edges and finishing edges that may require cut pavers. Other factors that determine the amount of cut pavers are the site features in the pavement such as trees, benches, utility access structures, etc.

Above all, visit the site prior to estimating to get familiar with the access for equipment, materials, and places for storage.

Edge restraints are straight forward. Measure the length and kind of edge restraints. Pavers next to buildings or other pavements generally do not require restraints. Reference the manufacturer's recommendations to determine type, size, and quantity of spikes to fasten the edge restraint to the base.

Section 4 Part C: Flow of Materials

Planning the flow of materials before the job begins are important to completing the job without delays and to profitability. Planning the timing of delivered materials and movement on the site also affects the productivity of the crew. This section covers some basic conditions that must be controlled in order to estimate and maintain productivity.

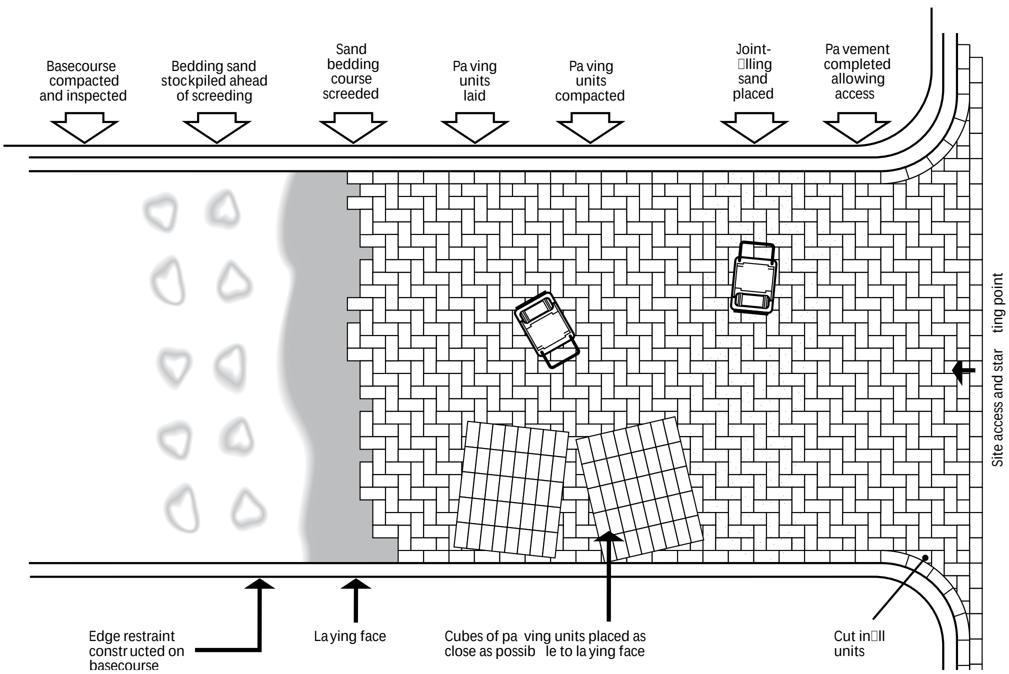


Figure 4-2: Flow of materials onto a job site.

When the aggregate base and bedding sand arrive at the site in dump trucks, consider where it should be dumped. Bedding sand is spread in front of the laying face so dump the sand in piles a short distance from it. The piles are spread as the paving progresses (Figure 4-2). Avoid placing the sand away from the pavement area and hauling it in small quantities to the laying face. This wastes time.

The base and bedding sand should be distributed by a loader, or wheelbarrow, and not moved from one large pile and dumped into small piles for spreading by others. This makes extra work.

Moving Concrete Pavers onto the Site

Boom trucks that deliver and unload pavers on the site will save the contractor from using a forklift for unloading, and a person to operate it. Be sure to ask the supplier if the pavers supplied are on a "boom truck", or if a forklift comes with each trucked shipment to place the pavers on the site.

Generally there are 10 layers of pavers in cubes of 2 3/8 in. (60 mm) thick pavers and 8 layers of pavers in cubes with 3 1/8 in. (80 mm) thick pavers. Ask the paver supplier how many layers are in each cube and how many square feet (m^2) are on each pallet. The supplier usually provides this information on product data sheets. Some manufacturers provide software that calculates total cubes needed given the area of the pavement.

Ask suppliers how many cubes will be on each truck when it arrives at the site. The cubes of pavers for the job and their sequence of arrival on the site should be timed to the best extent possible. Allow space on the site for their delivery (over hours or days) or full (all at once) delivery of the order.

Moving the Pavers Around the Site

Once the pavers are placed on the site they should be moved as little as possible. Determine how the pavers will be moved around at the site: on wood pallets via a forklift or without pallets via a clamp (Figure 4-3). Once a cube of non-palleted pavers is opened, it cannot be moved. Therefore, cubes with no pallets need a specific location for placement planned in advance of their arrival on the site. However, cubes can be set on wooden pallets (provided by the supplier or contractor) once they arrive at the site. The contractor must have equipment that can lift a pallet of pavers, typically 3,000 lbs. (1360 kg). This allows greater flexibility in moving material.

Leave enough distance between the laying face and the cubes to remove stacks of pavers from the cubes. Bundle buggies are used to “peel” off stacks of pavers from the cubes (usually 7-10 pavers high) and place them at the laying face ready for installation (Figure 4-4). Leave room around each cube to allow the buggy to fit around them. If the working area is so small that a bundle buggy can’t be taken to the laying face, then a wheel barrow may be needed. Sometimes a visit to the paver plant before ordering can ensure that the pavers are stacked for pick-up by a clamp and a bundle buggy.

Whenever possible, always work up-hill to maintain consistent joint widths. Take pavers from at least three different cubes to ensure a random distribution of color, even with solid colored pavers.

Figure 4-3: Clamp picking up cube of pavers with no wood pallet.

Figure 4-4: Bundle buggy used to bring pavers to laying face.

Productivity

Estimating productivity is important because all contracts have a deadline and productivity determines job scheduling. Of course, in every job the goal is to complete the job as quickly as possible without sacrificing quality. Job costing, through documenting the hours of labor, materials and equipment used on each job, is the certain way to estimate productivity.

A typical crew is three and five persons. The number depends on the size of the job and the tasks. A larger crew may be necessary when there is much cutting of pavers along edges. All must work as a team, trading jobs and doing the next essential task without hesitation. The job foreman or crew leader directs the tasks, switching people to tasks to get the best productivity and quality. Therefore, cross training is essential to productivity, especially when a crew member is absent.

When placing pavers, bending over is preferred to kneeling. Bending allows a greater range of arm motion and reach compared to kneeling. Bending with a back support is less physically tiring than placing weight on knees. Leather gloves are typically not worn. They get in the way of efficient handling and will slip off in hot weather. Cloth gloves with plastic palms work well in all kinds of weather. Many contractors prefer to work with bare hands. If pavers are abrasive to hands, spray-on or spread-on “plastic” gloves can be used for protection. This protection is needed when handling wet pavers as they tend to be very abrasive to skin.

The average output for a five person crew can be 1,200 $ft.^2$ (120 m^2) per 8 hour day, or 250 $ft.^2$ (25 m^2) per person per day [27–33 $ft.^2$ (2.7–3.3 m^2)/person/hour]. This includes screeding bedding sand, placing, compacting, filling joints with sand, final compaction, and removal of excess sand. Output on every job will be different, so no average productivity among paver installation contractors is consistent or reliable. The reason for such inconsistency is paver shape, job design, especially the width of the pavement, and the amount of cutting vary with each job. Obviously, a complex job with curves, corners, openings and obstructions will take longer to pave than the same area expressed as a large rectangle. Narrow pavements require more cutting and limit the number of persons on the laying face. They take longer to pave than wider areas.

The typical crew assignments for working from a prepared base might be as follows: Two or three people screed the sand. Another brings sand to them with a loader. As the screeding begins, the remaining two place the pavers. One is on the laying face placing the units. Another is bringing the pavers to the laying face. This is usually done with a bundle buggy (provided that the paver bundle configuration allows this).

When the two persons have finished screeding, or have a section ready after several hours of laying, they can move to cutting edge pavers. The person on the loader (with a clamp or forks) checks to see if additional cubes of pavers need to be brought with the loader or bundle buggy near the laying face. If there are enough pavers, then the person on the loader may help remove the screed bars, if needed. Depending on the need of the moment, he may compact an area of pavers and distribute sand for placing into the joints. Each job site establishes its own pattern of tasks for the crew. The objective is to function as a team, anticipate everyone's movement and tasks which are rotated throughout the job.

For edge cutting, one person cuts the pavers, while the other marks those to be cut. The saw or splitter is as close as possible to the edge. The cut pavers are placed into the pattern. Cutting methods are covered in a later Section.

Productivity depends on a combination of factors: the job design and amount of cutting, the experience and efficiency of the work crew, the uninterrupted flow of materials onto and through the job, the owner and the weather. Delivery, storage and movement of excavated soil, base, sand and pavers will be easier on a cul-de-sac that might serve as temporary storage. A project next to a busy street may mean that all materials will be stored on the site rather than the street. Every job needs timely delivery of materials so they aren't moved more than twice, once at delivery and again at installation. The time and costs savings can be substantial, especially when added over the course of many jobs. Savings from planning delivery, storage and movement of materials go right to the profitability of each project.

At the end of each day all litter, unused or cut pavers, edge materials, tools, and equipment should be picked up. Metal strapping around paver bundles is dangerous and should be disposed of as well. Some equipment and materials may remain on the site during the job. Be sure to obtain the owner's permission by including it in the quotation or proposal. A clean site will reduce the chance for accidents and impress the customer.

Clean-up at the end of the day and at the end of the job should be factored into estimating total productivity. It should be a separate labor item in estimating and job costing. Clean-up at the end of the job means removing all debris, materials and equipment. The price for hauling additional debris not related to the job should be agreed with owner prior to moving the debris. Remember, a clean site at the end of the day speaks well for your company and is good marketing.

DUCON OUTDOOR LIVING

Soil Characteristics and Compaction
[CPI05]

Student Manual

ICPI Concrete Paver Installer Course

icpi
Interlocking Concrete Pavement Institute®

Soil Characteristics and Compaction

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Interlocking Concrete Pavement Institute
14801 Murdock Street, Suite 230
Chantilly, VA 20151
Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

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Soil Characteristics and Compaction

Section 5 Part A: Gradation Fundamentals, Sieve Analysis and Standards

Gradation of soil, bedding sand, and crushed stone base is an important property of these materials. The size and distribution of their particle sizes greatly influence their performance under interlocking concrete pavers.

Soils range in particle size from coarse to fine grained. Sands are coarse soils, with silts and clays having the smallest or finest particles. Generally, the suitability of a soil for use under a pavement decreases with its particle size. In other words, clay soils are the least desirable for pavements.

Measuring the sizes of grains or particles in a soil is done by gradation. Soil gradation is measured with a series of sieves, circular pans with screens on the bottom. (The sizes of aggregate in crushed rock base materials are also measured with sieves.) The screens have various openings allowing any material smaller than the opening to pass through.

A sample of soil, bedding sand or crushed rock is dried in an oven and weighed. The sample is placed in the coarsest sieve while stacked over increasingly finer sieves. All of the stacked sieves are shaken together. Each sieve blocks a specific size particle (or larger) from passing to the next smaller sieve. Smaller particles pass to the next smaller sieve. The material remaining on each sieve is weighed. The weight is subtracted from the total sample weight. The difference is divided by the total sample weight to obtain the percent passing a particular sieve size.

The most common test method for sieve analysis of soils is ASTM D422, Standard Test Method for Particle-Size Analysis of Soil Fines. The test normally used for aggregates is ASTM C136, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.

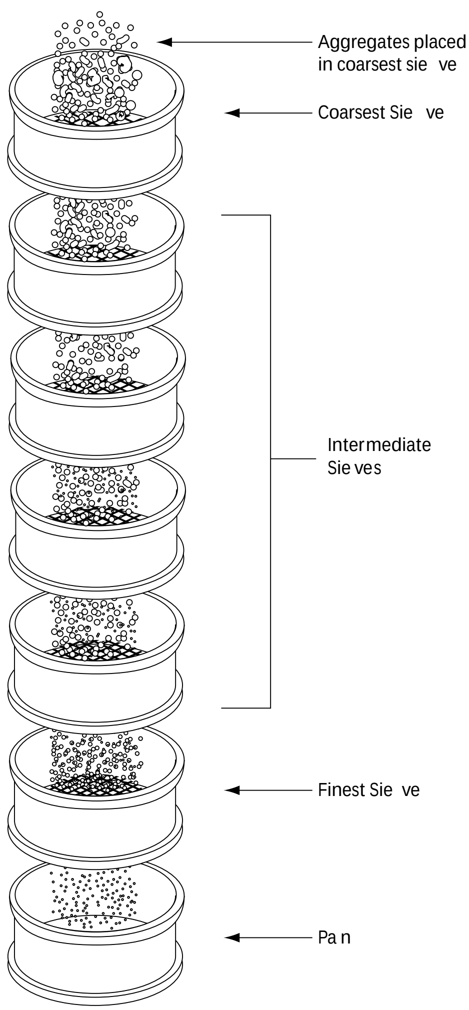


Figure 5-1: Sieve analysis is a key to understanding the characteristics of soils, aggregate base, bedding and joint sands.

(From National Stone Association)

The table below relates the sieve size to opening size of the screens in the sieve. Smaller screen sizes are designated by number as well as the by the actual size of the openings in the screens. The table lists the general terms for various particle sizes.

Table 5-1: Common Sieve Sizes

U.S. Sieve Size	Metric Sieve Size	Sieve Opening	General Term
2 in.	50 mm	2 in.	Gravel
1 1/2 in.	37.5 mm	1.5 in.	Gravel
1/2 in.	12.7 mm	0.500 in.	Gravel
3/8 in.	9.5 mm	0.375 in.	Fine Gravel
No. 4	4.75 mm	0.187 in.	Coarse Sand
No. 8	2.36 mm	0.093 in.	Coarse Sand
No. 16	1.18 mm	0.046 in.	Sand
No. 30	600 µm	0.024 in.	Sand
No. 50	300 µm	0.012 in.	Fine Sand
No. 100	150 µm	0.006 in.	Fine Sand
No. 200	75 µm	0.003 in.	Silts
	5µm	0.0002 in.	Clays

mm = millimeters µm=micrometers

Gradation of soil, or the various particle sizes, is used to classify it. Classi–fication indicates how it might perform under a pavement. Aggregate base materials and bedding sands are also classified by gradation using selected sizes of sieves.

Section 5 Part B: Soil Classification, Soil Properties and Quick Field Identification

Soil Classification

Most contractors are familiar with the general kinds of soil in their area. However, there are variations of soil types within the range familiar to the contractor. When a soil classification is known, the contractor can predict certain char ac-teristics such as its tendency to hold water, drain fast or slowly, compact easily or with difficulty. Soil classification assists in selecting compaction equipment and predicts the kind of drainage expected. These factors affect the time required to complete the job. For example, a heavy clay soil may require more time to excavate and compact than a sandy soil. Greater time would be required for water to drain from a clay soil after a rainstorm than from a sandy loam, thus affecting construction time. Clay soils tend to swell more than other soils when excavated, thereby using more dump truck space.

There are several ways to classify soil depending on its intended use. A common method for soils under pavements is to classify them by particle size into three groups—sand, silt, or clay. This is illustrated as a triangle as shown in Figure 5-2. It is called the USDA (U.S. Dept. of Agriculture) soil classification system.

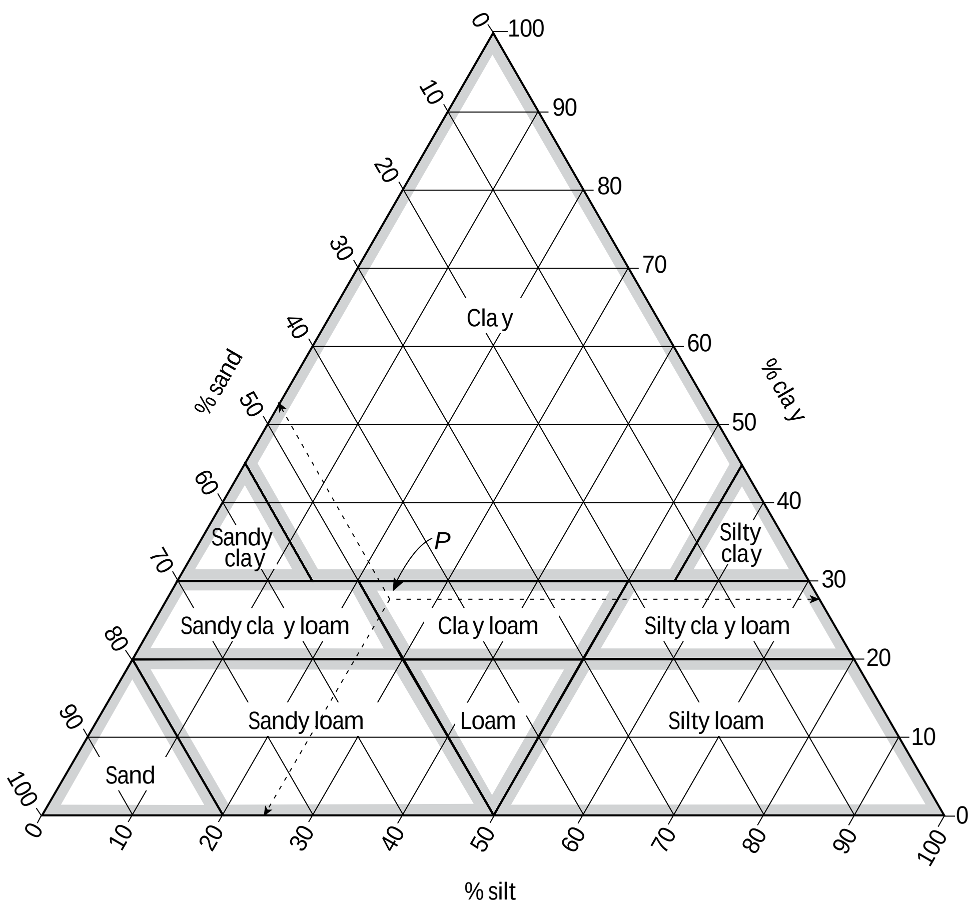


Figure 5-2:
There are several ways to classify soil depending on its intended use. A common method for classifying soils under pavements is into three groups separated by particle size—sand, silt, or clay. This is illustrated as a triangle in the USDA Soil Classification System.

To determine the USDA classification of a soil, a sieve analysis is conducted on a sample. Particle sizes are categorized as follows:

Coarse sand	0.079 in.– 0.009 in.	(2.0 mm – 0.25 mm)
Fine sand	0.009 in.– 0.003 in.	(0.25 – 0.076 mm or 250 µm – 76 µm)
Silt	0.003 in.– 0.0002 in.	(0.076 – 0.005 mm or 76 µm – 5 µm)
Clay	Smaller than 0.0002 in.	(Smaller than 0.005 mm or 5 µm)

The three–way percentage (by weight) of the particle sizes of clay, silt, and sand determine the classification. (Note the dotted lines on Figure 5-2.) For example, a soil sample with 28% clay, 25% silt, and 47% sand would be classified as a clay loam soil. This point is marked with a P on Figure 5-2.

This classification system illustrates that soils with approximately 30% or more clay perform as a clay soil. Clay soils hold moisture and are slow to drain, making them less desirable under pavements than other soils. They can also require more time for compaction.

Clay particles tend to lubricate any larger particles when wet. Soils with a percentage of clay lower than 30% have greater strength and stability since the lubricating influence of clay is not as great and water drains more readily.

Unfortunately, most of the soils in North America are clay, some good and others not very good as a foundation under pavements. Other classification systems were developed to distinguish adequate from not so adequate clay and silt soils for pavements. The two most common systems are the Unified Soil Classification System (USCS) and the AASHTO Soil Classification system developed by the American Association of State Highway and Transportation Officials (AASHTO). The AASHTO method is not covered in this course.

The Unified System was developed in 1942, modified since that date, and is used by the Army Corps of Engineers. The standard is described in detail as ASTM D 2487, Standard Classification of Soils for Engineering Purposes. In summary, fifteen soil groups are designated with two letters describing their characteristics. The first letter describes the prevailing type of soil, the second, other kinds of soil/gradation/liquid limit (the ability of the soil to hold water).

G = gravels or gravelly soils - passes 3 in. (75 mm) sieve and is retained on a No. 4 (4.75 mm) sieve.
S = sand or sandy soils - passes No. 4 (4.75 mm) sieve and is retained on the No. 200 (75 µm) sieve.
M = silt - passing the No. 200 (75 µm) sieve but non-plastic (non putty-like when wet), or very slightly plastic, and having little or no strength when air dry.
C = clay - passing the No. 200 (75 µm) sieve but plastic (putty-like when wet), and having considerable strength when air dry.
O = organic - silts or clays with organic soil (topsoil) in sufficient amounts to lessen the performance of the soil as a foundation for pavements.
Pt = peat - vegetation in various stages of decomposition usually black or dark brown in color.

Gradation (variation in particle sizes).
W = well-graded (high variation - good for pavements).
P = poorly graded (low variation - not good for pavements).

Liquid Limit Symbols. (Liquid limit is the ability of the soil to hold water.)
H = high (can hold water, does not drain well - not good for pavements).
L = low (does not hold water, drains well - good for pavements).

Using particle sizes, variation in their sizes and ability to hold water, the USCS places all soils into 15 groups:
GW = Well graded gravels and gravel sand mixtures, little or no fines.
GP = Poorly graded gravel and gravel-sand mixtures, little or no fines.
GM = Silty gravels, gravel-silt-sand mixtures.
GC = Clayey gravels, gravel-sand-clay mixtures.
SW = Well-graded sands and gravelly sands, little or no fines.
SP = Poorly graded sands and gravelly sands, little or no fines.
SM = Silty sands, sand-silt mixtures.
SC = Clayey sands, sand-clay mixtures.
ML = Inorganic silts, very fine sands, rock flour, silty or clayey fine sands.
CL = Inorganic clays of low to medium plasticity, gravelly clays, silty clays, lean clays.
MH = Inorganic silts, micaceous or diatomaceous fine sands or silts, plastic silts.
CH = Inorganic clays or high plasticity fat clays.
OL = Organic clays with low plasticity
OH = Organic clays of medium to high plasticity.
Pt = Peat

Most of the soils in North America are clay, some good and others not very good as a foundation under pavements

Figure 5-3 relates the Unified and classification systems to general ratings as a subgrade, subbase, or base. The chart also relates the soil types to the California Bearing Ratio (CBR). CBR is outside the scope of this course. For the purpose of this course, the USCS classification system will be used.

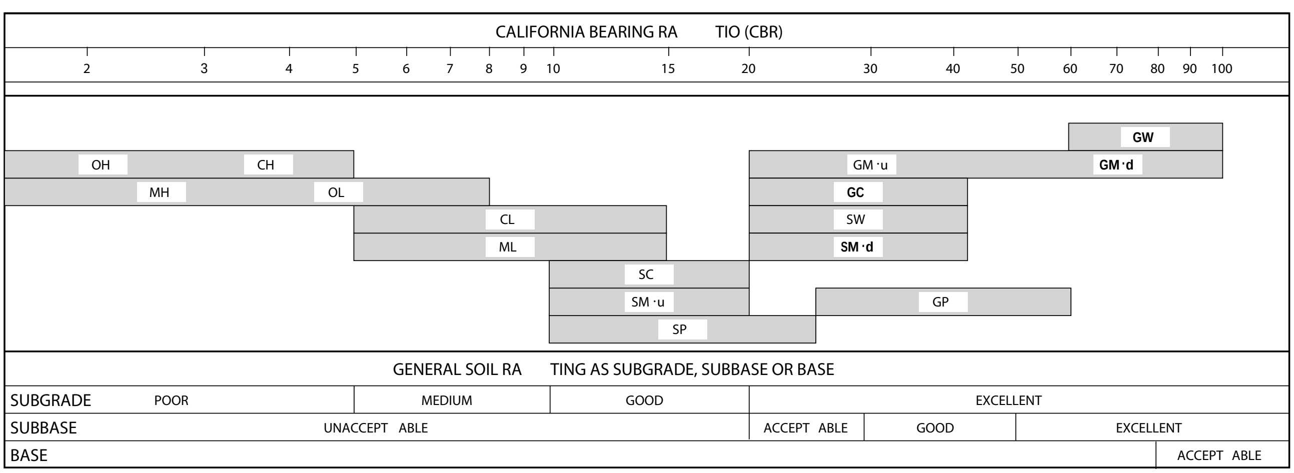


Figure 5-3: Unified Soil Classification Related to Suitability

Quick Field Identification

Determining the USDA or USCS soil classification requires a sample taken from the job site and taken to a soils testing laboratory. A simple, faster way to quickly approximate soils classification in the field is by visual appearance and feel. If coarse grains can be seen and the soil feels gritty when rubbed between the fingers, then it is a sandy soil. If the grains cannot be seen with the naked eye and it feels smooth, then it is a silt or clay.

A primary factor in the performance of soil under pavement is its ability to hold water. The higher the water holding ability, the worse the soil generally performs as a foundation for pavement. The USCS suggests some easy ways for the contractor to make a quick field identification and through assessing the water holding capacity of soils. They are described below.

Patty Test – Evaluating the water holding capacity of a soil:

- Mix the soil with enough water to make a putty-like consistency.
- Form the sample into a patty, let it dry completely.
- The greater the effort required to break the patty with fingers, the greater the plasticity, or ability to hold water. In other words, the more water the soil can hold, the less suitable it is under pavement. High dry-strength is characteristic of clays. Silts and silty sands will break easily.

Shake Test – The dilatancy test, or a test for reaction to shaking:

- Mix a tablespoon (15 ml) of water with the soil sample in the hand. The sample should be soft but not sticky.
- Shake or jolt the sample in a closed palm of the hand a few times.
- If water comes to the surface, the soil is fine sand.
- If none or a little comes to the surface, it is silt or clay.
- If squeezing the soil between the fingers causes the moisture to disappear the soil is sandy.
- If moisture does not readily disappear, then the soil is silty.
- If moisture does not disappear at all, the soil is clay.

Snake Test – Evaluating the thread toughness for clay content:

- A small sample of soil is moistened to the point where it is soft but not muddy or sticky.
- It is rolled into a thread or “snake” between the hands.
- The longer the thread, and the more it can be rolled without breaking, the higher the clay content.

The field tests described above are quick and easy ones to classify soils and obtain a relative measure of their water holding capacity. This can provide general guidance on which compaction equipment to use on the soil. Specific guidelines are given in a later section.

The water holding ability of soil is expressed by engineers as the Plasticity Index or PI. The laboratory test methods used to determine the Plasticity Index are outside the scope of this manual. For readers who wish to pursue this subject, however, the PI is the numerical difference between the Liquid Limit and the Plastic Limit. For further reading on the test methods, see AASHTO T 89 and T 90.

Soils with high PIs are much less desirable under pavements than those with low ones. For example, a soil with a PI of 40 will hold much water, probably has a high clay content, and will not perform well under a pavement. Clean sand and many aggregate bases are non-plastic. An aggregate base material with a PI of less than 6 will generally not hold much water and can be qualified for use in a pavement. Many local, state, or provincial agencies use the PI as a means to evaluate and select soils and base materials for pavement construction.

Section 5 Part C: Soil Compaction and Moisture-Density Relationships

Compaction

Compaction mechanically increases the weight per unit volume of soil or aggregate base materials. Compaction increases the unit density, often expressed in pounds per cubic foot (kg/m^3). It increases the load bearing capacity of the soil and base. Compaction prevents settlement and reduces swelling and contraction of the soil due to seasonal changes in moisture and temperature.

Compaction moves soil or aggregate particles, rearranging them closer to each other, and the air between these particles is forced out. Compaction removes air from bedding sand, aggregate base, dry soils, clay and cohesive soils.

With increased density, the soil, or base, is better able to support a load without settling or rutting. Without compacting, or inadequate compaction, the soil or base supporting the load will slowly settle or rut. This will decrease the life of the pavement.

Three factors govern the extent to which soil (or base) can be compacted:

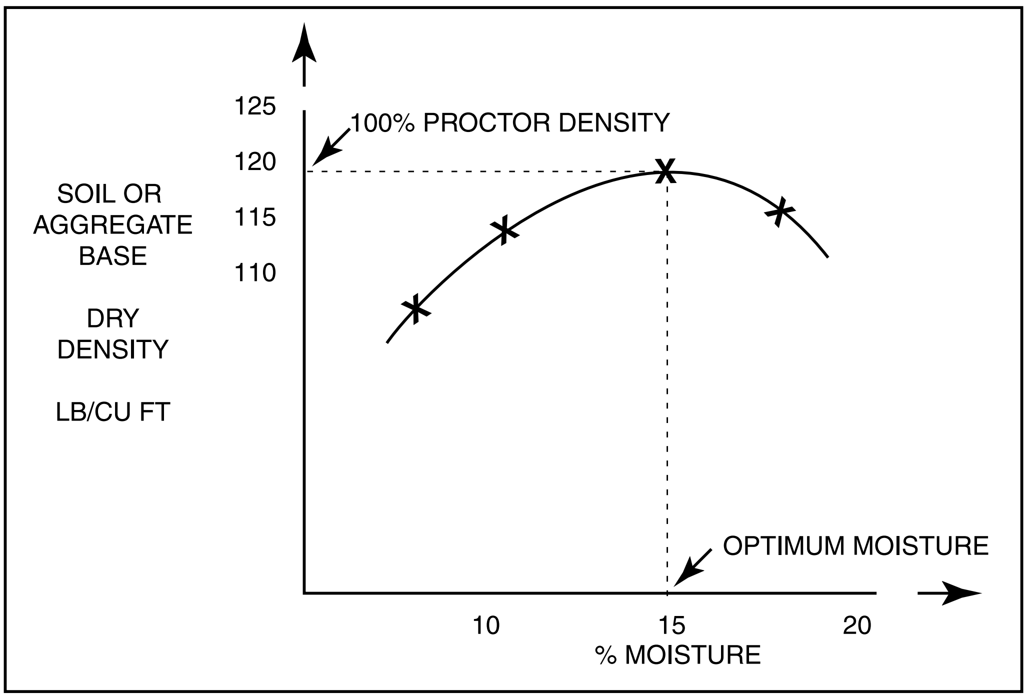
1. Soil type or classification – Nature, gradation or physical properties of the soil or base materials.
2. The moisture content of the soil or base being compacted.
3. The type and amount of compacting effort required–pressing, ramming or vibration. This is covered in a later section.

Soil type or classification – Soils are usually a mix of clay, silt or sand. As shown in the previous section, their particle size gradation determines their classification and their usefulness as a subgrade material. Silts and clays may require more time to compact than sandy soils because they have many small particles that are within a narrow range of sieve sizes. Some silts and most clay soils have more than 30% of their particles passing the No. 200 sieve (75 μm). These small particles are cohesive, they stick together with moisture and will hold their shape when compacted. In contrast, sand or granular soils rely on friction among their particles to hold together when compacted. Their larger particles make them easier to compact than clay soils. However, the ability of sandy soils to increase density through compaction can be very sensitive to the amount of moisture in them.

Moisture Content – Controlling the moisture content of the soil or base during compaction is critical to achieving maximum density. The optimum moisture level must be attained while compacting, i.e., not too little or too much. The correct amount of water is necessary to allow soil or aggregate particles to slide by each other. The water, in effect, acts as a lubricant. If there is too much water in the soil, however, the water will take up space between the particles and prevent them from staying together.

Figure 5-4 illustrates the effect of moisture on soil or base density. It shows that optimum moisture content corresponds to maximum dry density. As the moisture increases to the optimum percentage, density increases. If too much moisture is added, the soil or base density decreases and optimum density will not be attained. The relationship between soil or base density and optimum moisture will vary from soil to soil, and base to base.

Figure 5-4: The relationship between moisture and density: Too little moisture means that density decreases. Too much moisture also means density decreases. All soil and base materials have an optimum density– a balance between water content and weight per unit volume. The graph illustrates how density changes with moisture content.



From Wacker Corporation

A MOISTURE-DENSITY CURVE

Section 5 Part D: Measuring Soil Compaction

Measuring Compaction

Settlement of interlocking concrete pavements is the number one reason for customer call backs. In most cases the problem can be traced to inadequate compaction or lack of its measurement on the job site.

Subjective methods such as digging a heel into the base or soil have been used to evaluate their compaction. ICPI does not recommend this method to evaluate compaction.

On some projects, the contractor is often not responsible for compacting the soil or base. However, their density should be confirmed prior to placing bedding sand and concrete pavers. This section covers test methods to ensure adequate soil and base compaction.

A Simple Field Test for Estimating Optimum Moisture

When does the soil have enough moisture for compaction? A quick simple field test to evaluate the soil for the right amount of moisture for compaction follows. It is intended to give a general idea of the readiness of the soil for compaction

Squeeze a handful of the soil to be compacted into the size of a tennis ball.

- Drop the ball about 1ft (0.3 m) from the ground onto a hard surface.
- If the ball breaks into a small number of fairly uniform fragments it is close to optimum soil moisture.
- If the ball does not form into a ball at all, the soil is too dry and water must be added. (Gravel and mostly sandy soils often will not form into a ball.)
- If the soil is too moist, the ball will not break apart, unless the soil is very sandy. The soil to be compacted should be allowed to dry.

Proctor Density

Contrary to subjective test methods, establishing the right amount of compaction is only known by measuring density of the soil or base density at a given moisture content during compaction operations. Density and optimum moisture vary with the soil type or classification. Figure 5-5 shows various soil types with the range of densities and optimum moisture contents. Therefore, knowing the soil type provides information on the density and relative amount of water required to achieve maximum density during compaction.

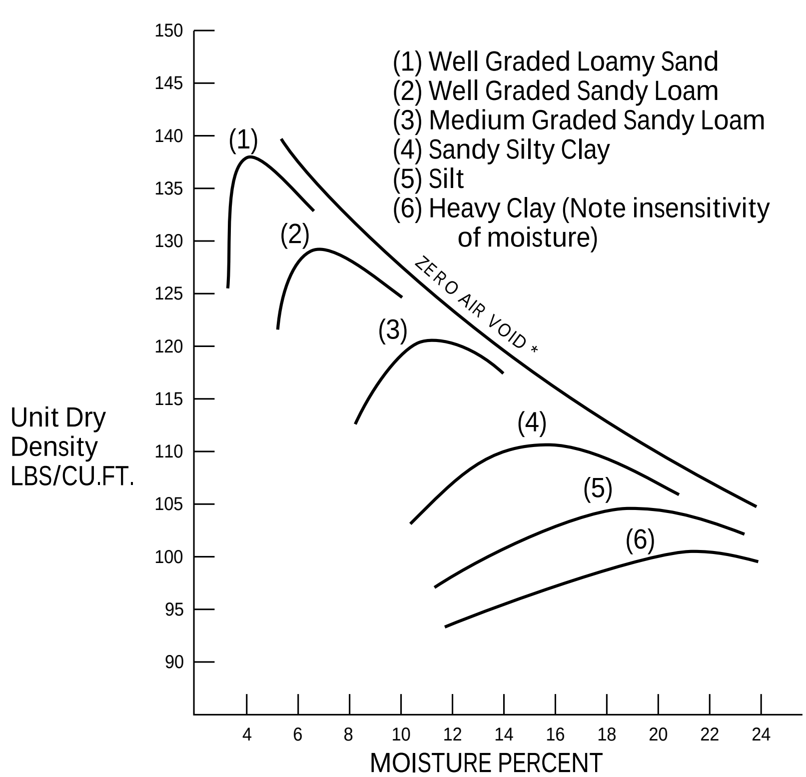
Proctor density is the most common method of determining the degree of compaction. R.R. Proctor, former field engineer for the Los Angeles City Bureau of Water Works and Supply, published a series of articles in 1933 describing the results of studies in compaction test procedures. Hence, the name Proctor density test.

Proctor tests are first performed on soil or base samples in the laboratory to determine the maximum soil density and its optimum moisture content, since both factors influence compaction. The laboratory results are compared to field testing for density. The results of field tests are divided by the laboratory results to obtain a percentage of Proctor density.

There are two kinds of Proctor tests depending on the degree of compaction required for the job, Standard Proctor and Modified Proctor density tests. The Standard Proctor Test is conducted in a soils testing laboratory by taking a soil sample from the job site and placing it in a container equal to 1/30 cubic foot (0.025 m^3). In the lab, a 5 1/2 pound (2.5 kg) weight with a striking face of 3.1 square inches (2,000 mm^2) is dropped 12 inches (305 mm) for 25 blows on each of three equal layers. The soil material is then weighed, less the mold, and recorded as wet weight/cubic foot. The material is then oven-dried for 12 hours to determine the water content.

This test is called AASHTO T 99, Test Method of Test for The Moisture Density Relations of Soils Using a 5.5 lb (2.5 kg) Rammer and a 12-in. (305 mm) Drop published by the American Association of State Highway and Transportation Officials (AASHTO). A similar test can be found in ASTM D689, Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort [12,400 ft-lbf/ft^3 (600 kN-m/m^3)] published by the American Society of Testing and Materials (ASTM). See Figure 5-6.

Figure 5-5: Comparison of the moisture-density relationship of various soils.



*Zero Air Void is the theoretical point at which a soil would be at its maximum density

From Wacker Corporation

The following is a range of densities that might be expected from this test:

Clays –Maximum density: 90–105 lb/ft ^{3} (1440–1689 kg/m ^{3}).
Optimum moisture content: 20–30%.

Silty Clays –Maximum density: 100–115 lb/ft ^{3} (1600–1840 kg/m ^{3}).
Optimum moisture content: 15–20%.

Sandy Clays –Maximum density: 110–135 lb/ft ^{3} (1760–2160 kg/m ^{3}).
Optimum moisture content: 8–15%.

Modified Proctor Test –The modified Proctor test is done in much the same way, except a 10 - pound (4.53 kg) hammer is used and dropped from a distance of 18 inches (457 mm) for 25 blows. The material is tested in a 1/30 cubic-foot (0.25 cubic-meter) container in five equal layers. The compaction effort produced is 56,200 foot pounds (76,197 N), while the standard Proctor test produces 12,400 foot pounds (16,812 N). The modified test is normally used to test soil and base materials for higher shearing strength which supports heavier loads such as those found on streets and industrial pavement.

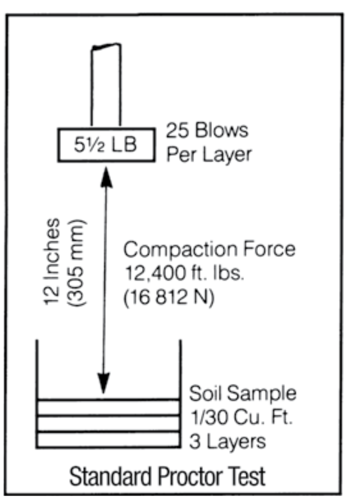
This test is called AASHTO T 180, Test Method of Test for The Moisture Density Relations of Soils Using a 10 lb (4.54 kg) Rammer and an 18-in. (305 mm) Drop. A similar test can be found in ASTM D1557, Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort [56,400 ft-lbf/ft ^{3} (2,700 kN-m/m ^{3})]. Figure 5-6 compares the standard and modified Proctor density tests.

Since this test involves greater compactive force, maximum densities can be 10 - 20 lb/ft ^{3} (160 -320 kg/m ^{3}) greater than those tested with the standard Proctor test. Moisture contents will be 3% to 10% lower. In practical terms, attaining modified Proctor density requires either more compaction time in the field to reach maximum density or heavier compaction equipment. The result is a substantially stronger foundation and potentially longer lasting pavement.

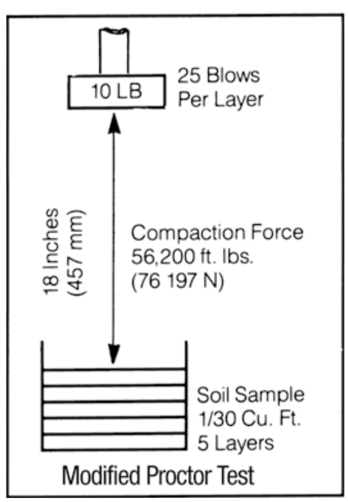
On-Site Density Tests

The nuclear density gauge test is commonly used to determine density of soil or base after compaction. The nuclear density gauge test is described in ASTM D2922 or AASHTO T 238. The density of the soil or base measured in the field. The density

Figure 5-6: Differences between Standard and Modified Proctor Density Tests.



AASHTO T99/ASTM D 689



AASHTO T180/ASTM D 1557

From Vibromax 2000

is divided by Proctor density test results obtained in the laboratory, and a density percentage is determined. For example:

Laboratory (Proctor) Test	Field Test (using a nuclear density gauge)
Maximum soil density:	Density after compaction:
117 lb/ft ^{3}	114.7 lb/ft ^{3}

In this instance the compaction equipment on the site achieved 114.7/117 = 98% Proctor density. This result would be checked for conformance to the job specifications.

It is possible that a soil or base may be compacted to more than 100% Proctor density. For example, a Proctor of 104% means that more compaction (and density) was attained in the field than in soil tested in the laboratory.

Nuclear density measurement consists of a testing probe that uses a radioactive source in combination with Geiger tubes to measure either density or moisture (see Figure 5-7). An external detector probe is inserted into the compacted soil to the desired depth {typically 6 in. (150 mm)} for pedestrian pavements and 12 in. (300 mm) for vehicular pavements. Gamma rays emitted from the detector probe are absorbed by the soil and water atoms. The denser the soil and the more water present, the more rays are absorbed. Therefore, fewer rays reach the instrument detector to be counted.

"Nuking" the soil or base is a fast and accurate density test. Nuclear density testing is conducted by a trained technician certified to use the gauge. The gauge is expensive (~$8,000) and generally not purchased by paver installation contractors. Rather, a trained certified technician from a soils testing company is hired by a contractor to take measurements. A phone call to a local soils testing laboratory can determine costs for laboratory tests, field tests and timing. This expense will likely be less than the cost of repairs to settlement from a customer call back .

Contractors are encouraged to use an experienced engineering testing company to conduct nuclear density tests on driveways and roads because:

- The machine can instantly check density after each pass of compaction equipment.
- The machine can establish optimum compactor use, eliminating wasted labor time, equipment wear, and money in over compacting or under compacting.
- The machine can be attached to roller compactors to obtain instantaneous readings during the compaction process, and machine adjustments can be made immediately.
- In short, nuclear density testing is inexpensive insurance to pay to reduce the chance of settlement and the cost of a call back.

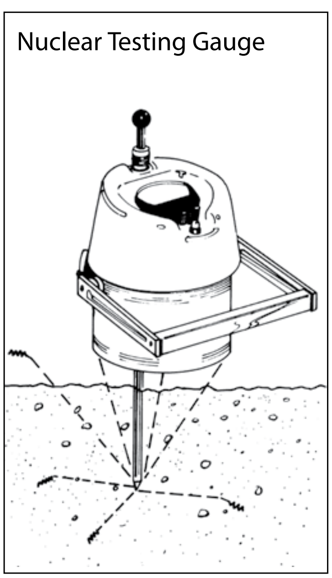
There are other resonably accurate ways to measure soil compaction.

Compaction Sensors –An affordable option for determining adequate density of compacted soils and base is using soil compaction sensors and monitoring equipment. The hand-held monitoring equipment is about $2200, and the disposable sensors are about $15 each. Sensors are placed at the bottom of the soil prior to compaction. Wires from the sensors are connected to a monitor that indicates when density has been achieved. The sensors are left in the soil. The same procedure can be used for compacting aggregate base materials. Soils and base must be moist prior to compacting, using the hands-on tests in this manual to determine adequate water content in each. Besides sufficient moisture in the soil, the lift thickness and size of compaction equipment will affect the level of density achieved in the soil or base when using the sensing equipment.

Compaction sensors provide instant monitoring and quality control of soil and base compaction. They do not require determination of laboratory Proctor density prior to field testing. Compaction data can be downloaded from the monitoring equipment and be stored as job documentation. A manufacturer of compaction sensor equipment reports densities correlating well with those measured with a nuclear density gauge. Regular correlation of Proctor density using the sensors and comparing results with a nuclear density gauge will provide greater assurance that the recommended Proctor density in this manual is being achieved. The economy of this test equipment pays for itself after five or six jobs compared to the cost of hiring someone to conduct tests with a nuclear density gauge. For further information, contact MBW Inc. at <www.mbw.com> regarding the Soil Compaction Supervisor.

Dynamic Cone Penetrometer –This test equipment and method is described in ASTM D6951, Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications. Figure 5-8 illustrates this equipment. A dynamic cone penetrometer (DCP) costs less than $1,000 including a carrying case a replacement cone tips. The device consists of a steel shaft with a sliding hammer on the shaft that is raised and dropped. The impact of the hammer drives the cone tipped drive rod into the soil or base. The number of blows and depth of each blow (in millimeters) are recorded. The total number of blows and penetration are correlated to density, California Bearing ratio, stiffness or other material characteristics. The penetrometer is intended for use on soils and base with particles less than 2 in. (50 mm) in size.

Figure 5-7: Nuclear Density testing equipment



From Vibromax

Figure 5-8: Dynamic cone penetrometer used to test compacted soil density. The sliding hammer is being raised into position by the operator's hands.

Before using the DCP, the contractor will need to establish the range of blows on compacted soils and base whose Proctor density is measured with a nuclear density gauge. This will give the contractor a feel for the number of blows and penetration required to confirm a minimum 98% Proctor density with the DCP. The soil or base must be near or at the optimum moisture content. After that initial testing and expense related to correlating, the DCP can be used by itself to check density. DCPs can be purchased from soil laboratory equipment suppliers such as Durham Geo, Kessler, or SoilTest/ELE.

Passes with Specific Compaction Equipment – This method relies on a specified number of passes across soil or base (at specific, consistent lift thicknesses). For example, six passes with a 9000 lbf (40 kN) roller compactor could render 98% Proctor density on a certain soil types. Like the other measurement methods, the nuclear density gauge test provides the means to correlate number of compactor passes to density (at optimum moisture content.) Again, the contractor will need to conduct tests on bases and some soils to gain correlations for the number of passes of compaction equipment.

Soil Compaction Guidelines

Since soils vary widely across North America, their ability to be compacted varies as well. Many soils can be compacted to at least 98% standard Proctor density. This is a minimum recommended guideline for pedestrian sidewalks and driveways. Higher standard Proctor densities are desirable. ICPI Tech Spec 2—Construction of Interlocking Concrete Pavements (see Appendix) recommends that compaction should be at least 98% of standard proctor density however modified proctor density is preferred for vehicular traffic

The depth of compaction to standard Proctor density in the soil should be at least 6 in. (150 mm) for pedestrian areas and 12 in. for (300 mm) for areas subject to vehicles. Soils that are continuously wet, very fine, or contain organic matter (decaying leaves, wood, etc.) will not compact to these recommended minimums. They may need other treatments. They include soil replacement, stabilizing the soil with lime or cement, or place an aggregate subbase over them before placing the base materials.

Modified Proctor density requires more compaction time. Equipment that exerts more force is often necessary to attain the higher densities associated with Modified Proctor. At least 98% modified Proctor density is desirable for streets, as well as for heavy duty pavements such as ports and airports.

Regardless of the test method used, density of soils and base should be checked in areas where it is difficult for compaction equipment to reach. These include areas next to concrete slabs, concrete curbs, and corners, near walls, next to utility structures and over wet soils or base. Whatever means is used, measuring density is critical to a quality job. Besides reducing expensive callbacks, measuring density will reduce liability and save time if too much labor is spent on compacting. Density measurement can be promoted as part of a quality job to the customer. All of these aspects improve a contractor's reputation.

Section 5 Part E: Soil Compaction Methods and Equipment

Compaction Equipment and Selection

The action of compaction equipment is described by its frequency (how often) and amplitude, or how high it bounces. Frequency is expressed in vibrations per second or hertz (Hz) and amplitude is expressed as half the distance traveled by the vibrating drum or base plate.

Machine Types

Compaction equipment is generally classified into five machine types, each producing a different kind of compaction effort: rammers (or jumping jacks), forward plate, reversible plate, vibratory rollers and static rollers.

Rammers are distinguished by their low frequency (800–2,500 blows per minute) and high stroke [1 1/2 in. to 3 1/2 in. (40–90 mm)]. The stroke of a rammer is the height the ramming shoe or plate reaches from ground level while operating. The difference between ramming and vibratory plate compactors is that rammers jump higher, but at a lower rate. The force of the impact is higher for a rammer. See Figures 5-9 and 5-10. This extra force is needed to compact clay soils.

Figure 5-9: Reversible Plate Compactor

5-10: Rammer (jumping jack)

Figure 5-9 shows a plate-type, self-propelled reversible plate compactor that uses eccentric counter-rotating weights to provide the ramming force and travel speed. This machine can be used to compact cohesive clay and silty soils and aggregate base materials. These compactors usually have a compaction (exciter) force starting at 5000 lbf (22kN) and going up to 14000 lbf (60 kN). A hand-held upright rammer ("jumping jack") uses a spring mechanism.

Rammers can be used for granular (sandy) soils if the soil being compacted is in a confined area such as a trench. If the area is not confined, the rammer will push the granular soil to the sides rather than compact it. Rammer plates can also be used on granular materials in confined areas, or on open areas with extension plates.

Forward plate compactors are recommended for non cohesive granular and sandy soils. They look much like the compactor in Figure 5-9, however they have a much lower compaction force, typically ranging from 1500 lbf (7kN) to 4500 lbf (20 kN). They exert low amplitude and high frequency (2,000–6,000 Hz).

Figures 5-11 and 5-12 show roller type vibratory compactors. Each rotation of the eccentric shaft in the drums forces energy into the ground. This vibration energy sets the soil particles in motion and rearranges them more tightly. They are suitable for compacting clay soils and aggregate base materials.

Static rollers use only their weight and no vibration for compaction. Large static rollers are used to proof-roll pavers in port and airport applications after plate compaction.They are used for compacting open-graded bases and asphalt, but not for compacting soil.

To understand compaction and select the right equipment, knowledge of the basic properties of soil is needed, as well as the soil's classification. Since many soils are usually mixtures of sand, silt and clay, machine selection becomes more difficult. Generally, the machine used should be the type required for whichever

Figure 5-11: Walk-behind Vibratory Roller

Figure 5-12: Riding Vibratory Roller

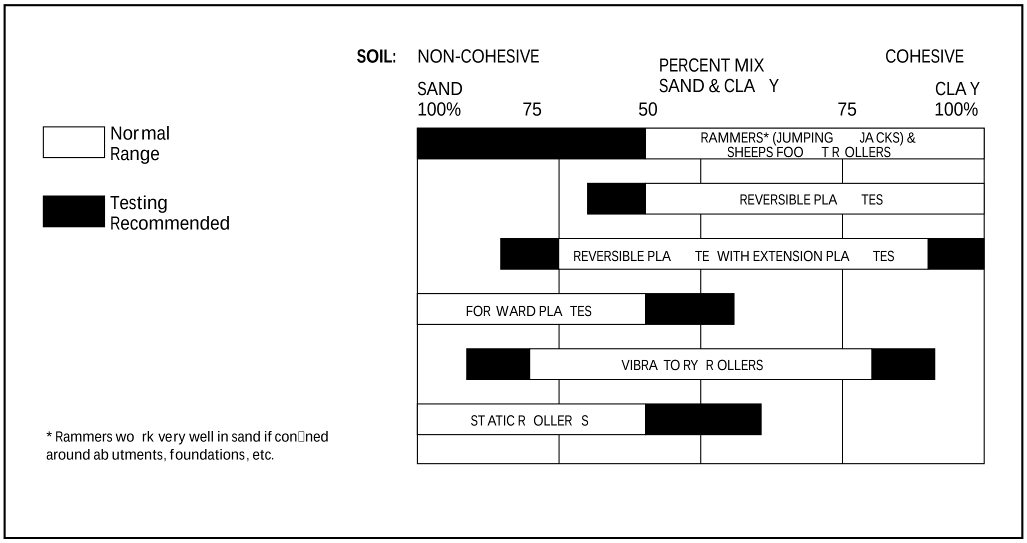


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Figure 5-13: Compaction machine application based on soil type

soil represents the largest percentage of material based on the classification. Figure 5-13 provides guidance on applying the right equipment to compact various soil types.

Compacting clay soils – Since clay is cohesive and the particles stick together, use a machine with an impact that rams the soil, forces out the air and rearranges the particles. For clay soils a reversible plate machine is best, or a sheepsfoot roller.

Compacting granular materials– Sand and aggregate bases are not cohesive. Therefore, their particles require shaking or vibratory action to move them. Forward plates and vibratory rollers are ideal for compacting aggregate base, bedding sand under paving slabs, or asphalt. Forward plate compactors are also used on pavers over bedding sand to rearrange the sand so it is tightly compacted. They also force sand up into the joints.

Rammers (jumping jacks) can also be used for granular soil if the soil being compacted is in a confined area such as a trench. If the area is not confined, the rammer will push the granular soil to the sides rather than compact it. Reversible plates can also be used on granular materials in confined areas, or on open areas with extension plates.

Soil Compaction Methods

A common error in compacting soil or base is compacting it all at once. Instead, soil and base are compacted in layers, or lifts. A lift of loose soil or aggregate is placed and compacted, and then another loose lift is spread and compacted. This continues until the soil or base is brought up to the specified elevation, usually marked with grade stakes.

If the lift is too deep, the machine will need more time to compact the soil or base. The soil or base may never reach full compaction, especially if a hard layer is compacted at the top of the lift and the density is not consistent to the bottom. No precise lift depth exists for soil or base compaction. Lift depth depends on the compaction equipment available to the contractor and machine selection depends on what equipment achieves optimum density in the least amount of time.

Many paver installation contractors have small compaction equipment, either vibratory plate or roller equipment. Since the equipment can exert a limited amount of compaction force, the lifts of soil or base should not be deep, usually no greater than 4 in. (100 mm).

Forward and reversible machines compact the soil or base in the same direction, from the bottom of the lift to the surface. As the machine hits the soil or base, the impact travels to the harder layers below the surface and returns upward. This action sets the particles in motion and compaction takes place. As the soil or base is compacted, the impact has a shorter distance to travel so more force returns to the machine, making the machine bounce higher off the ground.

Compactors that allow a variation in frequency and amplitude are more efficient in soil and base compaction. They can be adjusted to exert the right amount of force depending on the material. This saves time (and money) by selecting the frequency, amplitude, and force appropriate to reaching adequate Proctor density of the soil or base.

Whether rented or purchased, equipment selection will impact efficiency. A contractor may compact soil and base under thousands of square feet (m^2) in a year. A few hours saved on each job by using larger equipment equates to days of saved labor hours for the year. This savings yields high profitability. Technical staff with compaction equipment companies should be consulted for selecting equipment that will match the anticipated job sizes. Examples of compactors are on the following pages.

405 Single Drum Roller	Smooth	Padfoot
Engine	Cummins 4BT3.9C	
HP. SAE Net	76	76
Operating weight (lbs)	10,140	10,500
Drum width (in.)	55.1	55.1
Max. Comp. Depth (in.)	25.5	27.5
Max. frequency (vpm)	2016	2016
Max. centrifugal force (lbf)	18,698	18,698
Centrifugal force/width (lb/in)	340	340

605 Single Drum Roller	Smooth	Padfoot
Engine	Cummins 4BT3.9C	
HP. SAE Net	76	76
Operating weight (lbs)	14,850	14,975
Drum width (in.)	68.9	68.9
Max. Comp. Depth (in.)	29.5	35.4
Max. frequency (vpm)	2160	2160
Max. centrifugal force (lbf)	28,766	28,766
Centrifugal force/width (lb/in)	417	417

1105 Single Drum Roller	Smooth	Padfoot
Engine	Cummins 6BT5.9C	
HP. SAE Net	130	130
Operating weight (lbs)	27,720	29,375
Drum width (in.)	82.7	82.7
Max. Comp. Depth (in.)	39.4	49.2
Max. frequency (vpm)	2160	2160
Max. centrifugal force (lbf)	50,565	50,565
Centrifugal force/width (lb/in)	611	611

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Tandem Rollers	255	265
Engine	Kubota	Kubota
HP. SAE Net	29	29
Operating weight (lbs)	5843	6064
Drum width (in.)	39.4	47.2
Static linear drum load (lb/in)	74.1	64.2
Max. frequency (vpm)	3480	3480
Centrifigal force/drum (ibf.)	6744	8100
Total applied force (lbf/in.)	245.1	235.2

Tandem Rollers	355	365
Engine	Kubota	Kubota
HP. SAE Net	46.6	46.6
Operating weight (lbs)	8598	8776
Drum width (in.)	51.2	55.1
Static linear drum load (lb/in)	84	80
Max. frequency (vpm)	3300	3300
Centrifigal force/drum (ibf.)	10,787	11,911
Total applied force (lbf/in.)	210	233

Tandem Rollers	455	465
Engine	Kubota	Kubota
HP. SAE Net	46.6	46.6
Operating weight (lbs)	10,495	10,672
Drum width (in.)	51.2	55.1
Static linear drum load (lb/in)	102	97
Max. frequency (vpm)	3300	3300
Centrifigal force/drum (ibf.)	11,237	12,360
Total applied force (lbf/in.)	204	224

VIBROMAX

Trench Roller	1500
Engine	Kubota
HP	22.5
Operating weight	3307
Drum width (in.)	24.8
Max. Comp. Depth (in.)	31.5
Frequency (vpm)	1860
Centrifugal force (lbs)	18878

Walk-behind Rollers	62	70
Engine	Hatz	Hatz
HP. SAE Net	6.9	8.4
Operating weight (lbs)	1323	1614
Drum width (in.)	23.6	25.6
Max. Comp. Depth (in.)	11.8	13.8
Max. frequency (vpm)	3300	3300
Exciter force (lb)	3597	4496
Total applied linear force (lb./in.)	75.9	88

Reversible Plates	12	15
Engine	Hatz	Yanmar
HP	4.6	4.2
Operating weight	265	397
Max. Comp. Depth (in.)	15.7	15
Frequency (vpm)	4500	4500
Exciter force	4944	5850
Coverage (sq.yd./hr)	466	477

Reversible Plates	25	35	45
Engine	Yanmar	Yanmar	Hatz
HP	5.9	7.9	14.1
Operating weight	474	706	1124
Max. Comp. Depth (in.)	17.7	27.6	27.6
Frequency (vpm)	4500	3300	3000
Exciter force	7875	11250	15731
Coverage (sq.yd./hr)	631	775	789

Rammers	SL1R	SL2R
Engine	Robin	Robin
HP	3.3	4.5
Operating weight (lbs)	125	156
Max. Comp. Depth (inch)	15.7	17.7
Blows per minute	500 - 800	500 - 800
Impact force (lbf)	8992	12746

Vibratory Plates	600	900	1300
Engine	Honda	Honda	Honda
HP	4.0	4.0	5.5
Operating weight	150	192	238
Max. Comp. Depth (in.)	7.9	11.8	11.8
Frequency (vpm)	5800	6000	5400
Exciter force	1619	2023	4046
Coverage (sq.yd./hr)	598	715	897

VIBROMAX

Section 5 Part F: Geotextiles: Purpose and Uses

Separating the Base from the Soil

Geotextiles separate the base from the soil, and help contain and preserve the base. Geotextiles may be used in areas where soil remains saturated part of the year, or where there is freeze and thaw. While not necessary in all applications, geotextiles can delay soil deformation from repeated loads; however, geotextiles should not be relied upon to increase the strength of the base. Use of a geotextile does not allow for the reduction of base thickness. The use of geotextiles is particularly effective over clays and silts. They help prevent these soils from being pressed into the aggregate base under loads, especially when saturated, thereby reducing the likelihood of rutting. Geotextiles preserve the load bearing capacity of the base over a greater length of time. Woven or non-woven fabric may be used under the base with a maximum apparent opening size of 0.60mm as testing using ASTM D4751. Table 5-2 lists minimum requirements of geotextiles for soil separation. These requirements are taken from AASHTO M 288-06 Standard Specification for Geotextile Specification for Highway Applications. The minimum down slope overlap should be at least 12 in. (300 mm).

When the geotextile is placed on the soil in the excavated area, it should be turned up along the sides of the opening, covering the sides of the aggregate base layer. There should be as few wrinkles as possible on the bottom, and the ends should overlap at least 12 in. (300 mm). Overlap requirements for low strength subgrades are detailed in Table 5-3. When the aggregate base material is dumped on the fabric, tires should be kept off the fabric to prevent wrinkling.

Table 5-2. Geotextile Requirements for Separation

Geotextile Class		Class I [a]		Class II [a]		Class III [a]	
Elongation	ASTM D 4632	< 50%	> 50%	< 50%	> 50%	< 50%	> 50%
Grab Strength [b]	ASTM D 4632	315 lb [1400 N]	202 lb [900 N]	247 lb [1100 N]	157 lb [700 N]	180 lb [800 N]	112 lb [500 N]
Sewn Seam Strength [b,c]	ASTM D 4632	283 lb [1260 N]	182 lb [810 N]	223 lb [990 N]	142 lb [630 N]	162 lb [720 N]	101 lb [450 N]
Tear Strength [b]	ASTM D 4533	112 lb [500 N]	79 lb [350 N]	90 lb [400 N] [d]	56 lb [250 N]	67 lb [300 N]	40 lb [180 N]
Puncture Strength [b]	ASTM D 6241	618 lb [2750 N]	433 lb [1925 N]	495 lb [2200 N]	309 lb [1375 N]	371 lb [1650 N]	223 lb [990 N]
Permittivity [b,e]	ASTM D 4491	0.02 sec^{-1}					
Apparent Opening Size	ASTM D 4751	0.024 in [0.60 mm] maximum average roll value					
Ultraviolet Stability	ASTM D 4355	> 50% after 500 hr exposure					

[a] The severity of the installation conditions generally dictates the required geotextile class. Class I is the most severe and Class III is the least severe.
[b] All numeric values represent MARV in the weaker principal direction.
[c] When sewn seams are required.
[d] The required tear strength for woven monofiliment geotextiles if 250 N.
[e] Default Value. Permittivity of the geotextile should be greater than the soil.

Geotextiles are also used to prevent migration of bedding sand into cracks, joints and weep holes in or next to the pavement. Various applications are covered in later sections in the course.

Table 5-3. Geotextile Overlap Requirements

Soil CBR	Overlap
> 3.0	1.0 ft [0.3 m] to 1.5 ft [0.45 m]
1.0 to 3.0	2.0 ft [0.6 m] to 3.0 ft [1.0 m]
0.5 to 1.0	3.0 ft [1.0 m] or sewn
< 0.5	Sewn
All roll ends	3.0 ft [1.0 m]

Geotexile on Base Surfaces

Geotextile is generally not applied to the surface of a compacted, crushed aggregate base. Those who apply geotextile to the surface of the base often do it out of concern that the bedding sand will work down into the base and cause surface settlement. Such concerns are unfounded if the aggregate base has a sufficient amount of fines to choke or close the surface during compaction.

If there is concern that the base gradation will accept the entry of bedding sand, a thin layer of joint sand can be applied and compacted into the surface of the base during the final leveling and compaction process. This is an extra operation that increases the cost of installing the base. It can be avoided by regularly checking base gradations, or using an aggregate supplier that provides consistently graded base materials. If the base material gradation conforms to that recommended in this course, there is a low risk of settlement from bedding sand working into the surface of the base.

Other bases can require geotextiles on them. For example, in the Houston, Texas area, soils are very weak, often saturated, and cannot be easily compacted. Contractors use cement-treated bases, consisting of a mixture of cement and sand or aggregate. These bases are very durable. Cement-treated bases tend to shrink over time, and small cracks appear on the surface. Geotextile placed over the surface of cement-treated base can prevent loss of bedding sand into these cracks. This is a recommended practice for cement-treated bases.

Concrete pavers are often overlaid onto existing asphalt or concrete pavement. With the pavers and bedding sand applied to the surface, these pavements now become bases. The condition of their surfaces should be free from cracks and loose materials prior to applying the bedding sand and pavers. Any cracks should be patched. Joints in concrete pavement should have geotextile applied to them, as these are the most likely places where cracking will occur. If the pavement is rutted, heaving or faulted, an overlay should not be applied. These conditions suggest problems with the soil and/or base materials and they may need to be removed and replaced.

While not essential for overlays of pavers in pedestrian applications, vehicular applications should use geotextile over existing asphalt or concrete bases. While there may be no cracks in the existing pavement bases, the geotextile will prevent loss of bedding sand into any cracks that might appear during the life of the pavement.

References for this Section

TenCate Mirafi geotextile technical data — Appendix, pages 184–187
Vibromax roller technical data — pages 73–76

Base Materials

[CPI06]

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Pavement Institute®

Base Materials

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Interlocking Concrete Pavement Institute
14801 Murdock Street, Suite 230
Chantilly, VA 20151
Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

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Base Materials

Section 6 Part A: Gradation

Specifications typically used by cities, states, or provinces for dense graded aggregate base materials under flexible asphalt pavements are adequate for interlocking concrete pavement. These specifications can be obtained from engineering departments. If no specifications are available, then use the recommended grading for the aggregate base shown in Table 6-1.

Quarries certified by city, state or provincial highway agencies provide an extra measure of assurance that base materials meet agency specifications. Quarries maintain their certification by routine testing of gradation (plus other tests) and reporting to highway agencies. Whenever possible, materials from certified quarries that conform to agency standards and the guidelines in this manual should be used for the base, bedding, and joint sands.

Table 6-1: ASTM D2940 - Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways and Airports

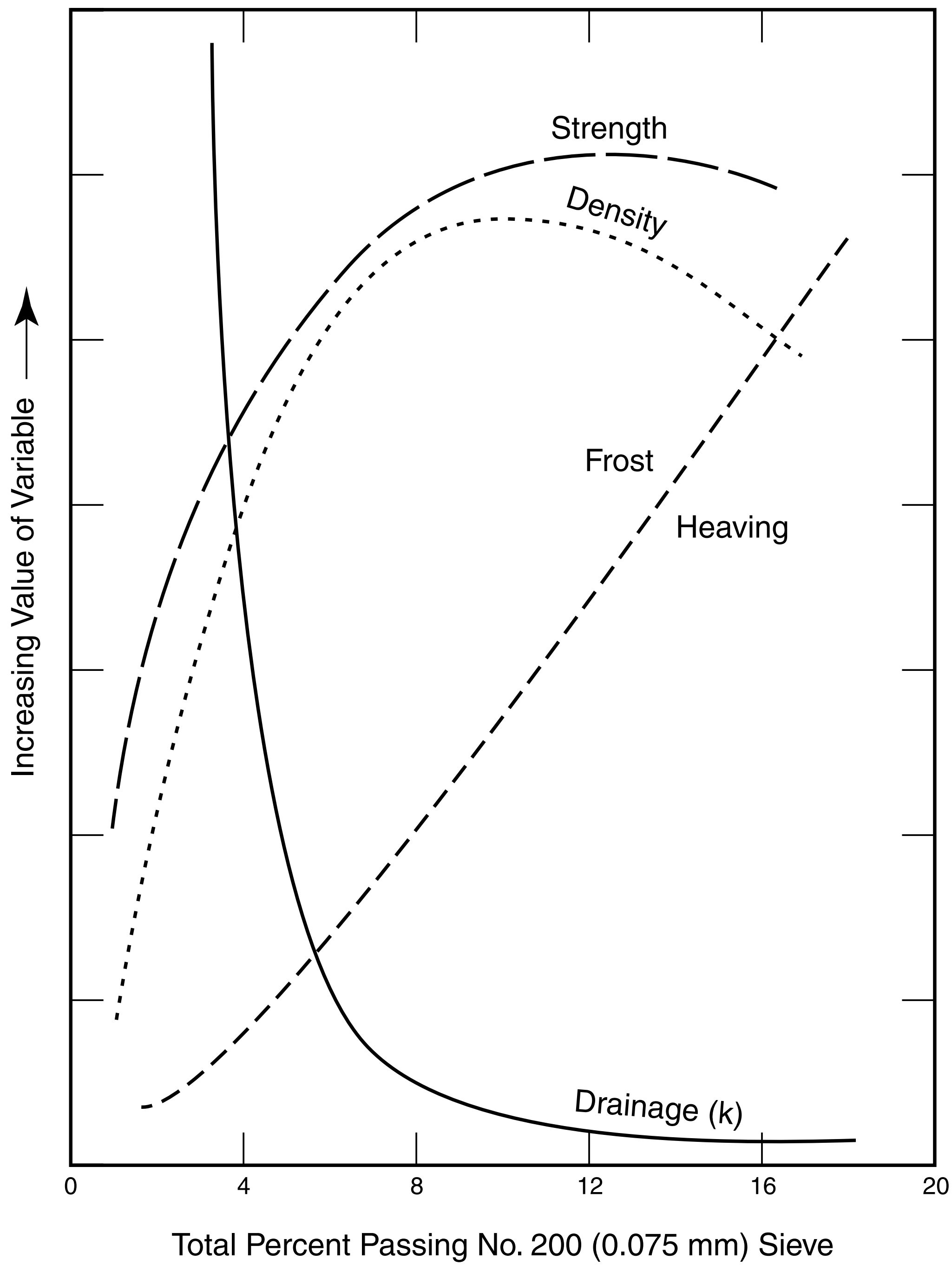
	Percent Passing		Job Mix Tolerance	
Sieve Size	Bases	Subbases	Bases	Subbases
2 in. (50 mm)	100	100	-2	–3
1 1/2 in. (37.5 mm)	95–100	90–100	±5	+5
3/4 in. (19 mm)	70–92		±8	
3/8 in. (9.5 mm)	50–70		±8	
No. 4 (4.75 mm)	35–55	30–60	±8	±10
No. 30 (600 µm)	12–55		±5	
No. 200 (75 µm)	0–8	0–12	±3	±5

Gradation of base materials is similar to that used for soils i.e., sieves measuring particle sizes. Like soils, the amount of material passing the No. 200 (75 µm) sieve is important to the gradation of base material. If there is too little fine material, the bedding sand will migrate into the surface of the base. While this is an unusual occurrence, it can be fixed by applying and compacting a 1/8 in.–1/4 in. (3–7 mm) thick choke course of joint sand over the surface of the base.

A more common occurrence is too much fines in the aggregate base. Fines are considered by quarries to be waste material, so there is an incentive to add as much as possible to base material. The fines should be periodically checked with a sieve analysis by an independent testing lab. This is an inexpensive test that assures quality of the base. Recycled concrete aggregate (RCA) is an acceptable material for base. Its gradation should conform to that in Table 6-1 or to local agency specifications. RCA can cause or aggravate efflorescence formation in concrete pavers.

Figure 6-1 below illustrates the effects of too many fines on strength, frost heaving, density and drainage in a limestone base with a maximum aggregate size of 1 1/2 in. (38 mm). As the percentage of fines passing the No. 200 sieve increases beyond 12–14%, base strength decreases, frost heaving increases, density and drainage decreases. This figure demonstrates why fines should be about 8 percent in most base materials. This value is the best compromise of desirable aggregate base properties.

Figure 6-1: The role of fines in aggregate bases.



From Aggregate Handbook, National Stone Association

Section 6 Part B: Factors in Determining Base Thickness

There are some general *minimum* base thickness (after compaction) guidelines that apply to most areas in North America:

- Sidewalks, patios, and pedestrian areas–4 in. (100 mm) over well-drained soils.
- Residential driveways on well-drained soils– at least 6 in. (150 mm) thick. In colder climates, continually wet or weak soils, add 2 in.–4 in. (50–100 mm).
- Parking lots and residential streets– 8 in.–10 in. (200–250 mm). Greater thicknesses for the above applications are often used in regions with numerous freeze-thaw cycles, expansive soils, or very cold climates.

The thickness of the base (after compaction) is determined by traffic loads, soil strength, subgrade soil drainage and moisture, and climate. Local, state, or provincial engineering standards for base thickness for asphalt pavements can be applied to streets constructed with interlocking concrete pavers. A qualified civil engineer familiar with local soils and traffic conditions should be consulted to determine the appropriate base thickness for streets and heavy-duty, industrial pavements.

Many localities, state and provincial agencies determine base thickness using the 1993 *Guide for the Design of Pavement Structures* published by the American Association of State Highway and Transportation Officials (AASHTO). The AASHTO procedure calculates a structural number (SN) from strength coefficients of each base and pavement layer. The SN is determined by assessing the traffic loads, soils, and environmental factors (e.g., drainage, freeze-thaw).

While it is outside the scope of this course, base thicknesses can be readily determined by using the procedures in *ICPI Tech Spec 4, Structural Design of Interlocking Concrete Pavement for Parking Lots and Streets* (see Appendix). The ICPI has a free software program available on www.icpi.org that can be used to determine the thickness of interlocking concrete pavements. This software uses the AASHTO pavement design procedure. In addition, the American Society of Civil Engineers published ASCE/ANSI 58-16 *Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways*. This design method is based on 1993 AASHTO *Guide for the Design of Pavement Structures*.

Section 6 Part C: Base Compaction Testing and Guidelines

ICPI Tech Spec 2–Construction of Interlocking Concrete Pavements (see Appendix) recommends that bases for pedestrian areas and residential driveways should be compacted a minimum 98% of standard Proctor density. For vehicular areas, compaction should be at least 98% of modified Proctor density.

Compaction tests should be conducted on bases subject to vehicles, including residential driveways. When spread and compacted, the aggregate base should be at its optimum moisture. A moisture meter on a nuclear density gauge can be used to quickly assess the amount of water in the base. A quick field test is pressing a handful of base material in the palm. If the particles stick to each other, there is a sufficient amount of moisture. If it is too wet, it should be allowed to dry. If it is too dry, water can be added by spraying it over each lift prior to compaction.

Density measurements of the compacted base should be made with a nuclear density gauge, compaction sensors, dynamic cone penetrometer or other methods approved by the local, state or provincial transportation department. Again, a nuclear density gauge requires trained, certified technicians to use them. However, the actual cost of the test is far lower than the cost of returning to the site to make repairs. It is the best insurance of quality control for the contractor. The contractor should contact an experienced soils testing company to measure density and moisture content.

Special attention should be given to testing and achieving compaction standards in corners, against concrete curbs, against walls, around utility structures, and over wet soils. These are places where settlement is most likely to occur. These areas often cannot be compacted with large compaction equipment. They may need a small machine compactor or the use of a hand tamper.

Base Compaction Guidelines

For vehicular areas base compaction should be at least 98% of modified Proctor Density as determined by ASTM D1557 or AASHTO T-80. While the highest percentage compaction (100%) is preferred, it may not be achievable over weak or saturated soils. To facilitate soil and base compaction, an information sheet follows on the next page that enables contractors to call and ask a local testing laboratory about tests. There is a place to fill in the name of the laboratory, other information, and the prices. Guidelines on when to conduct test are given below:

- Soils classification – for determining compaction equipment; influences base thickness.
- Laboratory and field density of soils and base – recommended for vehicular pavements, advisable for pedestrian areas.
- Gradation of base and bedding sand – check periodically for conformance to recommend specifications, check when changing suppliers.

Testing Information Sheet

Contact any one of these companies for information on testing services: •Soils/materials testing laboratory •Civil engineering firm with a soils testing laboratory •Geotechnical engineering firm with a soils testing laboratory

Company name________________________________ Address____

City____State/Province_____________Zip/PostalCode___________

Tel________________ Fax_______________________ Contact name____________________________________

Steps in Testing

1. Classify soil from soil samples.
2. Determine laboratory Proctor density of the soil. Use Standard Proctor for pedestrian areas or Modified Proctor for vehicular areas.
3. During and after compaction, determine field density of soils using the nuclear density method.
4. Determine laboratory density of the aggregate base.
5. During and after compaction, determine the field density of the aggregate base.

The recommendations for percentages of Standard/Modified Proctor density for soils and base given in Section 2, Part D are minimums. The closer to 100% compaction, the better. Consult a civil engineer or geotechnical engineer for guidance on what levels of compaction are attainable for soils and base material used on a specific job .

Test Methods Soils Classification

Unified Soil Classification System (USCS) test method is described in ASTM D2487.

The USCS test method is recommended since this soil classification is used in determining Proctor density. The AASHTO soil classification system test method is described in ASTM D3282.

Soil sample size required________

Price per test_____

Date tests taken_______

Date test results delivered_______

Density Tests

Standard Proctor Density Test can be used for soil or aggregate bases. Use Standard Proctor for pedestrian areas. ASTM D698 or AASHTO T-99

Soil sample size required___________________________

Aggregate base sample size required__________________

Price per test_______Date tests taken______ Date test results delivered_________

Modified Proctor Density Test can be used for soil or aggregate bases. Use Modified Proctor for vehicular areas.

ASTM D1557 or AASHTO T-180

Soil sample size required_____

Base sample required____________

Price per test______Date tests taken__________

Date test results delivered_________

Gradation Tests

Aggregate base material—See Section 3, Part A for a recommended gradation standard, if no local standards exist. Bedding or joint sand—See Section 4, Part A for industry recommended gradations. Gradation tests confirm consistency in gradation, conformance to local standards for base materials, and to ensure that material passing the No. 200 sieve (75 μm) is not excessive.

ASTM C136 or AASHTO T-27

Size of sample required__________

Price per test______

Date tests taken____________

Date test results delivered_________

On-site Density Tests (ask about lead time required)

Nuclear Density Method for soil density or density of aggregate bases

ASTM D2922 or AASHTO T-238

Number of tests________

Price or hourly rate_______________

Date tests taken____________

Date test results delivered_________

The following test for soil density is not as commonly used as the nuclear density method. It is not used to determine the density of compacted aggregate base materials.

Sand-cone Method for soils

ASTM D1556 or AASHTO T-191

Number of tests_________

Price or hourly rate________________

Date tests taken____________

Date test results delivered_________

Section 6 Part D: Base Installation

After a crushed stone base material is dumped with a skid steer machine or front-end loader, it is smoothed with the bucket of the machine. The operator spreads the base material evenly to a thickness that can be compacted by the available compaction equipment. This thickness is typically 2 to 4 in. (50 to 100 mm). Some smoothing of the loose base surface with tools will be required prior to compaction. Darby (asphalt) rakes work well. Screeds may be used. These should be accompanied by grading to string lines.The base should have some moisture in it in order to achieve a high density when compacted. Frozen base material should never be compacted, nor should material be placed over a frozen soil subgrade.They will settle after the spring thaw.

After placing and spreading the final lift of base, string lines can be set at the surface elevation over the base every 40 to 50 ft (12 to 15 m). Then the final compaction of the base surface begins. The distance between the compacted base surface and string line is checked after compaction of the final lift. There are some asphalt rakes whose height matches that needed between the string line and the uncompacted base. These allow enough height for the base to settle during compaction plus an inch (25 mm) of sand and 3 1/8 in. (80 mm) thick pavers. These rakes save much time and guess work. They indicate enough base when their top edge comes in contact with the taught string line.

Base compaction should be done with a vibratory roller or a reversible plate compactor in lifts or layers. A minimum 5,000 lbf (18 to 22kN) forward plate compactor typically used to compact 2 3/8 in. (60 mm) thick pavers is not recommended for base (or soil) compaction. It requires spreading and compacting 2 in. (50 mm) maximum thick layers of base material to achieve the Proctor densities recommended in this manual. Greater efficiencies can be achieved by using a reversible plate compactor of at least 7,000 lbf (31 kN) or a vibratory roller. These allow compaction of 4 in. to 6 in. (100 mm to 150 mm) thick base material or greater under heavier compaction equipment. As noted earlier, cost comparisons should be made between using small compaction equipment versus larger rented or purchased equipment, especially if driveways are constructed regularly. Compaction equipment companies can assist with this comparison.

As the base layers are installed, the compacted thickness of each individual base layer should be uniform and should not vary by more than +¾ inch (19 mm) to –½ inch (13 mm). This is to assist in achieving uniform density of each layer.

The final surface elevation of the base (Top of Base), however, should not exceed ± 3/8 inch (10 mm) over a 10 ft (3 m) straightedge. The final overall base thickness should also be within + 3/4 inch (10 mm) to –½ inch (13 mm) of the target base thickness. For example, an 8 inch (200 mm) base should be a minimum of 7½ inch (185 mm) thick to a maximum of 8 3/4 inch (220 mm) thick.

The surface of the base course and edge restraints should be inspected for areas that might allow sand to migrate after installation. Such locations can be joints in curbs, around utility structures, or catch basins. These areas should be covered with a 12 in. (300 mm) wide strip of geotextile fabric to prevent loss of the bedding sand and settlement. This is covered in greater detail in another section of the course.

Concrete bases – Concrete bases are generally not required under interlocking concrete pavements in residential applications. However, there are some exceptions. They are sometimes used if the soil is very weak or wet and it is prohibitively expensive to excavate and install a very thick aggregate base or in new developments, to reduce the risk of settlement from uncompacted fill soils. In other cases, utilities may be close the surface and a concrete base may not interfere with them. In certain coastal areas, the water table is close to the surface and it would saturate an aggregate base. Concrete bases are often used in these areas.

Concrete bases should be at least 3 in. (75 mm) thick for pedestrian areas and 4 in. (75 mm) thick to support residential driveways. When using a concrete base, consideration should be given to edge restraints and to weep holes at the lowest elevations to drain excess water out of the bedding sand. Fill weep holes with pea gravel. The holes should be at least 2 in. (50 mm) in diameter and be covered with geotextile to prevent loss of the bedding sand.

Existing concrete can be used as a base for patios or porches. The concrete should not be cracked or spalling or heaving. 3 1/8 in. (80 mm) thick concrete pavers can be adhered to the border, enclosing the space for bedding sand and 2 3/8 in. (60 mm) thick concrete pavers. A polymer adhesive works well for securing the border course. After the adhesive sets, geotextile can be placed against the thicker edge pavers to prevent loss of bedding sand. Once the sand is screeded, the thinner pavers can be placed and compacted, joints filled and compacted again. Occasionally, pavers might crack when compacted over concrete. If this occurs, use a pad under the plate compactor. Most compaction equipment companies supply these pads to protect the pavement surface.

Edge Restraints
[CPI07]

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Edge Restraints

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14801 Murdock Street, Suite 230
Chantilly, VA 20151
Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Every effort has been made to present accurate information. However, the recommendations herein are guidelines only and will vary according to local conditions. Professional assistance should be obtained in the design, specifications and construction with regard to a particular project.

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When raised, the covers and frames should be inspected for cracks that might allow migration of sand. Cracks should be repaired. Filter fabric should be applied on the base around the concrete collar and turned up against the collar to prevent sand loss.

Catch basins – During the early life of interlocking concrete pavement, there may be a need to drain excess water from the bedding sand. Drain holes may be drilled or cast into the sides of catch basins to facilitate this. They can be placed at the bottom of the sand layer, spaced at least 12 in. (0.3 m) apart, and be 1 in. (25 mm) in diameter. The holes should be covered with filter cloth to prevent loss of bedding sand. This drainage detail can prevent pumping and loss of jointing and bedding sand around the catch basin.

Crosswalks – Pavers in a crosswalk, or abutting another pavement, can be placed against a concrete beam (Figure 11-2), or a beam and slab base combination for pavements subject to heavy vehicular traffic. The beam prevents horizontal creep of the pavers due to braking and turning tires.

If a concrete or stabilized aggregate base (with cement or asphalt) is used under a crosswalk or plaza, drain holes should be drilled or cast at the lowest elevation(s) (Figure 11-3). These should be a minimum diameter of 2 in. (50 mm), filled with open-graded aggregate, and covered with filter cloth. This drain detail can be applied in areas where the water table is over 3 ft (0.9 m) deep. Otherwise, the drain should be enclosed in a pipe and directed to a sewer or other appropriate outlet. This detail applies to overlays of concrete pavers on existing asphalt or concrete pavements.

Figure 11-4 shows a crosswalk section through an existing saw-cut asphalt pavement. The existing asphalt should be in good condition with no cracks, raveling, or delamination. The thickness of the cut asphalt should extend below the bottom of the bedding sand in order to prevent loss of bedding sand. The typical asphalt thickness would be 4 in. (100 mm). Filter fabric placed along the base and the cut asphalt will prevent bedding sand from migrating.The underside of the cut asphalt edge is supported by concrete.

Gutters and drainage channels made with pavers should be embedded in fortified mortar, a bitumen-neoprene bed, or polymer adhesive. The mortar mix should resist degradation from freeze-thaw and salt. Care must be taken in applying the mortar as it can stain the pavers.

Sand is not recommended in joints sub ject to channelized water flow. The sand will eventually wash out of the paver joints and weaken the pavement. An alternate method of construction for gutters is to build a concrete base for the gutter and adhere pavers to it. A polymer adhesive made specifically for pavers can be applied directly to the pavers and the pavers placed on the concrete base. This is a simple and quick method. A more involved method involves placing a 3/4 in. (20mm) thick sand asphalt bed (bitumen setting bed) on the concrete base and using a neoprene-bitumen adhesive. Because this installation method is fairly complex, it is outside the scope of this course.

Elevations – When edge restraints are installed before placing the bedding sand and pavers, the restraints are sometimes used to control thickness when

Edge Restraints

Section 7 Part A: Types and Applications

Restraints hold the pavers tightly together, enabling consistent interlock of the units across the entire pavement. They prevent pavers from spreading due to horizontal forces from tires and minor settlement. Edge restraints are designed to remain stationary while receiving occasional impacts from tires.

The following is a discussion of methods of restraining concrete pavers placed on bedding sand and installed on a base. This is the prevailing method of construction. Similar requirements for edge restraints would be needed for concrete pavers joined to a rigid base with mortar, bitumen neoprene, or polymer adhesive.

Restraints are required along the perimeter of interlocking concrete pavements, or where there is a change in the pavement material. For example, when a paver shape changes within an area of paver, the edge paver at the end of each pattern can serve as a restraint (Figure 7-1). When a laying pattern changes direction, there may be a need for an edge paver to act as a restraint (Figure 7-2). If there is a change in slope, a straight edge should be formed at the top, with the pavers and the pattern resumed down the slope. Vertical walls of buildings can also provide a suitable restraint.

When a compacted aggregate base supports pavers and bedding sand, the base should extend beyond the restraint. The rule of thumb is that the base should extend beyond the restraint the same dimension as the thickness of the base material to a minimum of 6 in. (150 mm). For example, if the base is 6 in. (150 mm) thick, then it should extend at least 6 in. (150 mm) beyond the outside edge of the restraints. This contributes stability to the restraint, especially in soils subject to heaving. Soil backfill is never a suitable edge restraint, and edge restraints should never be installed on top of the bedding sand.

If there is a possibility of sand loss from beneath the pavers, or between the joints of the edge restraints, geotextile (filter cloth) is recommended to prevent its migration. A 12 in. (0.3 m) wide strip can be applied along the base and turned up along the sides of the restraints. Filter cloth generally is not required across the entire surface of the base, nor should it be placed on top of the bedding sand.

Table 7-1 shows the types of edge restraints and their application. There are two general types of edge restraints. Those made elsewhere and installed at the site include precast concrete, plastic, cut stone, aluminum and steel. Restraints formed on-site are made of poured-in-place concrete.

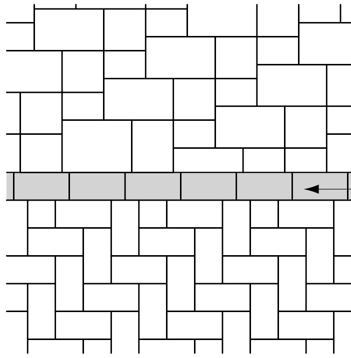

Figure 7-1: Change in paver shape

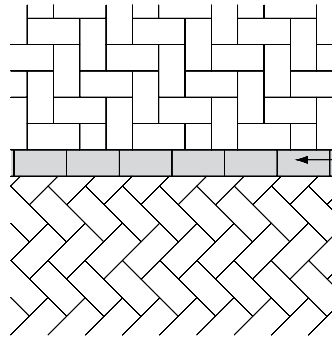

Figure 7-2: Change in laying pattern direction

Table 7-1: Application guide for edge restraints

	Poured Concrete and Walls	Precast Concrete and Cut Stone	Plastic and Aluminum	Troweled and Submerged Concrete
Sidewalks—no vehicular traffic	✓	✓	✓	✓[1]
Plazas—no vehicular traffic	✓	✓	✓	✓[1]
Residential driveways	✓	✓	✓	✓[1]
Commercial/Industrial driveways	✓	✓	✓[2]	
Parking lots	✓	✓	✓[2]	
Crosswalks in asphalt or concrete streets	✓	✓		
Streets—all types	✓	✓		
Utility covers	✓	✓		
Gas stations	✓	✓		
Industrial flooring	✓			
Trucking terminals	✓			

[1]not appropriate for areas with significant freeze thaw cycles
[2]only products designed for heavy duty applications

Manufactured Edge Restraints

Full depth precast concrete or cut stone edging generally extends the depth of the base material. They can be set in compacted soil (not subject to heaving), compacted aggregate or concrete backfill (Figure 7-3). The preferred method of installation with vehicular pavements is for the curb to rest on the compacted aggregate road base.

Partial depth precast concrete edge restraints may be used for residential and light duty commercial applications. (Figure 7-4). These precast units are anchored on a compacted aggregate base with steel spikes. The spikes are typically 3/8 in. (10 mm) diameter. Depending on the design, the top of the concrete edge can be hidden or exposed.

Aluminum and steel edging should be selected to provide a smooth vertical surface against the pavers. L-shaped edging provides additional stability. Stakes fastened to the edging should be below the pavers or on the outside of the restraints. Spikes to secure steel and aluminum edging should extend well into the base course (Figure 7-5). Consult manufacturer's literature for recommended spacing of the spikes. Aluminum and steel edgings are manufactured in different thicknesses. The thickest edging is recommended when pavers are subjected to vehicular traffic.

Plastic edging installs quickly and will not rust or rot. Plastic edging should be specifically designed for use with pavers. It can be used with light duty residential, commercial or on some heavy duty, industrial applications, depending on the design. It should be firmly anchored into the compacted aggregate base course with steel spikes (See Figure 7-6). Consult the manufacturer's literature for the recommended spacing of the spikes. Edging for planting beds and flower gardens is not an acceptable restraint for interlocking concrete pavements.

Elevations should be set accurately for restraints that rest on the base. For example, 2 3/8 in. (60 mm) thick pavers with 1 1/4 in. (30 mm) of bedding sand would have a base elevation set 3 in. (75 mm) below that of the finish elevation of the pavers. This allows 1/4 in. (7 mm) settlement from compaction and 1/8 in. (3 mm) for minor settling over time.

Restraints Formed On-site – Poured-in-place concrete curbs, or combination curb and gutters, required by municipalities make suitable restraints for pavers. Exposed concrete edges should have a 1/8 in. (3 mm) radius edge to reduce the likelihood of chipping. As with precast, the side of the curbs should extend well below the sand bedding course (Figure 7-7).

Troweled concrete from a bag mix, or batched on-site, can be applied without forms against edge pavers and on the compacted base. If the top of the concrete edge is recessed and slopes away from the pavers, grass can grow next to them (Figure 7-8). The depth below the surface of the pavers must be sufficient to prevent the concrete from becoming a heat sink that dries the grass and topsoil. This edge restraint is suitable for pavers subjected to pedestrian traffic and for residential driveways in non-freezing climates. Troweled edges should be at least 6 in. (150 mm) wide. Steel reinforcing can be placed in the concrete to increase service life.

In some regions a “submerged curb” is used for residential applications (Figure 7-8). The concrete is poured against the outside edge of the last course of pavers and leveled over the compacted base. Concrete edge pavers are immediately applied directly on the wet concrete. The edge pavers are tapped into place, setting them slightly below the last course already in place, since the pavers will move downward when compacted. This edge restraint is thicker and more durable than troweled concrete edges.

Compacting units against troweled concrete or submerged curbs must be done after the concrete has set. Care must be taken to ensure that the plate compactor does not crack the concrete edge or loosen pavers bedded in it. If the concrete is left to cure for a few days prior to compacting the pavers, the edges should be covered with plastic sheeting to prevent water from settling the uncompacted bedding sand. If water is allowed to enter the bedding sand, it will be difficult to compact the pavers into it. The pavers will need to be removed, the saturated bedding sand removed, unsaturated sand installed, and the pavers replaced and compacted.

Video Supplement Section 6

Troweled concrete and submerged curbs are not recommended in freezing climates as they may crack and be an ongoing maintenance problem.

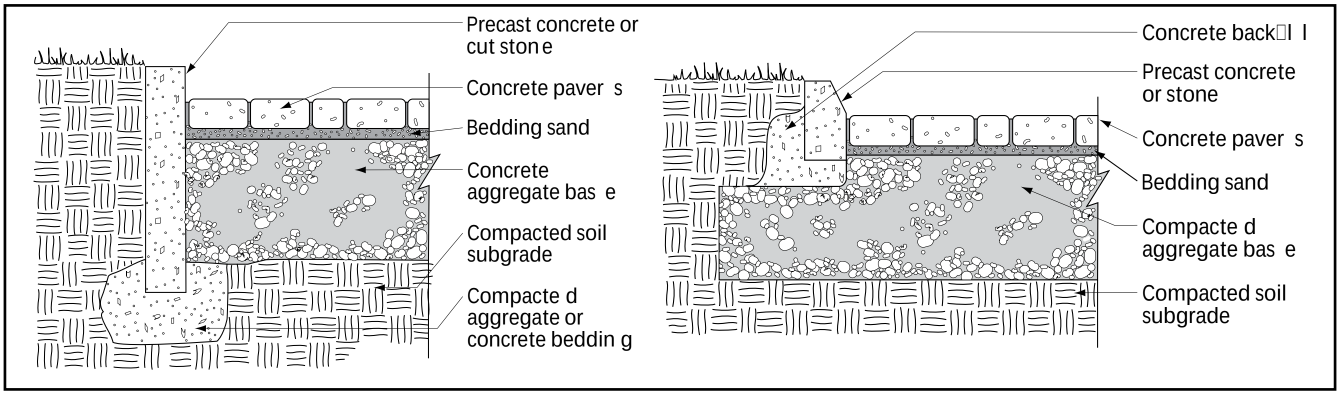

Figure 7-3: Precast concrete/cut stone

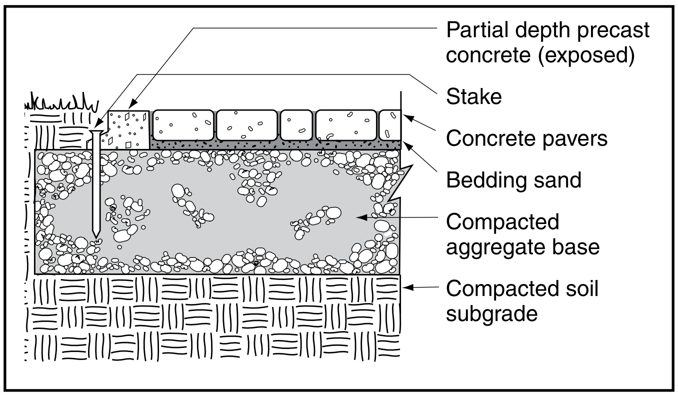

Figure 7-4: Partial depth precast concrete edge

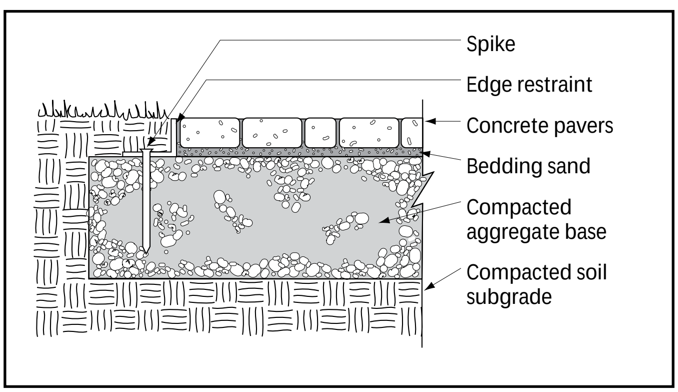

Figure 7-5: Aluminum and steel edging

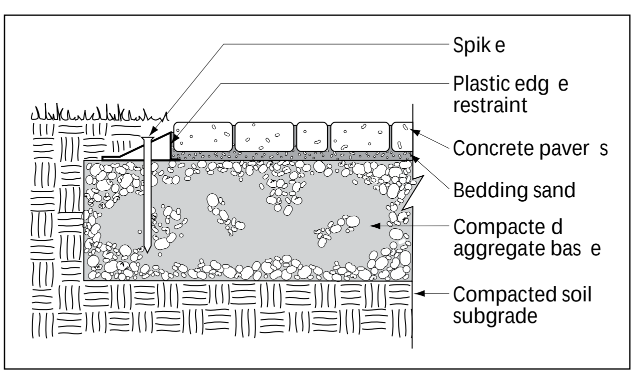

Figure 7-6: Plastic edge restraint

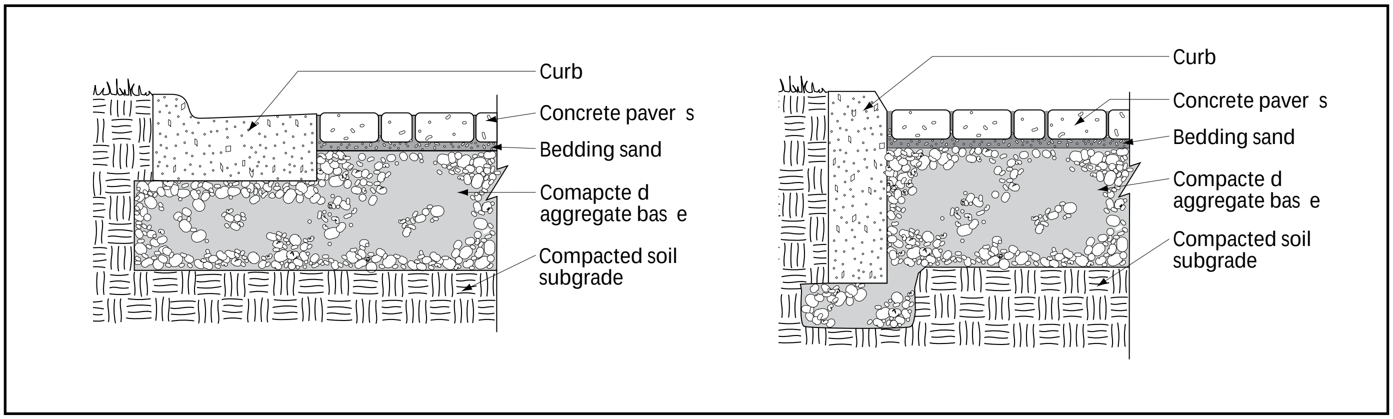

Figure 7-7: Poured-in-place concrete curbs

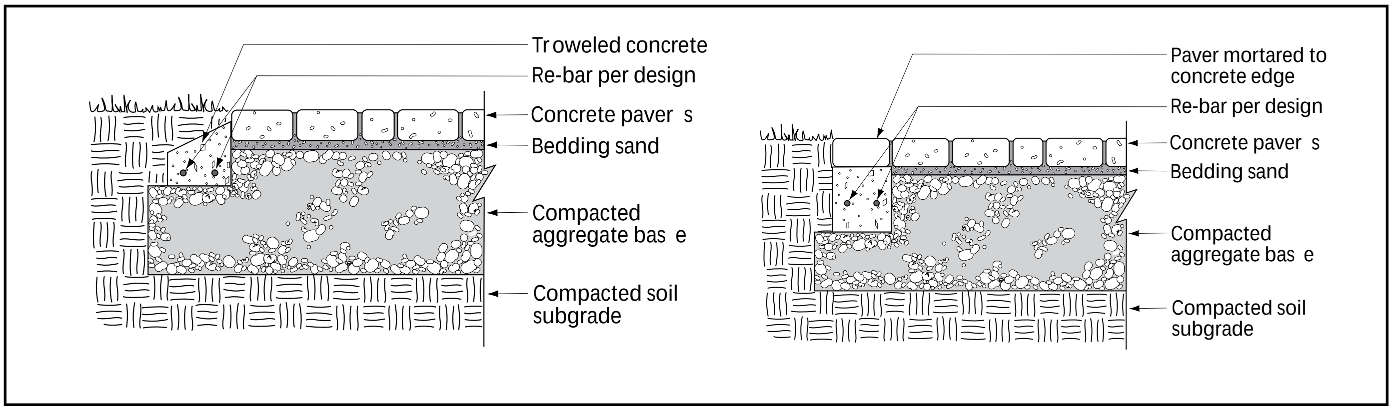

Figure 7-8: Troweled concrete and “submerged curb” edges

Bedding and Joint Sands

[CPI08]

Student Manual

ICPI Concrete Paver Installer Course

Interlocking Concrete Pavement Institute®

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Interlocking Concrete Pavement Institute
14801 Murdock Street, Suite 230
Chantilly, VA 20151
Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Every effort has been made to present accurate information. However, the recommendations herein are guidelines only and will vary according to local conditions. Professional assistance should be obtained in the design, specifications and construction with regard to a particular project.

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Bedding and Joint Sands

Section 8 Part A: Shape, Gradation, Moisture, and Hardness

Shape –Bedding and joint sand should be angular and have symmetrical particles (not flat or elongated ones). There should be no mud or foreign materials in the sand. Flat or elongated particles, such as those found with some limestones and granites, do not compact completely and settle unevenly over time.

Gradation – should conform to the requirements of ASTM C33, Standard Specification for Aggregate for Concrete or CSA A23.1. These are shown in Tables 8-1 and 8-2. These are course, multi-grained sands.

Table 8-1: ASTM C33 – Gradation for Bedding Sand

Sieve size	Percent passing
3/8 in. (9.5 mm)	100
No. 4 (4.75 mm)	95 to 100
No. 8 (2.36 mm)	80 to 100
No. 16 (1.18 mm)	50 to 85
No. 30 (0.600 mm)	25 to 60
No. 50 (0.300 mm)	5 to 30
No. 100 (0.150 mm)	0 to 10
No. 200 (0.075 mm)	0 to 1

Table 8-2: Canadian Standards Association (CSA) A23.1– Gradation for Bedding Sand

Sieve Size	Percent Passing
10.0 mm	100
5.0 mm	95 to 100
2.5 mm	80 to 100
1.25 mm	50 to 90
630 µm	25 to 65
315 µm	10 to 35
160 µm	2 to 10
80 µm	0 to 1

Note: Bedding sands should conform to ASTM C33 or CSA A23.1 FA1 gradations for concrete sand. For ASTM C33, ICPI recommends the additional limitations on the No. 200 (0.075 mm) sieve as shown. For CSA A23.1 FA1, ICPI recommends reducing the maximum passing the 80 µm sieve from 3% to 1%.

Either specification should be compared to the sieve analysis of the sand for the job. The amount of material (fines) passing the No. 200 (75 µm) sieve should be zero or very close to zero. Excess fines will slow the drainage of water from the bedding sand, lubricate it, and cause it to rut and settle unevenly. Check the sieve analysis for sand delivered to the site through a local materials testing lab. Sometimes the quarry, or supplier of the sand, will supply a sieve analysis. Check the analysis before accepting the sand on the site.

A common error is to use mason's sand for the bedding. Mason's sand is finer than concrete sand and is used to make mortar (sand plus cement). Fine mason's sand as a bedding for pavers can produce a wavy appearance in the surface of the pavement.

Concrete sand is also recommended to fill the joints in pavers, particularly for streets and parking lot applications. This often requires extra effort in placing and compacting sand into the joints. Finer sands such as mason's sand can be used for driveways, sidewalks and patios. The gradation for mason's sand is found in ASTM C144, Standard Specification for Aggregate for Masonry Mortar. CSA A179 gradation is recommended in Canada. See Tables 8-3 and 8-4. However, having two kinds of sand on the job site may increase construction time and costs. In either case, do not use stone dust or limestone screenings that do not conform to the grading specifications. Bagged sand may be used if its gradation conforms to Table 8-3 or Table 8-4. Being dry, it is very convenient to use in wet weather, as it fills joints faster.

Table 8-3: ASTM C144 – Gradation for Joint Sand

Sieve Size	Percent Passing
No. 4 (4.75 mm)	100
No. 8 (2.36 mm)	95 to 100
No. 16 (1.18 mm)	70 to 100
No. 30 (0.600 mm)	40 to 75
No. 50 (0.300 mm)	10 to 35
No. 100 (0.150 mm)	2 to 15
No. 200 (0.075 mm)	0 to 5

Table 8-4: Canadian Standards Association (CSA) A179 – Gradation for Joint Sand

Sieve Size	Percent Passing
5.0 mm	100
2.5 mm	90 to 100
1.25 mm	85 to 100
0.630 mm	65 to 95
0.315 mm	15 to 80
0.160 mm	0 to 35
0.075 mm	0 to 10

The joints must be checked to be sure they are completely full after vibrating. This is done by inserting a putty knife into the joints. If the joints are full, the metal blade barely moves into the joint with hard pressure.

Moisture – When sand is delivered it is often moist. However, it should not be saturated. This means there should be no water standing on it. If the sand particles are shiny in appearance from being coated with water, spread the sand and let the excess water evaporate. Sand should have some moisture in it when it is screeded so it will compact well. Like soil and base materials, bedding sand has an optimum moisture content at which maximum density can be attained. If it is too dry, or wet, it will not fully compact and will settle over time. Experience on the job is the best way to learn when sand is wet, too dry, or ready for use.

Hardness – Sand can be natural or manufactured from crushed rock and screened (and washed) at the quarry to obtain the proper blend of particle sizes. Limestone screenings from soft limestone are not recommended. They will dissolve over time from moisture and abrasion. This will cause depressions in the pavement (deformations). For street applications the sand should be the hardest that can be obtained economically. If the sand is soft, it may pulverize into finer particles under heavy and repeated traffic loads. ICPI Tech Spec 17—Bedding Sand Selection for Interlocking Concrete Pavements in Vehicular Applications (see Appendix) provides recommendations for evaluating sands for hardness for heavy vehicular traffic applications.

A quick test for hardness: if the larger sand particles cannot be scratched or broken with a pocket knife, then sand is generally hard enough for driveways and commercial entrances.

Section 8 Part B: Installation and Equipment

Delivery and Spreading Bedding Sand

Decide the location of sand stockpiles on the site before the job begins. Time and money can be saved if the sand is dumped in piles along the prepared pavement base, rather than in a pile that must be moved in loads to the pavement base.

If sand is brought to the site in trucks and dumped near the job during cold weather, the piles should be covered with plastic or canvas sheets to protect them from freezing. If the sand piles become saturated from rain, do not scoop loads from the bottom of the pile. This sand is saturated and time will be wasted waiting for it to dry when spread for screeding. Furthermore, pavers will not compact or settle into saturated bedding sand. For this reason, screeded bedding sand that becomes saturated must be removed and replaced with non-saturated sand.

Access to the site also determines whether sand can be dumped directly onto the compacted base. Streets and parking lot bases can accept trucks dumping sand. Jobs for pedestrian use or light vehicular use, such as driveways, may not be able to take the loads from heavy dump trucks without damage to the base. In such cases, the sand may need to be piled close to the base, and placed on it by a front end loader.

Only enough sand is spread and screeded for use in a day. If a crew can install 2,000 ft^2 (200 m^2) per day, then 10 tons of sand are required for the day's work. Spreading is usually done with a small front end loader and workers using shovels.

As mentioned in a previous section, the bedding sand should be placed on an even base surface. Sand should not be used to fill depressions in the base. The filled depressions will be reflected in the surface of the pavers within a few weeks or months, creating a wash board appearance. To prevent this, the evenness of the surface of the base should be checked with a straightedge before placing the bedding sand. Unless otherwise specified, the surface tolerance should be ± 3/8 in. over a 10 ft. straightedge (± 10 mm over 3 m). Elevations should be checked with a transit level.

The evenness of the base surface can be checked with screed rails or string lines. Screed rails will not lie flat on an uneven surface. The distance between level string lines pulled over the base and the base surface can be checked with a tape measure. Correct depressions by filling and compacting to level elevations. High spots should be shoveled away and the areas compacted.

On some jobs the base has been installed by another company, i.e., the base is not part of the contract to supply and install sand and pavers. On many contracts, placing pavers and sand means the paver installation contractor has accepted the base. Therefore, it is advantageous to check that the base has been installed properly.

Elevations should be checked with a transit level. Establish a datum or fixed point on the site that will not be disturbed. Use this point as the datum location for the transit level. Check for slopes that drain water away from buildings. Slopes should be at least 1.5% or 1/4 in. fall for every 18 in. (15 mm for every 1 m).

Screeding

Screeding is the process of leveling the bedding sand prior to placing the pavers. Screeding is typically done on 1 in. (25 mm) diameter or 1 in. square pipe or bars set on the compacted base prior to dumping and spreading the sand. When the sand is spread, care must be taken to not move the screed bars while spreading the sand with shovels. A front end loader used to dump or spread the sand should be kept clear of the screed bars.

Figure 8-1: Screeding bedding sand on screed bars

Check the elevations of the screed bars, once in place, to be sure that the screeded sand and pavers conform to finish elevations when compacted. Checking can be done with string lines or with a transit level. Be sure to maintain a consistent thickness of bedding sand. Do not compensate for depressions in the base by adding more sand. Instead, add and compact more base material.

A screed, or strike board, usually 10-12 feet (3-4 m) long, is pushed and pulled along the top of the screed rails to smooth the sand. The screed can be wood, although aluminum lasts longer and remains straight. Pull the sand away from the laying face. Two people can pull the screed while one or two others either add or remove sand from behind the screed with shovels. One-person screeds save time and money. See Figure 8-1.

Mechanical screeds save time and reduce fatigue because they are pulled by a small loader (Figure 8-2). These screeds can increase productivity of the operation by three to four times. The screed rails are set on the base and checked with a transit level or string line. The height of each end of the screed can be adjusted to accurately obtain the needed depth of bedding sand. Some screeds extended up to 14 ft (4 m) between rails. A wider area can be screeded by connecting more rails and lengthening the screed. As the screed is pulled, one or two persons spread the pile of sand that accumulates behind it. Check the depth of the screeded bedding sand to be sure that the screeds are not sagging in the middle. This can result in a thinner sand layer.

Figure 8-2: Powered screed pulling bedding sand.

Sometimes the existing curbs are used as elevation guides for powered screeds. If so, then check the curbs for accurate elevations with a transit, and the depth of the bedding sand for consistent thickness as the screeding progresses.

Pre-compaction of the Bedding Sand

The ICPI recommends compacting the sand after the pavers are placed on it, not before. Pre-compacting the bedding sand is the process of compacting before, rather that after, placing concrete pavers. Pre-compaction is typically done with the same plate compactor used on the pavers. After the pre-compacting, a 1/4 in.–3/8 in. (7–10 mm) thick loose layer is made on the surface of the compacted bedding sand. This layer enters the bottom joints of the pavers when they are compacted.

The loose layer is created two ways. After pre-compaction, sand is spread over the compacted bedding sand and screeded. This is sometimes called “dressing” the bedding sand. A second method, called “fluffing” consists of raking the compacted surface and screeding it again.

While some paver projects have done well, others have suffered from pre-compaction of the bedding sand. There are several problems with pre-compaction. The first problem with pre-compaction is that it is often used to compensate for variations in the surface of the base. This course recommends a minimum base surface tolerance of ± 3/8 in. (10 mm) over a 10 ft (3 m) straightedge. If there are deviations that exceed this (or project specifications), then the elevations should be corrected with more base material, not with more bedding sand. Variability in the elevations of the surface of the base beyond this tolerance will eventually be reflected in the surface of the pavers.

Compaction of pavers over a thin, "fluffed" or "dressed" sand layer may not allow as much sand to enter the bottom joints of the pavers when compared to compaction of pavers on non-compacted bedding sand. The sand in the joints can diffuse some of the force necessary to compact the bedding sand and to drive the pavers into it. The degree of potential interlock between the units may be lessened. Bedding sand pre-compaction is desirable for placing concrete paving slabs (defined by ASTM C1781 and CSA A231.1) because larger units do not rely on much interlock for spreading applied loads.

In some regions with continuous wet weather conditions, bedding sand moisture control is impossible. To help avoid construction delays, bedding sand pre-compaction helps close the sand surface, increases density, and reduces the risk of saturation during wet weather. Bedding sand pre-compaction can save time compared to waiting for the sand to drain and dry. In these cases, compaction of the bedding sand is recommended because it allows construction to proceed.

Compaction of the bedding sand occurs when the pavers are vibrated into it. If compaction of the bedding sand is insufficient, a heavier plate compactor may be needed, not pre-compaction of the bedding sand. Most contractors in North America use plate compactors exerting 75 to 90 hertz and 3,000 to 5,000 lb. force (13 to 22 kN).

Use of variable frequency compactors that allow an increase in frequency (and applied energy) may develop more thorough compaction. As interlock develops during compaction of the pavers, the ability of the plate vibrator to compact the laying course lessens. It may be desirable to be able to increase the vibration rate so that the energy input increases as compaction continues.

Selection and Installation of Concrete Pavers
[CPI09]

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Interlocking Concrete Pavement Institute
14801 Murdock Street, Suite 230
Chantilly, VA 20151
Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

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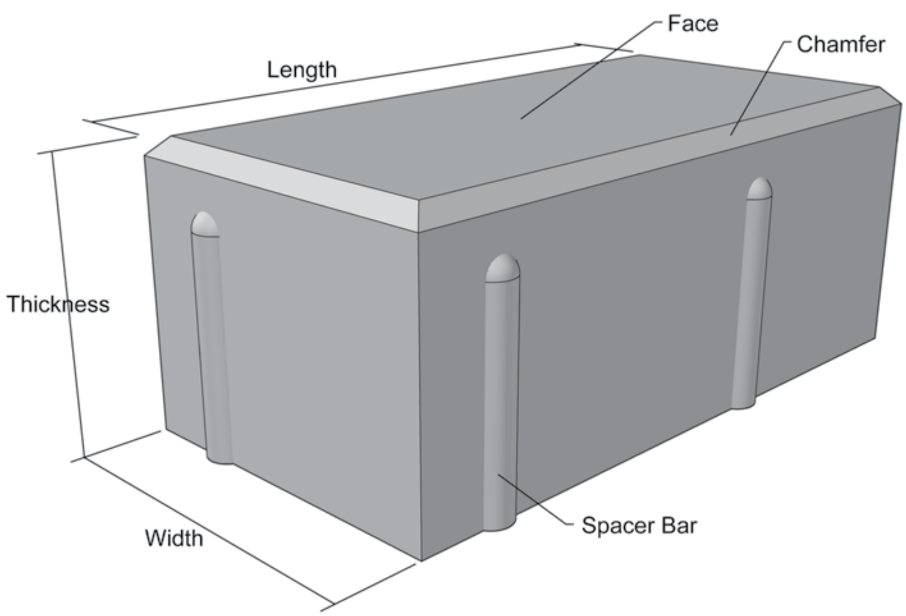
Selection and Installation of Concrete Pavers

Section 9 Part A: Selecting Pavers for Various Applications

As a rule, interlock among pavers used for pedestrian areas and residential driveways is achieved with 2 3/8 in. (60 mm) thick units. For vehicular pavements including streets, industrial port and airport pavements, 3 1/8 in. (80 mm) thick pavers are used since loads are higher. Herringbone laying patterns should be used in these pavements, as they offer greater resistance to horizontal "creep" from turning, braking, and accelerating tires.



Some pavers have chamfers around the perimeter of the face. The main purpose of a chamfer is to reduce the potential for chipping of the paver face during shipment. Chamfers also aid in the drainage of water from the pavement surface. Spacer bars, included on some pavers, help to maintain a minimum space between pavers so that sand can enter the joints.

Concrete Paver Standards

There are two paver standards in North America, one for Canada and one for the U.S. The Canadian standard is published by the Canadian Standards Association (CSA). It is called CSA-A231.2 Precast Concrete Pavers. The standard requires that units have an average minimum compressive strength of 7,200 psi (50 MPa) based on testing a cube or core cut from them. Meeting dimensional tolerances for the length, width and height of each unit are also required. Dimensions for length, width and thickness are agreed upon by supplier and purchaser. Tolerances for these dimensions are ±2 mm for length and width and ±3 mm for the height.

The CSA standard has a rigorous freeze-thaw deicing salt durability test. Units are completely immersed in a 3% saline solution and placed through 49 freeze-thaw cycles. The units must not lose more than 500 grams/m^2 of total surface area after 49 cycles. If the pavers lose less than 225 grams/m^2 after 28 cycles, they have then met the standard without continuing to 49 cycles.

The paver standard used in the U.S. is published by the American Society for Testing and Materials (ASTM). It is called ASTM C936, Standard Specification for Solid Concrete Interlocking Paving Units. This standard requires a minimum average compressive strength of 8,000 psi (55 MPa) from a whole or half paver, maximum average water absorption of 5%, conformance to freeze-thaw in tap water (no salts) and abrasion durability tests. Like the CSA standard, dimensional tolerances are required in ASTM C936 as well. These are ±1/16 in. (1.6 mm) for length and width and ±1/8 in. (3.2 mm) for the height. ASTM C936 has an optional freeze-thaw durability test method and loss criteria like CSA A231.2.

The manufacturer can provide copies of the CSA or ASTM standards and test results from an independent testing laboratory. The results should verify that their concrete pavers meet the standards that pertain to the respective country. Test results should be requested at least annually.

Section 9 Part B: Aspect Ratio and Its Effect on Applications

There are many shapes and sizes of concrete unit paving available. They generally fall into two categories, interlocking concrete pavers and concrete paving slabs. Contractors should be aware of some principles that distinguish one product group from the other. These principles can help guide product selection and installation.

The rule of thumb for selecting the right size units for pedestrian and vehicular application depends on two important ratios. One is the ratio of overall length to width, or plan ratio. If it is roughly between 2:1 and 3:1, the unit generally can be placed in an interlocking pattern. Interlocking patterns have proven to provide greater stability and structural support than other laying patterns when subjected to vehicular traffic.

Table 9-1: Plan ratio

Plan Ratio			
		Pedestrian Loads	Vehicular Loads
less than 2:1	Reduced interlock	✓	
2:1 up to 3:1	Effective interlock, structural support	✓	✓
more than 3:1	Reduced structural support	✓	

The other important ratio is the overall length of a unit to its thickness, or aspect ratio. When this ratio exceeds 4:1, units should not be used in streets and parking lots. Pavers having ratios between 3:1 and 4:1 generally can be used in residential drives. Figure 9-1 illustrates these differences.

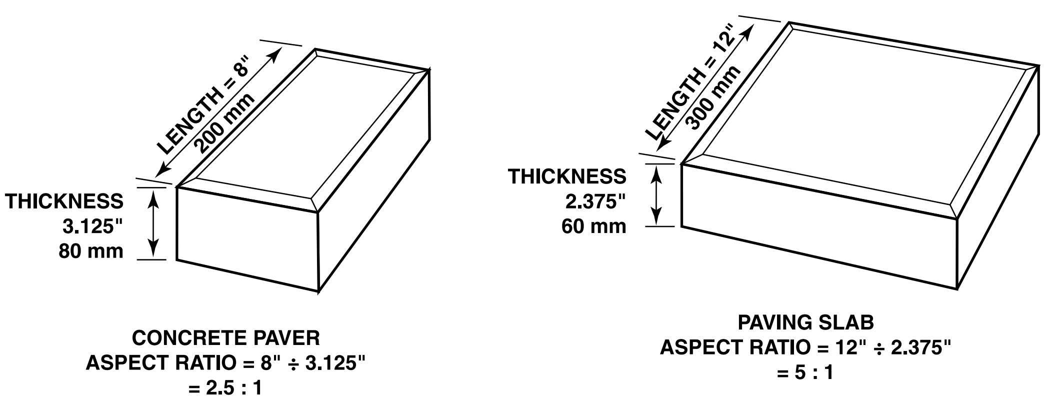


Figure 9-1: Aspect Ratio = Length ÷ Thickness

Units with length to thickness aspect ratios between 3:1 and 4:1 are generally not subject to flexing and cracking under vehicular loads. Those with an aspect ratio of 3:1 can be used in all vehicular applications. For example, pavers 4 in. by 8 in. by 3 1/8 in. (100 mm wide by 200 mm long by 80 mm thick) rectangular pavers have an aspect ratio of 200: 80 or 2.5:1. This makes them suitable for streets.

Table 9-2: Aspect Ratio

Aspect Ratio				
		Pedestrian Load	Residential Driveways Loads	Vehicular Loads
4:1 or more	Reduced rotational and vertical interlock	✓		
between 3:1 and 4:1		✓	✓	
3:1 or less	Higher rotational and vertical interlock	✓	✓	✓

In U.S. and Canadian product standards for concrete pavers, a concrete paver is defined as having a maximum aspect ratio of 4:1, and a minimum thickness of 2 3/8 in. (60 mm). In addition to aspect ratio and thickness, both standards have maximum surface area requirements. The U.S. standard requires the maximum surface area less than or equal to 100.25 in.^{2} (0.065 m^2) and the Canadian standard requires the maximum surface area to be less than or equal to 144 in.^{2} (0.090 m^2).

The definitions do not include larger paving slabs. Generally they have an aspect ratio greater than 4:1, a minimum thickness of 2 in. (50 mm) and surface areas greater than those defined in the above paver standards. Slabs are also incorrectly called concrete pavers. They will be referred to as paving slabs in this course. These range in a variety of sizes larger than 10 in. x 10 in. (250 mm x 250 mm), depending on the thickness and resulting aspect ratio. The slab standard in the U.S. is ASTM C1782 Standard Specification for Segmental Concrete Paving Slabs. In Canada, the standard is CSA A231.1 Precast Concrete Paving Slabs.

Users tend to confuse interlocking concrete pavers with paving slabs as being appropriate for the same applications. They are not. The thinner, larger paving slabs are not suited for vehicular traffic because they may flex and crack from loads. Interlocking concrete pavers, however, can be used in either vehicular or pedestrian applications.

Interlocking concrete pavers contribute greater structural bearing and load spreading capacity than thinner paving slabs. When properly installed, interlocking concrete pavers are tightly fitted together with sand filled joints. The sand transfers loads to surrounding units, reducing the load on the compacted aggregate base and soil subgrade.

Interlocking concrete pavers have more vertical area on their sides to "lock up" and distribute loads to their neighbors. Paving slabs, however, have less vertical surface for interlock and spreading loads (unless they are very thick). They rely on their larger horizontal area to spread loads. Interlock is incidental to their structural performance and load bearing capacity, whereas, with interlocking concrete pavers, interlock is critical to them.

The larger paving slabs are generally not compacted into bedding sand, since the slabs may crack under the force of the plate compactor. In many cases the bedding sand is screeded smooth and compacted prior to placing the larger slabs. The joints, usually 1/16 in. to 1/8 in. (2–3 mm) wide, are then filled with sand.

As discussed in a previous section, pre-compaction of the bedding sand is not necessary, even detrimental to interlocking concrete pavers achieving interlock. Since interlock is not a factor in the load spreading of paving slabs, the bedding sand may be pre-compacted. However, the same guidelines for bedding sand under concrete pavers apply to sand under paving slabs. The thickness should be nominal 1 in. (25 mm), maintained as consistently as possible, and not be used to compensate for depressions in the surface of the base.

To summarize, concrete pavers and concrete paving slabs are two different products. They are installed differently and they spread applied loads differently. Therefore, care in product selection and installation will save potential problems after the job is done.

Section 9 Part C: Paver Installation

Maintaining Consistent Joints with the Click and Drop Method

Consistent joint widths contribute to spreading loads evenly as they are applied to pavers. Tight joints (with sand in them) will spread loads better than wide ones. Consistent joint widths also give a neat and orderly visual appearance.

The easiest way to maintain joint consistency during paving is by the "click and drop" method. This method will create a consistent joint of about 1/16 in. to 1/8 in. (2–3 mm).

Procedure:

- While holding a paver, the bottom 1/4 in.–1/2 in. (7–13 mm) should click firmly against the top portion of the sides of the pavers resting on the sand.
- Don't click the pavers on the sand so hard that they move.
- Release grip, dropping the paver an inch or so (25–30 mm) directly downward.

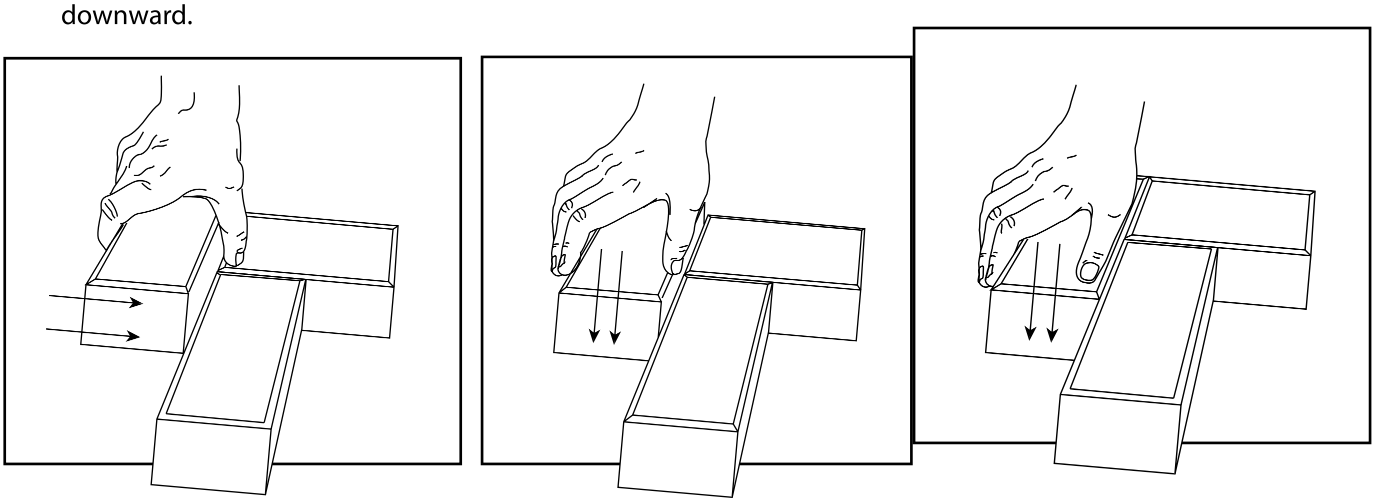


Figure 9-2: Click and drop

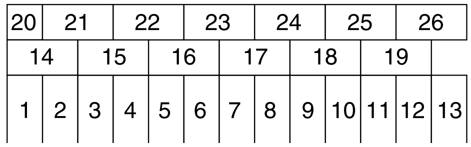
Starting Laying Patterns

Starting the first few rows requires attention to the order of placing the units. This establishes the rhythm and pattern for the remaining courses. The order for starting runner, parquet, and herringbone patterns are illustrated when starting from a corner. Other shapes have variations in their order of placing. Manufacturer's literature will often show this.

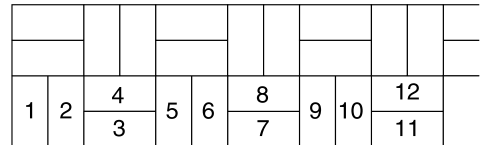
Pavers should be taken from different pallets and not from a single pallet or cube. Mixing the pavers ensures a blend of the colors. If there's only one color of pavers on the job, installing pavers from several pallets at the same time will hide slight variations in that color.

Many jobs will have the pavers start from the middle of the pavement. This may be done for several reasons. First, pavers may flow onto the site faster if

Figure 9-3: Starting Runner and Parquet patterns from corner.

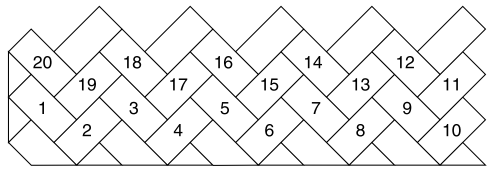


Runner Pattern

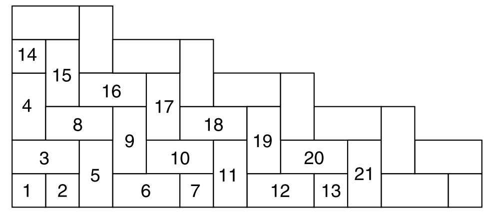


Parquet Pattern

Figure 9-4: Starting Herringbone patterns from corner.



45° Herringbone Pattern



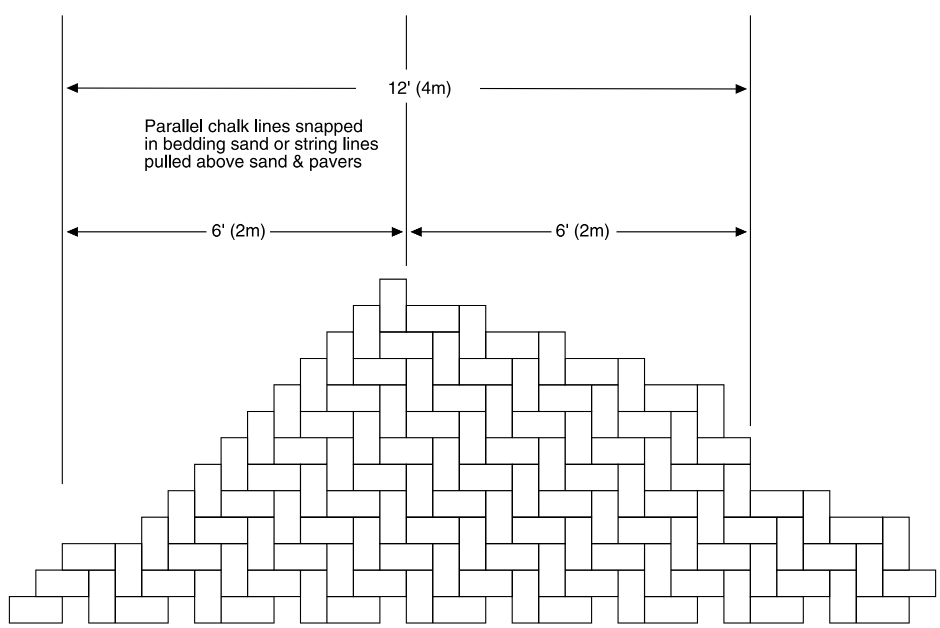
90° Herringbone Pattern

paving begins at the center of the pavement, rather than from a corner location. Second, by starting at the center, a wider laying face is possible. A wider laying face allows more people to place pavers. This can increase productivity. Third, cut units along the edges of the pavement will be practically the same size on both sides. Their symmetrical appearance is attractive on narrow pavement such as driveways and patios. It is not important on large areas where both sides of the pavement can't be viewed at the same time. Finally, starting at the middle of the pavement may be necessary because there may be no perpendicular corners from which to begin the laying patterns.

Holding Straight Lines

Lines that are held straight will produce an impressive appearance and help maintain consistent joint widths, thereby supporting interlock. Snapping lines with a chalk box and string every six to ten feet (2–3 m) down the length of the screeded sand. On most jobs, string lines are laid to keep the lines of the paver joints running straight.

Figure 9-5: Marking parallel lines and creating a pyramid-shaped laying face.



Procedure:
• Snap a string line on the screeded sand in the center of the area(s) to be placed.
• The line should be perpendicular to the laying face.
• Place pavers in the given laying pattern on both sides of the line.
• If additional lines are snapped, they should be parallel to each other. Check this by measuring the distances at the opposite ends of each line. They should be equal.
• If they are not parallel, they can be erased and snapped again.

Establishing Perpendicular Lines

Another technique that helps in keeping joint lines straight with herringbone patterns is by building a pyramid-shaped laying face (See Figure 9-5). A string line is pulled, or line snapped, on the bedding sand. The line is perpendicular to the edge from which paving begins. The perpendicular line is the center of the pyramid. Paving begins with two installers, each one working on either side of this line. The pyramid takes shape as paving progresses. This method works well for paving open areas where there are no corners from building or curbs. The pyramid shape of the paved area has a longer laying face than one that is straight. Since this increases the length of the laying face, there is more room to work, and possibly more room for the crew to place pavers.

Depending on the project, most string lines should be perpendicular to a starting line or edge restraint. However, in many jobs restraints are curved or not installed straight. In either case they don't make a perpendicular edge against which to lay pavers. A wall or corner that appears perpendicular may not be 90° square with the direction of the string lines and joint line of the pavers.

Procedure:
• Place one stake in the corner and another stake 10 ft (5 m) from the first stake along one edge of the corner to be squared. Tie a string tightly between these two stakes and place a mark on the line 6 ft (3 m) from the corner.

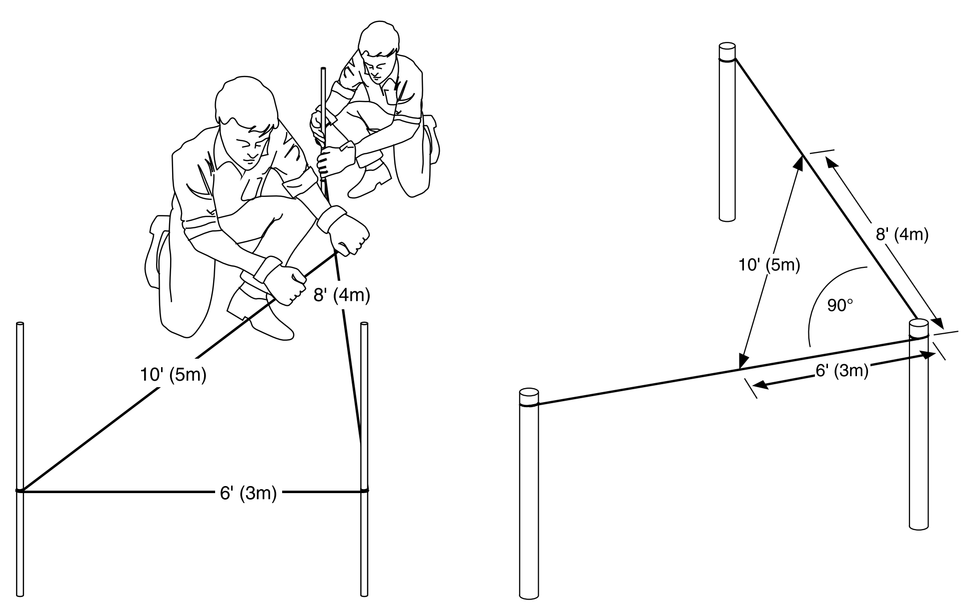


Figure 9-6:
String lines may be used to check for squareness to the edges by using the 3-4-5 triangle. Once this right angle is established, string lines can be laid and pavers can be laid easily, especially when working from a corner. A right angle is laid out with a mason's line, stakes, and a measuring tape. Laying out a 3-4-5 triangle requires two people.

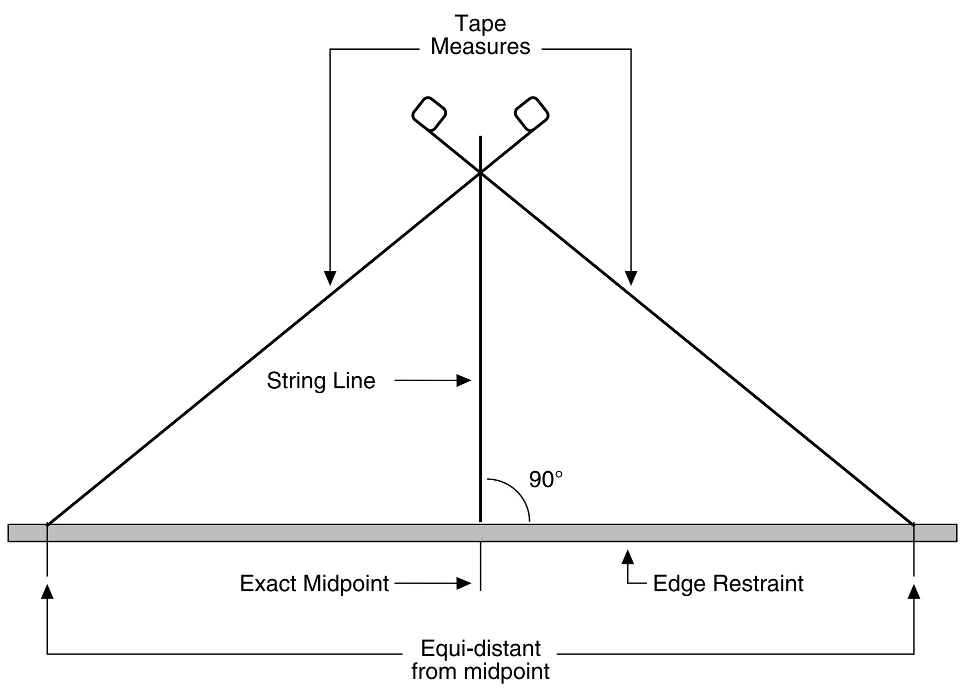
- Place another stake ten feet (5 m) from the corner stake along the other edge of the corner to be squared. Visually place this stake as close as possible to 90°. Tie a string tightly between these two stakes and place a mark on the line 8 ft. from the corner.
  - With a tape measure, measure between the 6 ft (3 m) mark and the 8 ft (4 m) mark. This measurement should be exactly 10 ft if the corner is square. If this measurement is not exactly 10 ft (5 m), move one of the edge lines until this diagonal measurement is exactly 10 ft (5 m). This indicates a 90° angle or a square corner.

A quick way to establish a line perpendicular to an edge (no corner walls) is with the following procedure:

- Measure and mark the length of the edge, or line, from which paving will begin. The line can be 10–20 ft (3–7 m) long. This line is where an edge restraint will be placed, or where one already is placed.
- Mark exactly the half way point on the line that was just measured. In other words, divide the line in half.
- Take one tape measure and extend it from one end of the line at an angle toward the center. Be sure the tape extends past the middle of the line by a foot or two (0.2 m–0.6 m).
- Take a second tape measure and extend it from the other end of the line at an angle toward the center.
- Overlap one tape on the other and match the length of both tapes. The same marked dimensions on each tape should be touching each other.
- Snap a line from the point where the two tape measures cross to the center of the line.
- This line is perpendicular to the line from which paving will begin.

Figure 9-7 below illustrates this procedure.

Figure 9-7: Making a perpendicular line



Circles and Fans— The centers of circles and fans are established by laying string lines in both directions. A grid is established with the perpendicular lines. Each intersection string line represents the center paver for starting the fan or circle. A paver is placed at each and courses “radiate” from that center. Full circles are paved in all directions. Fans or arcs will radiate and touch adjacent fans at the same courses. This ensures that all fans are the same size. Figure 9-8 shows this procedure.

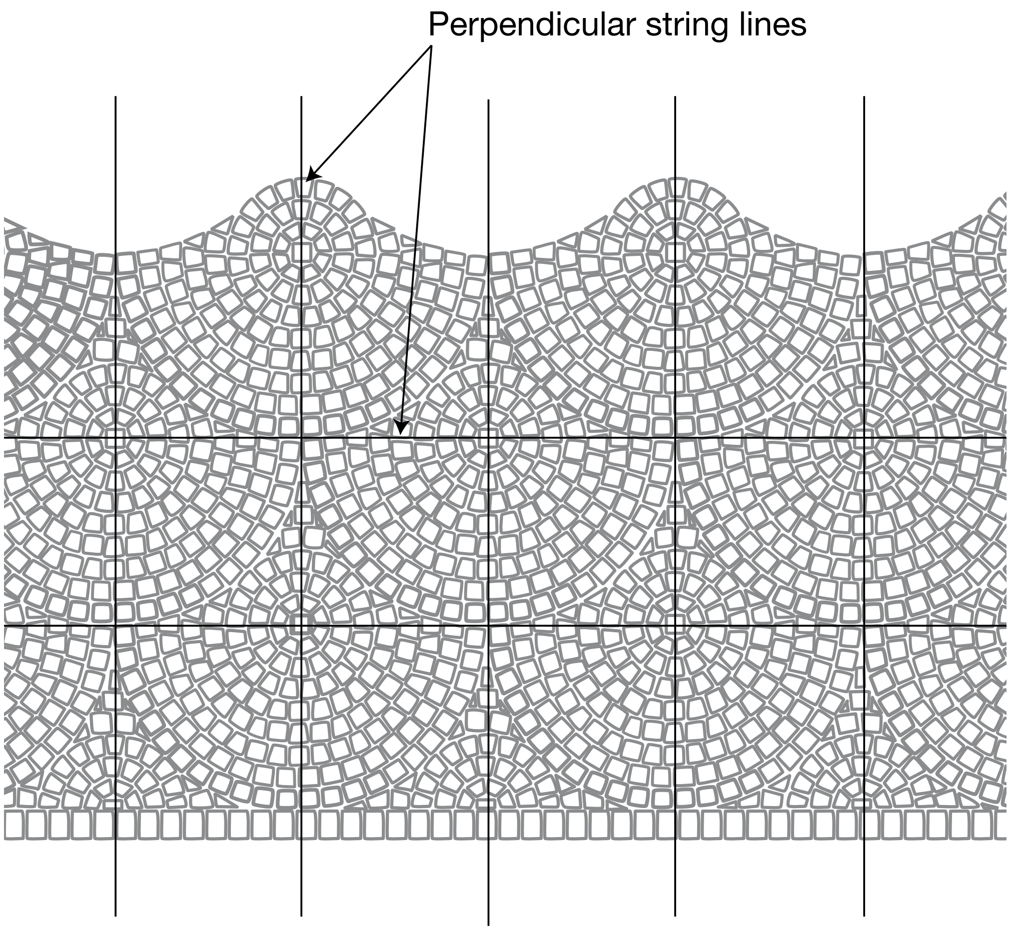


Figure 9-8. Perpendicular, evenly spaced string lines mark the center of circles for layout.

Section 9 Part D: Paving Around Obstructions, Non-aligned Edges and Openings

Often string lines are needed to align the first row when edges are curved or not perpendicular to the direction of paving. This often occurs with poured curbs and building walls. Figures 9-9 and 9-10 show how to establish a straight starting line, square with the direction of paving.

Procedure:

- Place square string or chalk lines at 90° angle.
- Lay a few square yards (m^2) to these lines.
- Check the alignment with the strings.
- Straighten the pavers as needed, then continue.
- Fill the gaps against the uneven edge with cut pavers.

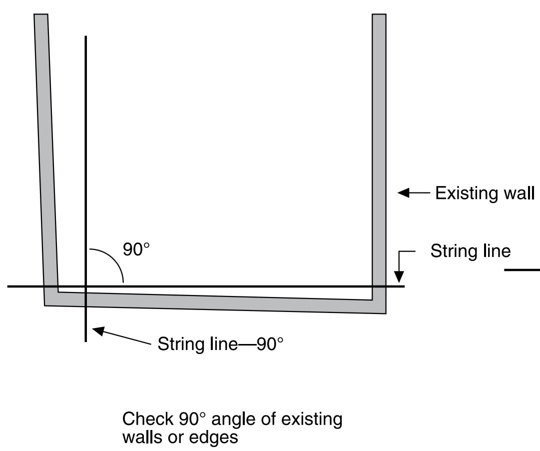


Figure 9-9: Squaring an uneven corner

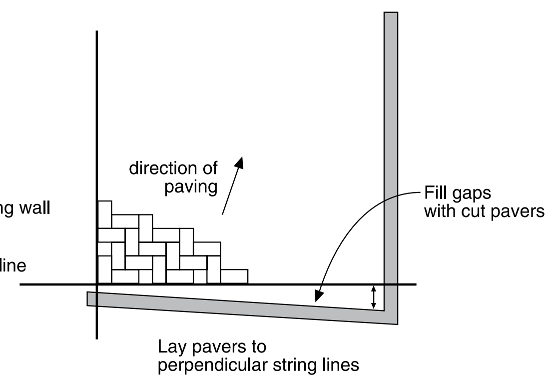


Figure 9-10: Filling the corner

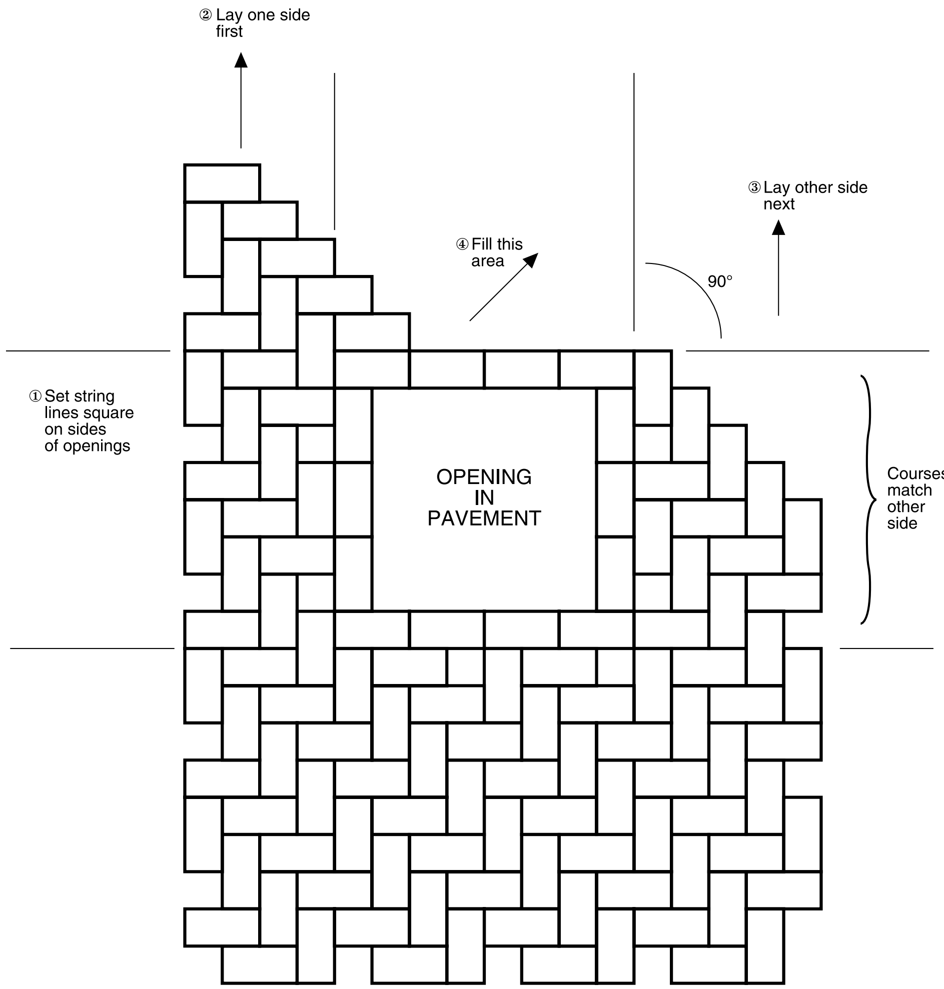
Pavers around openings are handled in a similar manner. Openings can be tree wells, utility structures, gardens and even swimming pools. There must be an adequate edge restraint in place around the opening against which to place the pavers. This is typically, plastic, steel, aluminum or concrete.

Procedure:

- Pull perpendicular string or snap chalk lines on all four sides of the opening.
- Lay pavers on one side, then the other.
- Count the courses needed to surround the opening on each side. They should be equal in number on both sides.
- Then fill around the remaining side of the opening.
- Cut pavers to fit and fill against the edge restraints around the opening.

Tip: Place a border of full-sized pavers (soldier, string, or sailor course) against the edge restraint. This makes a neater appearance than placing cut pavers against the edge of the opening. See Figure 9-11.

Figure 9-11: Paving around an opening or obstruction



Section 9 Part E: Cutting Equipment and Techniques

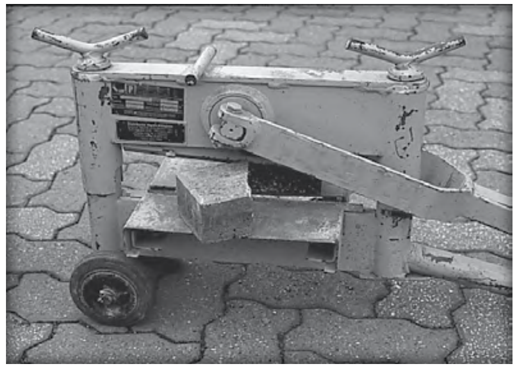


Figure 9-12: Paver splitter

Figure 9-13: Masonry saw

Most jobs with concrete pavers involve cutting. Pavers are typically cut along the edge of the pavement, around planters or drainage inlets, or when there is a change of pattern. Logos, or letters, can be cut and placed in a field of pavers. Contrasting colors can be used to highlight these areas.

There are three basic tools for cutting pavers. One is called a paver splitter, the second a powered masonry saw, and the third a hand-held powered quick saw. A paver splitter may be referred to as a stone cutter or guillotine. It is a non-motorized piece of equipment that relies on leverage, or hydraulic action, to cut a paver. See Figure 9-12.

In the jaws of the splitter are two hardened pieces of steel that cut by pinching the paver. If the blades are smooth and the paver is dense, a mechanical cutter can produce a cut with a fairly flat face. Absence of either condition can produce an uneven, bumpy appearance on the vertical cut face. An uneven surface will make the unit difficult or impossible to install in the pavement.

A key to using a mechanical splitter is placing the unit between the blades at a slight angle. When cut, this position will produce an angled face on the cut or "under cut." Since the bottom of the paver is slightly shorter than the top, the unit should easily slip into its designated opening in the pavement. The bottom of the paver should not be more than 1/4 in. (6 mm) shorter than the top surface. If there is a big difference, the top of the joint may not fill with sand, and the unit may shift and chip.

Masonry saws should use a diamond blade. It produces a smooth, precise cut. Masonry saws are gasoline or electric powered. Most masonry saws can run either wet or dry. Wet saws that apply water to the blade reduce workers exposure to respirable silica dust. When water is used, it also provides lubrication and reduces wear on the blade. If water is needed by the saw, anticipating a nearby faucet in planning the job will save delays and money. If possible, use clean water and do not recirculate it as it will likely stain the pavers.

A by-product of cutting with a wet masonry saw is residue-filled water. This can stain pavers, so wash and remove the slurry from the pavers before it dries. Cut in an area where drainage from the saw doesn't run on pavers or on nearby areas where there might be pedestrian or car traffic. Dry cut saws have a vacuum attachment and filter to control dust. This cutting method does not stain the pavers. See Figure 9-14.

Hand-held saws (also called quick or demolition saws) are gas powered, with engines similar to those used on chain saws. Since they don't need electricity, hand-held quick saws are completely portable. Hand-held quick saws have been used to cut pavers in-place on the bedding sand. The edge pavers are not restrained, but will have edge restraints installed after cutting is complete. ICPI does not recommend the use of a hand-held quick cut saw without some form of dust suppression to cut pavers, due to the significant release of dust, potentially containing respirable silica, which is certain to exceed permissible exposure limits.

OSHA recommends the use of water to reduce the volume of dust. However, as mentioned above the slurry created will stain the pavers if not removed immediately. The water will disturb the loose bedding sand, making paver compaction difficult and may lead future settlement problems. Use of vacuum equipment and a hose to collect dust at the blade is highly recommended. A hand held quick saw with a 12 in. (0.3 m) blade can cut about 4 ft. (1.2 m) or larger radius.

Basic Rules

Always mark a paver before cutting. Put a V on the line to show exactly where the cut should be made. The saw blade should meet the tip of the V. The side of the paver with the V is the end that will not be used. While crayons and pencils are used to mark pavers, welder's soap stone works very well. Marks will endure dust and water from cutting and they will eventually wear away.

Cut pavers are generally not re-used. It is usually not worth the time to sort them and find ones that fit an opening. A time-saving exception is when the paver pattern is centered and it creates cut units on one side where the remaining pieces can be used on the other. For example, 45° herringbone pattern can create cut units that can be used on both sides of the pavement. However, where there is space, it is faster to overpave both sides and cut them to fit within spiked edge restraints installed after the cuts. In addition, 90° herringbone patterns require half units to fill the edges. Both ends of cut half units can be placed along the edges.

For pedestrian areas and driveways, the rule of thumb is that cut pieces should be no less than 3/8 in. (10 mm) wide. If installed, small slivers of concrete pavers can crack and become unsightly. On the practical side, it is difficult to cut a piece thinner than this with a mechanical splitter. If a masonry saw is used, pieces smaller than this dimension are highly susceptible to being caught by the blade and being thrown from the saw.

A sharper appearance can be created by shifting the pavers behind the edge several feet (meters) so as to eliminate any gaps under 3/8 in. (10 mm). This should be done before compacting the pavers. Shifting the field of pavers to eliminate this gap may be difficult or impossible along a narrow area such as a sidewalk. In these cases, precise layout and double-checking measurements between the edge restraints avoids gaps.

Good judgement should be exercised in sizing cut pavers exposed to vehicles. Cut units receiving tires should not be less than one third of a whole paver. Pieces smaller than this can crack from repeated exposure to tires.

Bring the Saw to the Work

A common scene at a paver site is this: pavers are marked for cutting, brought to the saw operator, cut, brought back to edge and placed. This is an inefficient procedure because it involves two or three people walking most of the time rather than paving. Whenever possible, the saw should be brought to the pavers to be cut, not the pavers to the saw. One person can perform this operation.This efficiency can be accomplished by using cart-mounted masonry saws, or cutting the pavers in-place on the bedding sand with a quick saw.

For example, masonry saws can be mounted on a wheeled cart for easy movement around the site. Marked pavers can then be reached by the operator, cut and placed along the edge. The operator can move down the edge to the next area. Typical productivity is 25 to 30 ft (6 to 9 m) per person per hour. Blades typically last 400-600 linear ft (120-180 m) for dry or wet 12 in. (300 mm) diameter quick saws, 14 in. (530 mm) diameter table saw blades can last 1500 (dry) to 2000 (wet) lineal feet. Besides using dry or wet saw, blade wear depends on the hardness of the aggregates in the concrete pavers.

Figure 9-14: Dry saw increases speed and accuracy for paver cutting. However, they should include integral vacuum dust collection systems to meet OSHA regulations.

The pavers should not be compacted before cutting. Those to be cut with a quick saw along a straight line are marked with a chalk line. The bedding sand and pavers should extend past the edge that pavers are to be cut by 8 to 10 in. (200 to 250 mm). This adds stability during cutting. The saw blade should be set to the thickness of the pavers. Some saws have a special attachment to control the depth of the cut and hold the saw in position for easier movement along the pavers.

Increased regulation of silica dust on construction sites is changing preferences for cutting equipment. ICPI encourages the use of gasoline powered saws that do dry cutting. The saw should be attached to a dust collection system. While collections systems are expensive, they are less expensive than fines from agencies that regulate safety on construction sites. Furthermore, collection systems make the site cleaner for everyone and greatly reduce dirt on windows, plants, cars, etc.

Above all, wear ear protection and safety glasses when cutting with powered saws. Always wear a dust mask when cutting with dry cut saws. A rubber apron will keep clothes from getting soaked when using a wet saw. Overalls will keep debris from getting on clothing or skin while using a dry saw. Wear safety boots to protect feet from injury when using all types of cutting equipment.

Maintenance of saws is key to their long life and that of the diamond saw blades. Air filters should be checked replaced regularly or the engines will not operate. Oil bath filters require less time in maintenance and are effective in removing dust. Saw blades should be checked for squareness and warping. An out-of-square or warped blade will wear faster because it is using the sides of its teeth to cut rather than the fronts. Also check the steel sides of the blades for wear and reduced thickness. This type of wear is common with saw blades used on a hand-held dry saw. Keep in mind that saw bearings wear quickly due to cutting and dust. Follow the manufacturer's recommendations on when these should be replaced.

Section 9 Part F: Compaction Equipment and Compacting Pavers

Compaction Equipment

A centrifugal plate vibrator (plate compactor) is shown below. The compactor should have a minimum compaction force of 5,000 lbs. (22 kN), weighing 165 to 240 lbs (70 to 110 kg).

Compacting the Pavers

Figure 9-15:
Plate Compactor

Starting procedure:

- Wear ear protection
- Be sure vibrator is disengaged
- Check gas and oil levels
- Adjust choke and throttle
- Start by pulling on the cord
- Adjust choke and throttle as needed

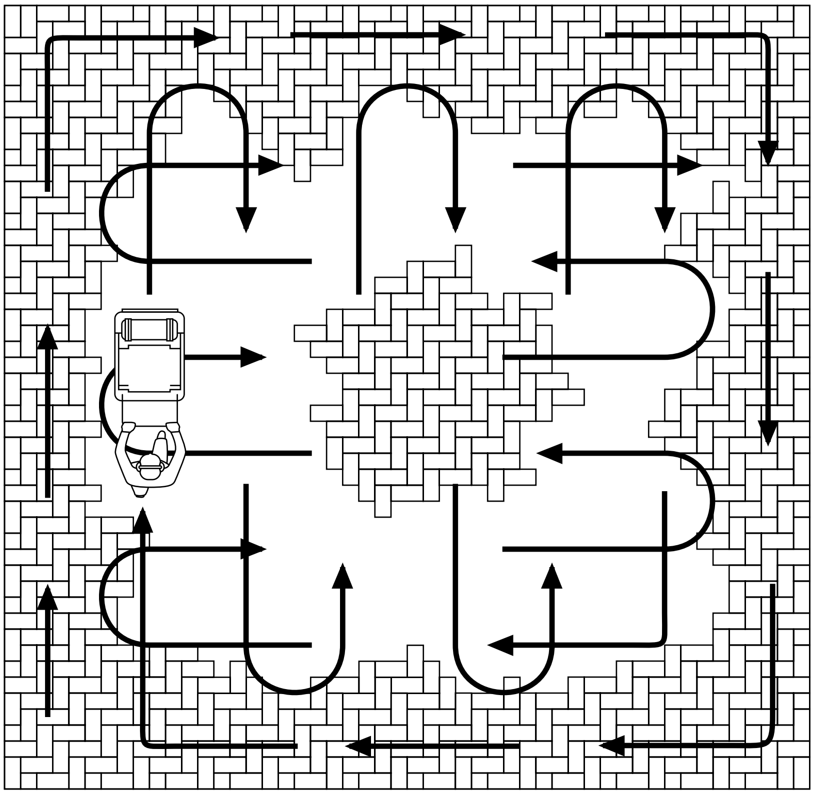
Compacting procedure:

- Start on one edge of the pavement and compact the perimeter.
- Compact in overlapping rows on the rest of pavement.
- Compact the pavement again but in the opposite direction. All pavers will need to be exposed to at least two passes of the compactor.
- Do not compact within 6 ft (2 m) of an unrestrained edge or the pavers will creep out.
  The operator looks for broken pavers just behind the plate compactor and marks them while compacting. The broken pavers are removed with a paver extractor and replaced with whole units.

Wet joint sand does not easily move down into the joints. If the sand is wet, spread it on the pavement and let it dry before it is swept and vibrated down into the joints. Allowing the sand to dry so that it can move down into the joints will save a return trip a few weeks after the job is finished to refill the joints with sand.

Use bagged sand if weather and temperature won't allow the sand to dry prior to filling the joints. This will save time and money. The gradation of these bagged sands should be checked for conformance to ASTM C144 or CSA A179. Bagged sand often is evenly graded as with some play sand or sandbox sands. Evenly graded sands do not assist with interlock as well as those with a range of particle sizes.

Dry joint sand should be evenly spread across the surface of the pavers to speed movement into joints during vibration with a place compactor. A fast way of spreading sand is using an asphalt lute or rake. This rake has a blade with small notches. When pulled across joint sand spread on the surface of the pavers, small lines of sand are formed. If the sand is dry, these lines of sand will roll into the joints with a pass or two of the plate compactor.



When placing sand into the joints, use a stiff bristle push broom. Fill the joints and leave a thin layer of excess sand. Follow the previous compaction pattern. After the compactor passes, place more sand into the joints until full and make another pass with the plate compactor. Fill the joints full and remove excess sand.

At the end of each day's work, all edge pieces must be cut and placed, all paver surfaces compacted, cracked or broken pavers replaced, joints filled with sand, and the area compacted within 6 ft (2 m) of open unrestrained edges. Protecting the uncompacted, unrestrained edges with plastic or canvas during rainy weather is preferred to re-laying these areas after the storm due to saturated bedding sand.

Figure 9-16: Compaction sequence–working from the perimeter to the center of the pavement. All pavers should have two passes of the plate vibrator over them prior to filling the joints. After the joints are filled with sand, follow the same compaction sequence from the perimeter to the center.

Several factors affect productivity of compacting pavers. They include the width of the plate on the compaction machine, the amount of overlap on passes taken by the operator, the travel speed of the machine, and the thickness of the pavers. The wider the plate, the greater the area covered in each pass. Overlap should be at least 4 to 6 in. (10 to 15 cm), or about a half a paver length. Larger overlaps will waste time. Faster travel speed from a machine will cover more area. Thicker pavers will take more time to compact than thinner ones. An average production rate for compacting 2,000 sf (200 m^2) of pavers per hour.

Plate compactors should be operated at full throttle operating speed. Decreasing engine speed and the vibration rate does not increase the compactive force exerted by the plate. Two persons are generally required to place sand into the joints. A third simultaneously uses the plate compactor to work the sand further into the joints during the placing process.

Some units have uneven top surfaces to replicate stone and they are sometimes called "embossed" pavers. These high spots can be scuffed and damaged by a plate compactor. When compacting such pavers, a rubber or nylon pad should be fastened to the compactor plate. If no pad is available, woven geotextile placed over the pavers when compacting has been show to prevent scuffing.

Maintenance and Management
[CPI10]

Student Manual

ICPI Concrete Paver Installer Course

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14801 Murdock Street, Suite 230
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Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Every effort has been made to present accurate information. However, the recommendations herein are guidelines only and will vary according to local conditions. Professional assistance should be obtained in the design, specifications and construction with regard to a particular project.

Table of Contents

Maintenance and Management

Section 10 Part A: Introduction

Interlocking concrete pavements are recognized as very low maintenance when compared to other pavement alternatives. It is important, however, for installers to understand and identify the potential pavement distresses that can occur. Many of these distresses can be addressed during the installation of the pavement. Section 1 described these pavements as flexible pavements but with the unique feature of having a hard concrete wearing surface. Because of this unique design, distresses and maintenance procedures differ from traditional asphalt and concrete pavements. This is the case for patios, driveways, sidewalks, and streets.

Section 10 Part B: Problem Areas

The number one cause of pavement failure is settlement from inadequate compaction. In street applications, this can be seen as rutting in the wheel paths (See Figure 10-1). In residential projects this can be seen as settlement at entrances to driveways or garages, at the curb-edge of the pavement, or where the pavement meets the foundation of the house (See Figure 10-2). By following the practices described in Sections 5 and 6, this type of settlement can be avoided. Minor settlement can always occur, and pavers should be set at approximately 3/8 in. to 1/4 in. (10 to 6 mm) higher than curb, driveway or garage entrances to allow for this.


Figure 10-1: Rutting in a vehicular pavement


Figure 10-2: Settlement at a driveway entrance from inadequate compaction


Figure 10-3: Settlement at a curb due to bedding sand loss at the concrete curb joint.


Figure 10-4: Geotextile at the curb can eliminate bedding sand loss

The next important layer in the system is the bedding sand layer. Failure of the bedding layer also results in settlement of the surface, and can be mistaken for soil or base settlement. Causes of bedding layer failure are usually due to incorrect sand material or failure by the

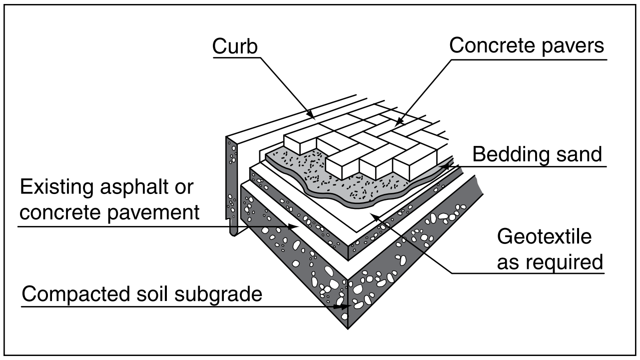

Figure 10-5: Overlays over concrete or asphalt require geotextile below the bedding sand layer

installer to prevent bedding sand loss into places where sand can migrate. Proper bedding material and installation is discussed in Section 8.

Figure 10-3 shows settlement of the pavement due to bedding sand loss. The bedding sand was not prevented from moving through the joints in the concrete curb. Figure 10-4 shows a proper installation using a one foot (300 mm) strip of geotextile to contain the bedding sand. Bedding sand can also migrate through the joints in plastic edge restraints.

Bedding sand loss can also occur in pavement overlays over asphalt or concrete. In these applications, ICPI recommends overlaying the concrete or asphalt surface with geotextile so that the bedding sand does not migrate through any cracks. This is also recommended over the drain holes to ensure that the sand does not plug the drainage stone and water will not saturate the bedding layer over time (See Figure 10-5). This is an important detail in any overlay, including pool decks. Overlays are covered in greater detail in the Residential Specialist Course and the Commercial Specialist Course.

Problems with the top surface (pavers, jointing sand and edge restraints) are usually due to loss of interlock in the system and can be seen as paver shifting or “creeping.” The most common reasons for loss of interlock are: 1. improper edge restraint, 2. using the wrong size paver or paving pattern for the application, and 3. loss of jointing sand. Section 7 outlined the proper edge restraint for different applications and Section 9 discussed paver selection and installation. Remedial measures are discussed in part D of this section.

Figure 10-6: ICPI recommends herringbone layout for vehicular applications such as streets and parking lots. For residential driveways, when using running bond patterns, install the pavement so that the bond lines are perpendicular to the direction of the traffic.

Figure 10-7: A herringbone pattern for a residential driveway application. Note the discontinuity in the bond lines.

Section 10 Part C: Cleaning, Sealing and Joint Stabilization

Loss of joint sand can occur in high slope areas, high wind areas or areas where there is concentrated surface water run off. In these areas, installers should consider the use of joint sand stabilizers. These include pavements on high sloped areas and places subject to aggressive and regular cleaning by power washers or vacuum systems. Pavements that see regular, heavy rainfall such as tropical locations could also benefit from stabilization of the joint sand. Areas with low slopes (< 1%) exposed to aggressive chemicals that could potentially leach into the base are also good candidates. Some pavers that are textured by tumbling or other methods will result in wider joints (> 5 mm or 3/16 in.) that should also be stabilized.

In residential applications stabilization is very beneficial on pool decks and under downspouts and eaves. Stabilization materials also reduce the potential for weeds in the joints.

Using joint sand stabilization products should be evaluated on a project-by-project basis. It is important to first evaluate the need and benefit. If sand loss is expected, joint sand stabilization is a solution. The choice should also be weighed against the added expense to the owner. Installers should contact the stabilizer manufacturer for estimated application rates to evaluate the labor hours and cost. If this initial cost will extend the life or the maintenance schedule for the pavement, it will be recovered in the long term.

From a structural standpoint, stabilizers and sealers are not necessary. Joint stabilization, however, can contribute to long-term performance by helping prevent infiltration of water to the bedding sand and base.

There are two types of sand joint stabilization, the first being a water or solvent-based liquid and the second being a modified sand. For water or solvent-based liquid, the primary resin or bonding agent is an acrylic, or modified acrylic as solids (by volume) typically 21% to 23%. The percentage of solids is an important factor. Once solvent or water has carried the solids into the joint sand, they will evaporate and leave the solids behind as the binding agent. Modifiers such as epoxy resins may also add to the ability of the product to create a solid matrix in the joint sand.

All water-based or solvent-based liquid stabilizers need to meet federal and local regulations for emissions due to volatile organic carbons (VOC's). Contractors are encouraged to become familiar with local regulations and to consult the manufacturer's material safety data sheet (MSDS) for total VOC content. In addition, contractors should take precautions such as the use of respirators to ensure that installers do not have prolonged exposure to noxious fumes during application.

When using either solvent or water-based products, they should be capable of penetrating at least 1 inch (25 mm) into the joint sand. On larger jobs, an off-site pre-job mock-up is beneficial in determining application rates for specific products and for specific job site conditions. A physical examination of the mock-up will determine the effective penetration rate. In addition, the mock-up will

Figure 10-8: Cleaning the surface of the pavement prior to sealing or stabilizing

determine the appropriate application rate of the liquid stabilizer. Penetration rates can vary depending on the type of paver, size of joint, the gradation of joint sand, moisture condition of joint sand and climatic conditions. Water based stabilizers may need more time and effort to penetrate solids into the joint sand. Installers should also contact the supplier of the liquid solvent or water-based product for typical penetration rates.

Prior to applying liquid materials, the surface should be clean and dry and any efflorescence removed from the pavers (See Figure 10-8). Dry joints are essential. A broom or leaf blower can efficiently remove excess sand. Sand displaced during the cleaning process will need to be replaced. Determine the most efficient method for applying the liquid stabilizer based upon specific job site conditions and past experience.

Some successful methods of application involve applying liquid joint stabilizers with low pressure, high volume spray, followed immediately by a squeegee to move the material into the joint. Other methods use rollers or hand pumped, garden-type sprayers. Some equipment for big jobs has multiple spray nozzles and mechanized rollers and/or squeegees. Whatever the choice, the key is uniform dispersion and effective penetration. Consult the manufacturers of liquid materials for additional advice.

Most liquid products also effectively seal the paver surface. All liquid based stabilizers will affect the final pavement surface appearance by creating a moderate to high gloss sheen. Solvent-based products create a higher surface gloss. Sealing will alter the color, inhibits fading, and protects against staining. It can also make the paver surface easier to clean and maintain. As the liquid joint stabilizer/sealer wears, the sealer will need to be reapplied. Consult with specific manufacturers for reapplication procedures.

Another type of joint sand stabilization uses dry additives to joint sand. These additives are organic or polymer compounds that, when activated with water, stiffen and stabilize the joints. Joint sand additives come pre-mixed and pre-bagged with the sand, or are sold separately as an additive mixed with the joint sand on the job site. On larger jobs, mechanical mixing is recommended for better dispersion. Pre-bagged sand guarantees additive dispersion.

The pavers are initially compacted into the bedding sand. Joint sand is applied with a stabilizer additive mixed in it. When activated with water, this material stabilizes the full depth the joint to create a firm yet flexible material that maintains and enhances interlock among the pavers. For pre-mixed or job-site mixed additives a pre-job mock-up is beneficial in determining the depth of stabilization. The mock-up will determine the rate and application method of water to ensure full activation of the stabilizer. A mock-up will confirm a consistent method for uniform distribution of the additive in the sand for job-site mixed additives in particular.

Pavers need to be completely dry before the application of modified sand. After modified joint sand has been swept into pavers and the pavers compacted, it is necessary to remove excess sand and residue from the paver surface. The most efficient way to accomplish with is with a stiff broom, follow-up by a leaf blower. Once the sand and residue have been completely removed, the joint sand is ready for activation with water. The water is applied according to manufacturer's recommendations. A quick check of water penetration can be done with a putty knife in randomly selected sand joints. ICPI Tech Spec 5 Cleaning–Sealing and Joint Sand Stabilization of Interlocking Concrete Pavement (see Appendix) provides additional guidance for installers and is included in this section.

Section 10 Part D: Remedial Measures

To fix distressed areas, pavers can be removed with a paver extractor (See Figure 10-9). Generally, settlement that exceed 1/4 inch (6 mm) should have the pavers removed and the problem addressed before it gets worse. Sometimes this involves removing a larger area of pavers. ICPI Tech Spec 6–Reinstatement of Interlocking Concrete Pavements (see Appendix) provides a step by step procedure and can be summarized as follows.

Figure 10-9: Removing pavers with a paver extractor

1. Locate underground utilities in the area to be excavated and determine the depth of the excavation. Mark the area of pavers to be remove which will be about 32 in. (0.8 m) beyond the extent of the excavation. Pavement can easily be marked with chalk or paint. If pavers are to be re-used chalk may be preferable. Use paint if it is necessary to establish a more permanent marking.

2. Remove the first paver. Start at one end of the area to be removed. Scrape the sand out of the joint using a putty knife or small trowel. Use a paver extraction tool or two large flat screwdrivers to pry or wiggle the paver out. In some cases it may be necessary to break the first paver into smaller pieces to get it out.

3. Remove the remaining pavers. If the pavers are to be reused scrape off the sand that sticks to the sides and bottom of each paver and stockpile. Temporary bracing at the pavement opening will help keep units in place during excavation and repairs, prior to paver reinstatement.

4. Remove the bedding sand. The bedding sand can be reused, if it is separated and contains no aggregate pieces, or replaced. Leave 6 to 12 in. (150 to 300 mm) of bedding sand next to the pavers.

5. Excavate the base material and subgrade. It may be possible to separate base aggregate for reuse if separated from subgrade soil. Once repairs are complete compact the bottom of the excavation. Place excavated subgrade soil back in the trench and compact in 2 to 4 in. (50 to 100 mm) lifts to 98% Standard Proctor Density.

6. Replace the base material. Place and compact crushed stone aggregate in 2 to 4 in. (50 to 100 mm) lifts to 98% Modified Proctor Density. Controlled low strength fill may also be used. Bring top of reinstated base level with undisturbed base.

7. Replace the bedding sand layer. If pavers around the excavation have been disturbed, they should be removed. Use the bedding sand around the perimeter as a guide. Crown the sand at the middle of the excavation.

8. Reinstate the pavers. Cut pavers as necessary and compact them into the bedding sand. Spread the joint sand and compact to fill joints.

Joint sand loss in excess of 1/2 inch (12 mm) requires joints to be refilled. In this case, the contractor should also determine if there is a need to stabilize or seal the joints to prevent future repeated joint sand loss. Joint sand loss should be measured down from the bottom of the chamfer with a blunt object such as a putty knife.

Construction Tips
[CPI11]

Student Manual

ICPI Concrete Paver Installer Course

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14801 Murdock Street, Suite 230
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Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Every effort has been made to present accurate information. However, the recommendations herein are guidelines only and will vary according to local conditions. Professional assistance should be obtained in the design, specifications and construction with regard to a particular project.

Construction Tips

Paver sidewalks against curbs – Joints throughout poured-in-place or precast concrete curbs should allow excess water to drain through them without loss of bedding sand. If there are no joints, weep holes placed at regular intervals will prevent the sand from migrating. Joints in curbs often have expansion material in them. This material tends to shrink and decompose. Filter cloth placed over joints, or over weep holes, will prevent the sand from migrating. Expansion joint materials are not required between the pavers and the curb.

Utility covers in streets and walks (e.g., sewers, water and gas valves, telephone, electrical) should have concrete collars around them. Consistent compaction of aggregate base against cast iron is difficult, so a concrete collar placed after compaction reduces the potential for settlement. It further protects the iron frames and covers. The collars should be 1/4 in. (7 mm) below the pavers to prevent catching snowplow blades (Figure 11-1). Drain and catch-basin inlets should have a concrete collar around them if they are not encased in concrete.

When overlaying existing asphalt, or concrete streets with pavers and bedding sand, utility covers are raised and new concrete collars poured around them.

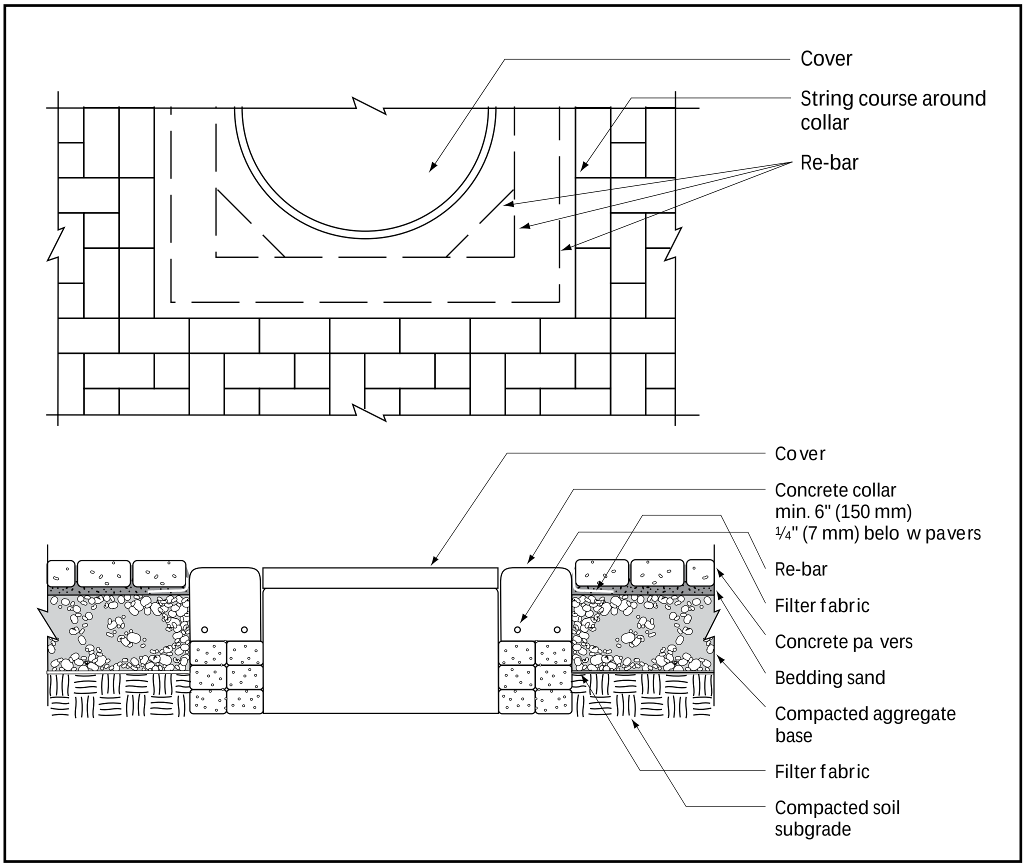

Figure 11-1: Utility cover

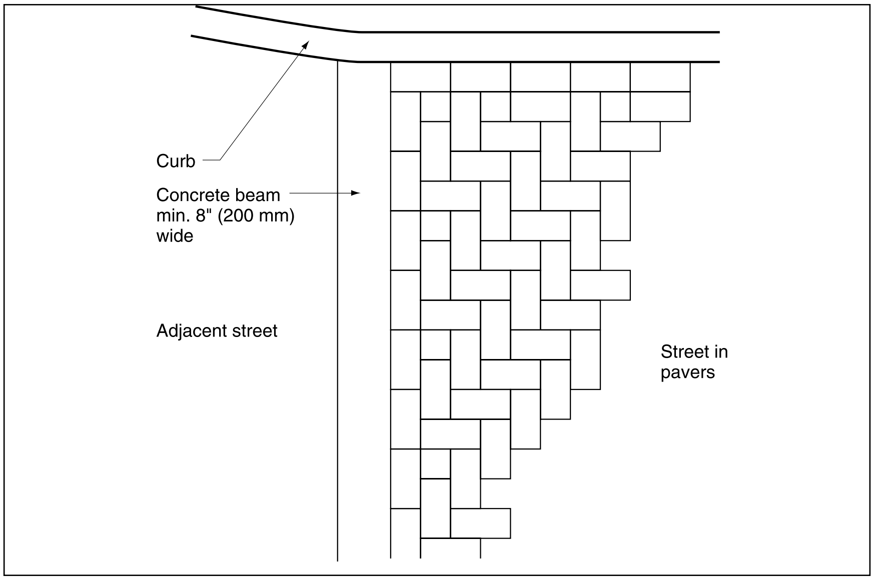

Figure 11-2:
Concrete beam

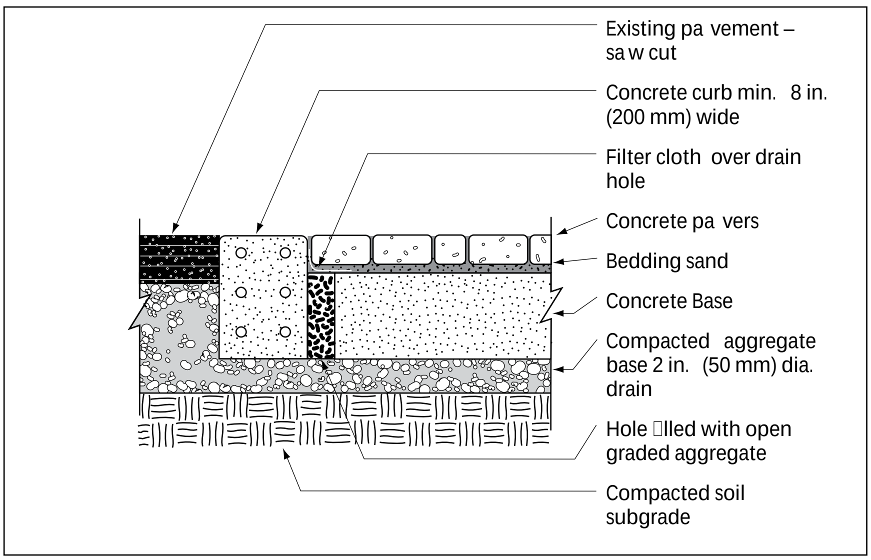

Figure 11-3:
Crosswalk with
concrete base

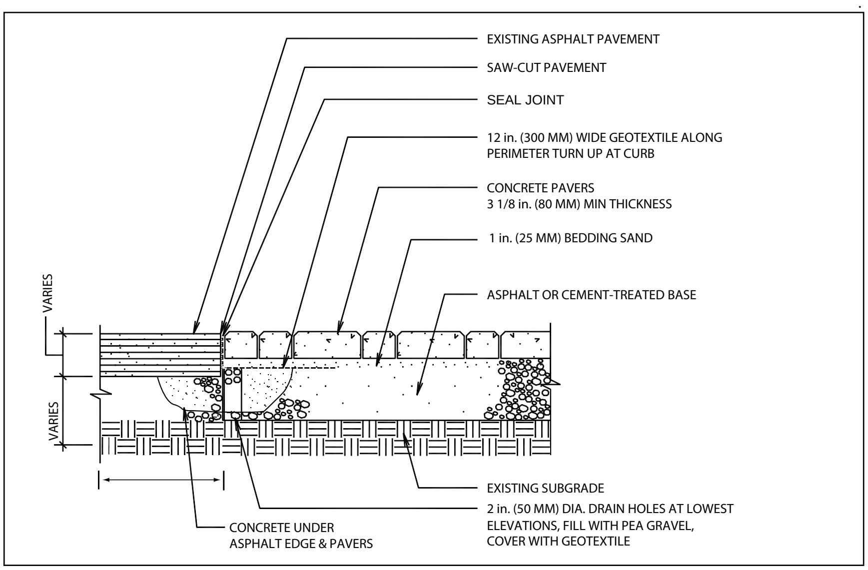

Figure 11-4:
Crosswalk in existing
asphalt pavement

screeding the bedding sand. Elevations for screeding should be set from the restraints after their elevations have been verified.

Attention should be given to the elevation of the pavers next to the restraints. Some pavers may require a finish elevation 1/4 in. (7 mm) above the top of the restraint. This allows for minor settlement of the pavers and surface drainage. It further minimizes potential tripping due to excessive wear on the restraining material. Other restraint designs help prevent minor settlement of edge pavers by extending slightly under them. These restraints do not generally require any adjustment of the final elevation of the edge pavers to compensate for minor settlement. Pavers and bedding sand will not settle when placed on a concrete base.

Cutting edges – Some restraints allow the pavers and bedding sand to be installed prior to placing the edge materials. The field of pavers is extended past the planned edge location. The pavers are marked with a chalk line, plastic pipe (Figure 11-5), or by using the edge material itself as a large ruler for marking. The marked pavers are then cut with a paver splitter or a powered saw (Figure 11-6). The cut ends and excess bedding sand are removed and the edge restraints installed. This technique is particularly useful for creating curved edges.

A clean appearance is achieved when a soldier, or sailor course is placed parallel to the edge restraint or concrete collar. Pavers are cut to fit against the course. Other shapes include edge pavers that make a straight, flush edge. This detail can reduce incidental chipping of cut pavers.

In some situations, site fixtures can be installed after the pavers are placed and vibrated and the joints filled with sand. Openings can be saw cut, the edge restraints placed, and the tree grates, bollards, or other fixtures installed.

Figure 11-5: Marking a curve to be cut


Figure 11-6: Cutting a curve with a dry saw

TECH SPECS

TECH SPEC

NUMBER 1

Glossary of Terms for Segmental Concrete Pavement

AASHTO: American Association of State Highway and Transportation Officials is an association that includes U.S. state and Canadian provincial highway engineers. AASHTO publishes structural design methods for pavement, material standards and test methods, as well as many other documents on roads, highways and transportation.

Abrasion: The mechanical wearing, grinding, scraping or rubbing away (or down) of paver surface by friction or impact, or both.

Absorption: Weight of water incorporated by a concrete paver unit during immersion under prescribed conditions, typically expressed as a percentage relating to the dry weight of the unit.

Admixture: Prepared chemicals added to the concrete during the mixing process to improve production efficiencies and/or hardened properties such as density, absorption, efflorescence control, visual appeal, durability and strength.

Aggregate: Sand, gravel, shell, slag, or crushed stone used in base materials, mixed with cement to make concrete, or with asphalt.

Albedo: The ratio of outbound reflected solar radiation from a pavement surface to inbound radiation.

Angularity: The sharpness of edges and corners of particles. Used to describe sand and aggregates.

Arris: The sharp or salient angle formed by the meeting of two surfaces.

Aspect Ratio: The overall length of a paver divided by its thickness. Example: A 4 in. (100 mm) wide by 8 in. (200 mm) long by $3\frac{1}{8}$ in. (80 mm) thick paver has an aspect ratio of 2.5. Compare to Plan Ratio.

ASTM C 936: American Society for Testing and Materials, Standard Specification for Solid Concrete Interlocking Paving Units. This product standard defines dimensions, dimensional tolerances, maximum absorption, minimum compressive strength, maximum abrasion and freeze-thaw durability through various test methods.

Aquifer: A porous, water-bearing geologic formation that yields water for consumption.

Band Cutter: A plier-like tool designed to cut metal or plastic bands around cubes and bundles of paving units without injury.

Base or Base Course: A material of a designed thickness placed under the surface wearing course of paving units and bedding course. It is placed over a sub-base or a subgrade to support the surface course and bedding. A base course can be compacted aggregate, cement or asphalt stabilized aggregate, asphalt or concrete.

Base Rake: A rake with a flat and toothed side to move and level aggregate base (similar in appearance to an asphalt lute). A base rake can be used to evenly spread joint sand on the surface of paving units for faster drying.

Bedding Sand Degradation Tests: Evaluation of the degree of attrition of sand. Tests are conducted with steel balls or other abrading devices agitated with a sand sample in a container. Pre- and post-testing sieve analyses are conducted to determine the increase in fines. The tests are used to evaluate the durability of bedding sand under heavy loads or channelized traffic. Tests are often called Micro-Deval tests.

Bedding Sand or Bedding Course: A layer of coarse, washed sand screeded smooth for bedding the pavers. The sand can be natural or manufactured (crushed from larger rocks) and should conform to the grading requirements of ASTM C 33 or CSA A23.1 with limits on the percent passing the No. 200 (0.075 mm) sieve. A screeded sand layer is 1 to $1\frac{1}{2}$ in. (25 to 40 mm) thick.

Bentonite Clay: Clay with a high content of the mineral montmorillonite, usually characterized by high swelling on wetting that can be used to help seal paver joints.

Best Management Practice (BMP): A structural device or non-structural program designed to reduce stormwater runoff and water pollution.

Bishop's Hat: A five-sided paver often used as an edge paver with a 45° herringbone pattern.

Bitumen: A class of asphalts combined with neoprene and used as an adhesive under unit paving.

Bitumen Setting Bed: A sand-asphalt mix used for a bedding layer typically less than 1 in. (25 mm) thick. Paving units are often adhered to the layer with a neoprene-asphalt adhesive.

Blending Pavers: Mixing colored concrete pavers from three or four cubes to insure an even color distribution.

Bulge or Belly: Convex sides of a concrete paver that are often due to excessive water in the concrete mix.

Bundle: Paver clusters stacked vertically, bound with plastic wrap and/or strapping, and tagged for shipment to and installation at the site. Bundles of pavers are also called cubes of pavers. Concrete paver bundles supplied without pallets are strapped together for shipment then delivered and transported around the site with clamps attached to various wheeled equipment. Bundles can also refer to a portion of paving units or band of pavers for transport around the site with wheeled equipment such as a bundle buggy.

Bundle Buggy: A wheeled device (with or without an engine) specifically designed to carry a band or portion of a cube of pavers around a job site.

California Bearing Ratio (CBR): A standardized soils test defined as the ratio of: (1) the force per unit area required to penetrate a soil mass with a 3 in. sq. (19 cm sq.) circular piston (approximately 2 in. (51 mm) diameter) at the rate of 0.05 in. (1.3 mm)/min, to (2) that required for corresponding penetration of a standard material. The ratio is usually determined at 0.1in. (2.5 mm) penetration, although other penetrations are sometimes used. See ASTM D 1883.

Cation: A positively charged atom or group of atoms in soil particles that, through exchange with ions of metals in storm water runoff, enable those metals to attach themselves to soil particles.

Cement-Aggregate Ratio: The proportional weight of cement to fine and coarse aggregate in concrete.

Cement, Portland: Hydraulic cement produced by pulverizing clinker consisting essentially of hydraulic calcium silicates, and usually containing one or more forms of calcium sulfate.

Chamfer: A 45° beveled edge around the top of a paver unit usually 1/16 to 1/4 in. (2-6 mm) wide. It allows water to drain from the surface, facilitates snow removal, helps prevent edge chipping, and delineates the paving individual units.

Choke Course: A layer of aggregate placed or compacted into the surface of another layer to provide stability and a smoother surface. The particle sizes of the choke course are generally smaller than those of the surface into which it is being pressed.

Clay: Fine-grained soil or the fine-grained portion of soil that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when air-dry. The term can designate soil particles finer than 0.002 mm (0.005 mm in some cases).

Cluster: A group of pavers forming a single layer that is grabbed, held, and placed by a paver-laying machine typically on a sand bedding course.

Coarse Aggregate: Aggregate predominantly retained on the U.S. Standard No. 4 (4.75 mm) sieve; or that portion of an aggregate retained on the No. 4 (4.75 mm) sieve.

Compaction: The process of inducing close packing of solid particles such as soil, sand, or aggregate.

Compressive Strength: The measured maximum resistance of a concrete paver to loading expressed as force per unit cross-sectional area such as pounds per square inch or newtons per square millimeter (megapascals).

Concrete Block Pavement: A system of paving consisting of discrete, hand-sized paving units of either rectangular or dentated shapes, manufactured from concrete. Either type of shape is placed in an interlocking pattern, compacted into coarse bedding sand, the joints filled with sand and compacted again to start interlock. The paving units and bedding sand are placed over an unbound or bound aggregate layer. Also called interlocking concrete pavement.

Concrete Grids: Concrete units (generally small slabs) that have up to 50 percent open area. The units are generally no larger than 16 in. (400 mm) by 24 in. (600 mm). Aggregate or grass can be placed in the openings to promote infiltration of stormwater. Grids are generally used for intermittent parking, access lanes, abating runoff and/or controlling erosion. See ASTM C 1319, Standard Specification for Concrete Grid Paving Units for product standards.

Concrete Pavers: Concrete paving units, rectangular, square or dentated, capable of being placed with one hand into a laying pattern. The surface area is typically 100 in.^{2} (0.065 m^2) and the overall length to thickness is 4 or less. Compare to Paving Slab.

Concrete Sand: Washed sand used in the manufacture of ready-mix concrete which conforms to the grading requirements of ASTM C 33 or CSA A23.1. See Bedding Sand.

Course: A row of pavers.

Creep: Slow lateral movement of pavers from horizontal forces such as braking tires. The movement is usually imperceptible except to observations over a long duration.

Crown: The slightly convex shape of a road cross section. It is beneficial to surface drainage and interlock.

Crushed Stone: A product used for pavement bases made from mechanical crushing of rocks, boulders, or large cobblestones at a quarry. All faces of each aggregate have well-defined edges resulting from the crushing operation.

Crusher Run: The total unscreened product of a stone crusher.

CSA-A231.2: Canadian Standards Association product standard for Precast Concrete Pavers (interlocking units) that defines standards for dimensions, minimum compressive strength, and durability under freeze-thaw cycles with deicing salt through various test methods.

Cube(s): Pavers stacked at the factory, strapped or wrapped, with or without a wooden pallet, for shipping and for transfer around the site. The cube has several layers of pavers. The number of layers and pavers on a cube varies with their thickness and shape. See Bundle.

Curve Number (CN): A numerical representation of a given area's hydrological soil group, plant cover, impervious cover, interception, and surface storage. A curve number is used to convert rainfall depth into runoff volume.

Deflection: The temporary movement of a pavement structure due to traffic loads.

Deformation: A change in the shape of the pavement.

Degradation Testing: Testing of sands or aggregate to determine resistance to change in particle size or gradation under loading.

Dense-Graded Aggregate Base: A compacted crushed stone base whose gradation yields very small voids between the particles with no visible spaces between them. Most dense-graded bases have particles ranging in size from 1 1/2 in. (38 mm) or 3/4 in. (19 mm) down to fines passing the No. 200 (0.075 mm) sieve.

Density: The mass per unit volume.

Dentated Paver: A unit that is not rectangular or square in shape.

Detention Pond or Structure: The temporary storage of stormwater runoff in an area with the objective of decreasing peak discharge rates and providing a settling basis for pollutants.

Drainage Coefficient: Factor used to modify layer coefficient of pavements. It expresses how well the pavement structure can handle the adverse effect of water infiltration. See Layer Coefficient.

Dry Mix Joint Sand Stabilizer: Joint sand treated with chemicals that when placed in contact with water, activates them to bind together the sand particles. This stabilizes the joint sand, reduces its permeability, sand loss and helps prevent weeds.

Edge Paver: A paving unit made with a straight, flush side, or cut straight for placement against an edge restraint.

Edge Restraint: A curb, edging, building or other stationary object that contains the sand and pavers so they do not spread and lose interlock. It can be exposed or hidden from view.

Efflorescence: A white deposit of calcium carbonate on concrete surfaces. It results from the reaction of calcium hydroxide with carbon dioxide from the air. The calcium hydroxide is a byproduct when cement hydrates. It is slightly soluble in water and migrates to the surface through capillary action. The calcium hydroxide remains on the surface, reacts with carbon dioxide, which forms calcium carbonate and water. This conversion, depending on weather conditions, will dissipate over time. Calcium carbonate is the most common type of efflorescence. The presence of efflorescence does not compromise the structural integrity and is not indicative of a flawed product.

Elastic Deformation: A reaction from applied loads where pavement returns to its original position after the load is removed. Compare to permanent deformation under Rutting.

Elephant's Foot: A solid extension formed as part of the bottom of the paver typically the result of a rounding at the bottom of the mold due to excessive wear. Also known as legs.

Embodied Energy: The energy used through the life-cycle of a pavement material or product to extract, refine, process, fabricate, transport, install, commission, utilize, maintain, remove, and ultimately recycle or dispose of pavement materials.

Engraved Pavers: Pavers that have been engraved with letters or images by molding during or after manufacture, shot blasting, wet cutting or that have a cast metal plate set into the surface.

Equivalent Single Axle Loads (ESALs): Summation of equivalent 18,000 pound-force (80 kN) single axle loads used to combine mixed traffic to a design traffic load for the design period; also expressed as Equivalent Axle Loads or EALs.

Erosion: The process of wearing away soil by water, wind, ice and gravity; also the detachment and movement of soil particles by the same forces.

Exfiltration: The downward movement of water through an open-graded, crushed stone base into the soil beneath.

Face Mix or Hard Facing: The application of a thin layer of fine aggregate and cement to the top surface of a concrete paver. The layer is often colored and is used to provide a more intense appearance, greater abrasion resistance, or provide a base for a textured finish.

Failure: The point at which a pavement does not adequately service its intended use. For flexible pavements, rut depth is often a criterion for failure.

False Joints: Grooves on the surface of concrete pavers that appear as full joints between pavers that contribute to the installed joint pattern. False joints can enhance the appearance of the pattern and speed installation compared to placing separate (sub) units. Sometimes called dummy grooves.

Fines: Silt and clay particles in a soil, generally those smaller than the No. 200 or 0.075 sieves.

Fineness Modulus: A factor obtained by adding the total percentages by weight of an aggregate sample retained on each of a specified series of sieves, and dividing the sum by 100; in the United States the standard sieve sizes are No. 100 (0.150 mm), No. 50 (0.300 mm), No. 30 (0.600 mm), No. 16 (1.18 mm), No. 8 (2.36 mm) and No. 4 (4.75mm), and 3/8 in. (9.5 mm), 1 1/2 in. (37.5 mm), 3 in. (75mm), and 6 in. (150 mm).

Finished Grade: The final elevation of a soil, base, or pavement surface which is often indicated on construction drawings. Also Finish Elevation.

Flash: A thin, brittle layer of cement around the bottom edges or at the top edges of a paver composed of cement, typically due to minor leakage of liquid cement between elements of the mold assembly. Also known as Flange.

Flexible Pavement: A pavement structure which maintains intimate contact with and distributes loads to the subgrade. The base course materials rely on aggregate interlock, particle friction, and cohesion for stability.

Flexural Strength: A property of a paver or slab that indicates its ability to resist failure in bending.

Flowable Fill: A low-strength concrete mix used to fill utility trenches and other excavated pavement openings; also known as unshrinkable fill or controlled low strength material (CLSM). See ASTM D 6103, D 6023, D 6024 and D 4832.

Freeze-Thaw Durability Testing: Tests in which pavers are exposed to cycles of freeze and thaw, partially or totally immersed in water, and with or without salt water.

Frost Action: Freezing and thawing of moisture in pavement materials and the resultant effects on them.

Frost Heave: The raising of a pavement surface due to the accumulation and expansion of ice in the underlying soil or rock.

Geogrids: Geogrids are two dimensional or three dimensional. The two dimensional type are flat and have small, "TV screen" shaped openings. The material is generally placed between the soil and the base to reduce rutting. Three dimensional geogrids are 4 to 8 in. (100 to 200 mm) high and provide stability under loads for cohesionless soils.

Geotextiles: Woven or non-woven fabrics made from plastic fibers used for separation, reinforcement, or drainage between pavement layers.

Gradation: Soil, sand or aggregate base distributed by mass in specified particle-size ranges. Gradation is typically expressed in percent of mass of sample passing a range of sieve sizes. See ASTM C 136.

Grade: (noun) The slope of finished surface of an excavated area, base, or pavement usually expressed in percent; (verb) to finish the surface of same by hand or with mechanized equipment.

Gravel: Rounded or semi-rounded particles of rock that will pass a 3 in. (75 mm) and be retained on a No. 4 (4.75 mm) U.S. standard sieve which naturally occurs in streambeds or riverbanks that have been smoothed by the action of water. A type of soil as defined by the Unified Soil Classification System having particle sizes ranging from the No. 4 (4. 75 mm) sieve size and larger.

Half Stone: A half of a paver.

Hard Edges: A field of pavers that is restrained against a visible edge restraint or curb, thus visually reinforcing the edge of pavement.

Herringbone Pattern: A pattern where joints are no longer than the length of 1 1/2 pavers. Herringbone patterns can be 45° or 90° depending on the orientation of the joints with respect to the direction of the traffic.

Hotspot: A land use that generates highly contaminated runoff with concentrations higher than those typical to storm water.

Human Scale: Using paver sizes, patterns, colors and textures next to large buildings or open areas with the intent of reducing the user perception of being overwhelmed by the large scale of these spaces.

Hydrological Soil Group: The soils classification system developed by the U.S. Soil Conservation Service, now the Natural Resources Conservation Service that categorizes soils into four groups, A through D, based on runoff potential. A soils have high permeability and low runoff whereas D soils have low permeability and high runoff.

Impervious Cover: Surfaces that do not allow rainfall to infiltrate into the soil such as pavements, roofs, sidewalks, driveways, etc.

Infiltration Rate: The rate at which water moves through a soil tested in the field. Measured in inches per hour or meters per second. See ASTM D 3385 and 5093 and compare to Permeability.

Interlock: Frictional forces between paving units that prevent them from rotating, or moving horizontally or vertically in relation to each other; also defined as the inability of a concrete paver to move independently of its neighbors. The friction forces enable load transfer among the paving units. The three kinds of load transfer are vertical interlock, horizontal interlock and rotational interlock. Vertical interlock is achieved by shear transfer of loads to surrounding units through sand in the joints. Horizontal interlock is primarily achieved through the use of laying patterns that disperse forces from braking and accelerating vehicles. The most effective laying patterns for maintaining horizontal interlock are herringbone patterns. Rotational interlock is maintained by the pavers being of sufficient thickness, placed closely together, and being restrained by a stationary edge such as a curb.

Interlocking Concrete Pavement: A system of paving consisting of discrete, hand-sized paving units with either rectangular or dentated shapes manufactured from concrete. Either type of shape is placed in an interlocking pattern, compacted into coarse bedding sand, the joints filled with sand and compacted again to start interlock. The paving units and bedding sand are placed over an unbound or bound aggregate layer. Also called concrete block pavement.

Joint: The space between concrete paving units typically filled with sand.

Joint Filling Sand: Sand used to fill spaces between concrete pavers.

Joint Sand Gap: The vertical distance between the bottom of the chamfer on a paver and the top of the sand in the joint.

Joint Sand Stabilizer: Liquid penetrating or dry mix applied or materials that provide early stabilization of joint sand, reduces its permeability, sand loss and helps prevent weeds. See Dry Mix Joint Sand Stabilizer and Liquid Penetrating Joint Sand Stabilizer.

Joint Sand: Sand swept into the openings between the pavers.

Joint or Joint Spacing: The distance between the sides of the pavers not including the spacers that is typically filled with joint sand.

Karst Geology: Regions of the earth underlain by carbonate rock typically with sinkholes and/or limestone caverns.

K-pattern: A paving pattern with one square unit surrounded by rectangular units. Sometimes called an I-pattern.

Layer Coefficient: From the AASHTO pavement design procedure; a dimensionless number that expresses the material strength per inch (25 mm) of thickness of a pavement layer (surface, base, or sub-base). Example: The layer coefficient of 3 $^1/_8$ in. (80 mm) thick pavers and 1 in. (25 mm) bedding sand is 0.44 per in. (25 mm), therefore, the Structural Number (SN) = 4 $^1/_8$ x 0.44 = 1.82.

Layer or Cluster: A group of pavers manufactured in a laying pattern, generally placed by mechanical equipment.

Laying Face: The exposed, vertical face of a row of pavers on bedding sand; the working edge of the pavement where the laying of pavers occurs.

Laying Pattern: The sequence of placing pavers where the installed units create a repetitive geometry. Laying patterns may be selected for their visual or structural benefits.

Lean Concrete: Concrete of low-cement content used as a structural base material or as flowable fill in utility trenches.

Life-cycle Cost Analysis: A method of calculating all costs anticipated over the life of the pavement including construction costs. Discounted cash-flow methods are generally used, typically with calculation of present worth and annualized cost. Factors that influence the results include the initial costs, assumptions about maintenance and periodic rehabilitation, pavement user and delay costs, salvage value, inflation, discount rate, and the analysis period. A sensitivity analysis is often performed to determine which variables have the most influence on costs.

Lift: A layer of spread or compacted soil fill or aggregate. The rated compacted soil depth achieved by compaction equipment.

Lippage: The difference in vertical distance between the surface of one paving unit and an adjacent unit. An excessive amount of lippage is sometimes called fish scale.

Liquid Penetrating Joint Sand Stabilizer: Polymer liquid spread over the surface of pavers and allowed to penetrate the joint sand. After curing, the material stabilizes the joint sand, reduces its permeability, sand loss and helps prevent weeds.

Macro Texture: The deviations of a pavement surface from a true planar surface with dimensions generally 0.5 mm or greater or those that no longer affect tire-pavement interaction.

Markers: The use of concrete pavers with different colors, textures or shapes to mark underground utilities, traffic direction, parking stalls, lanes, pedestrian/vehicular areas, etc.

Mechanical Installation: The use of machines to lift and place layers of pavers on screeded sand in their final laying pattern. It is used to increase the rate of paving.

Mechanistic Design: Elastic analysis of structural response of applied loads through modeling of stresses and strains in a pavement structure.

Micro Texture: The deviations of a pavement surface from a true planar surface with dimensions generally less than 0.5 mm.

Modified Proctor Test: A variation of the Standard Proctor Test used in compaction testing which measures the density-moisture relationship under a higher compaction effort. See ASTM D 1557.

Modulus of Elasticity or Elastic Modulus: The ratio of stress to strain for a material under given loading conditions.

Moisture Content: The percentage by weight of water contained in the pore space of soil, sand or base, with respect to the weight of the solid material.

Mortar: A mixture of cement paste and fine aggregate (sand).

Mortar Sand: Sand used in mortar that typically conforms to ASTM C 144 or CSA A179.

Mosaics: Pavers used as pictorial maps, murals, or geometric patterns as a landmark, to emphasize an area, or suggest movement.

Multi-Colored Paver (Color Blend): A paver with two or more colors. The appearance is usually variegated.

Multi-layer Machine: A machine that manufacturers concrete paving units one layer at a time and places each layer consisting of a number of units on top of each other to form a cube that is allowed to cure prior to packaging for delivery to the site.

National Pollutant Discharge Elimination System (NPDES): A broad regulatory program that seeks to control water pollution by regulating point (sewage discharge) and non-point (runoff discharge) into streams, lakes and bays of the United States. The federal program is implemented at the state and local level via water pollution control plans and a permit system for sewage discharge, as well as runoff from construction sites, urban areas and farmland.

Nuclear Density Testing: The use of a nuclear density gauge to accurately and quickly assess the density and moisture content of soils and dense-graded aggregate in the field. The machine uses a probe inserted into the soil or base that emits very low intensity radiation. See ASTM D 2922.

Observation Well: A perforated pipe inserted vertically into an open-graded base to monitor infiltrate rate of water into the underlying soil.

One/One Hundred Year Storm: A rainfall event that occurs at least once a year and has a 100% chance of occurring within a given year/an event that occurs once in 100 years or has a 1% chance of occurring within a given year.

Open-graded Aggregate Base: A compacted crushed stone (granular) base whose gradation has relatively large spaces between the particles. It can be used as a drainage course in base design, or as a reservoir medium for storing stormwater in permeable pavements.

Optimum Moisture Content: The water content at which a soil can be compacted to a maximum dry unit weight by a given compactive effort.

Organic Impurities: Peat, roots, topsoil or decomposing materials in soil, sand or aggregate.

Organic Soil: Spongy, compressible soils usually consisting of peat humus or vegetative matter that have undesirable construction characteristics.

Outlet: The point at which water is discharged from an open-graded base through pipes into a storm sewer or watercourse.

Pavement Performance: The trend of service ability under repetitive loads.

Pavement Rehabilitation: Work undertaken to extend the service life of an existing pavement. This includes placement of additional surfacing material and/or other work necessary to return an existing roadway to a condition of structural or functional adequacy. This could include the complete removal and replacement of the pavement structure.

Pavement Structure: A combination of subbase, base course, and surface course placed on a subgrade to support traffic loads and distribute it to the roadbed.

Paver Extractor: A tool used to grab a paver and remove it from the laying pattern.

Paving Slab (or Flag): A paving unit with a surface area over 100 $in.^2$ (0.065 m^2) and with maximum length and width dimensions of 48 in. by 48 in. (1.2 m x 1.2 m). Its overall length to thickness ratio is greater than 4. Paving slabs do not rely on interlock as the principal means of load distribution.

Paver Splitter: A hand operated machine, sometimes hydraulically assisted, for cutting concrete pavers; also called a guillotine splitter.

Peak Discharge Rate: The maximum instantaneous flow from a detention or retention pond, open-graded base, pavement surface, storm sewer, stream or river; usually related to a specific storm event.

Performance: The total number of vehicle or ESAL applications withstood by a pavement before it reaches failure, rehabilitation, or a lower level of serviceability.

Performance Period: The period of time that an initially constructed or rehabilitated pavement structure will last (perform) before reaching its terminal serviceability. This is also referred to as the design period or life, expressed in years. Twenty years is normally used in North America.

Permeability: Measured in the laboratory, the rate of water movement through a soil column under saturated conditions, usually expressed as k in calculations per specific ASTM or AASHTO tests, and typically expressed in inches per hour or meters per second. See ASTM D 2434. Compare to Infiltration.

Permeable Interlocking Concrete Pavement: Concrete pavers with wide joints (5 mm to 10 mm) or a pattern that creates openings in which rainfall and runoff can infiltrate. The openings are typically filled with aggregate and occasionally with topsoil and grass. The pavers are typically placed on an open-graded aggregate base which filters, stores, infiltrates, and/or drains runoff.

Pervious or Permeable Surfaces/Cover: Surfaces that allow the infiltration of rainfall such as vegetated areas.

Plan Ratio: The overall length of a paver divided by its width. Compare to Aspect Ratio.

Plastic Limit: (1) The water content corresponding to an arbitrary limit between the plastic and the semisolid states of consistency of a soil. (2) Water content at which a soil will just begin to crumble when rolled into a thread approximately $^1/_8$ in. (3.2 mm) in diameter.

Plate Compactor: Also known as a plate vibrator, which is used to compact pavers into bedding sand in order to promote interlock among the individual units.

Poisson's Ratio: The ratio of transverse (lateral) strain to the corresponding axial (longitudinal) strain resulting from uniformly distributed axial stress below the proportional limit of the material; the value will average about 0.2 for concrete.

Porosity: The volume of voids in an open-graded base divided by the total volume of the base.

Pozzolanic Materials: Fly ash, pozzolan, silica fume, or blast furnace slag used as substitutes for cement. They are generally used in the concrete mix to increase density and durability of concrete pavers.

Prepared Roadbed: In-place roadbed soils compacted or stabilized according to provisions of applicable specifications.

Present Serviceability Index (PSI): A rating, usually between 0 (completely non-functional) and 5 (new/perfect) that generalizes several measurements of the condition of pavement. It is a convenient method of rating the overall condition and usefulness of a pavement over time and is from AASHTO pavement design methods.

Pre-treatment: BMPs that provide storage and filtering of pollutants before they enter another BMP for additional filtering, settling, and/or processing of stormwater pollutants.

Proctor Compaction Test: A test which measures the relationship of soil density with respect to soil moisture content under a standard compaction effort. This test identifies the maximum density obtainable at optimum moisture content. See ASTM D 698.

Progressive Stiffening: The tendency of pavements to stiffen over time. Interlocking concrete pavement stiffens as it receives increasing traffic loads thereby offering increased structural contribution structure; also referred to as "lock-up."

Pumping: The ejection of saturated bedding and joint sand, through joints or cracks or along edges of pavers when a load is applied.

Reflecting: Using pavers to mirror geometric patterns, shapes, colors or textures in the surrounding site.

Retention Pond: A body of water that collects runoff and stays full permanently. Runoff flowing into the body of water that exceeds its storage capacity is released into a storm sewer or watercourse.

Running Bond Course: A paver course or two where lengths abut against the edge restraint. Also known as a "sailor course."

Running or Stretcher Bond: A laying pattern with continuous joint lines in one direction and four pavers are staggered from one row to the next.

Rutting: Permanent deformation from repetitive traffic loading that exceeds the ability of the pavement structure to maintain its original profile.

Sand: Granular material passing the $^3/_8$ in. (5 mm) and retained on the No. 200 (0.075 mm) sieve, made from the natural erosion of rocks, and consisting of subangular or rounded particles. Sands made by crushing of coarse aggregates are called manufactured sands.

Sand Spreaders: Broomed attachments to motorized equipment used to efficiently spread joint sand across the surface of segmental concrete pavements.

Screed Board or Strike Board: A rigid, straight piece of wood or metal used to level bedding sand to proper grade by pulling across guides or rails set on the base course or edge restraints.

Screed Guides or Bars: Grade strips such as pipe that will guide the screed in producing the desired elevation of the bedding sand.

Screenings: A residual product not suitable for bedding sand. It is a by-product from the crushing of rock, boulders, cobble, gravel, blast-furnace slag or concrete. Most of the aggregate passes the No. 4 (4.75 mm) sieve; typically limestone or granite.

Sealer: A material usually applied as a liquid that is used to waterproof, enhance color, and in some cases reduce abrasion of interlocking concrete pavements.

Sediment: Soils transported and deposited by water, wind, ice or gravity.

Segmental Pavement: A pavement whose surface consists of discrete units typically made of concrete, clay, or stone.

Shrinkage: The reduction in volume in soil when moisture content is reduced.

Silt: Soil finer than 0.02 mm and coarser than 0.002 mm (0.5 mm and 0.005 mm in some cases).

Single-layer Machine: A machine that manufactures concrete paving units one layer at a time and places each layer consisting of a number of units on individual boards or pallets to cure prior to packaging into cubes for delivery to the site.

Skid Resistance: A measure of the frictional characteristics of a surface with respect to tires.

Slip Resistance: Resistance against pedestrian slipping; defined as the ratio of a minimum tangential force necessary to initiate sliding of a pedestrian's shoe or related device over a surface. Non-mobility impaired persons require minimum coefficient of friction values ranging from 0.2-0.3. Wheelchair users require friction values ranging from 0.5-0.7. Crutch users and those with artificial limbs require values from 0.7 to 1.0. Clean concrete pavers generally have values exceeding 0.7.

Slump: A measure of consistency and water content of freshly mixed concrete. Slump is the subsidence measured from a specimen immediately after removal of a cone shaped mold. See ASTM C 143. Unlike ready-mixed concrete, pavers are zero slump concrete because of low water content. They are not tested for slump.

Soft Edges: A field of pavers with no visible edge restraint that meets grass or other vegetation, thus giving a soft appearance to the edge.

Soil Separation Fabric: A layer of fabric typically placed between the subgrade and the base to reduce rutting, also called a geotextile.

Soil Stabilization: Chemical or mechanical treatment designed to increase or maintain the stability of a mass of soil or otherwise to improve its engineering properties. Lime, fly ash or cement are typical chemical stabilization materials. Geotextiles and geogrids are typical mechanical materials for soil stabilization.

Soldier Course: A paver course where widths abut against the edge restraint.

Solid Color Paver: A paver with one color created by adding iron oxide, metal oxide, or other mixed metal oxide pigment to the concrete mix.

Spacer Bars, Spacers or Nibs: Small protrusions on each side of the paver (typically 1.5 to 2 mm) that maintain a minimum space so sand can fill into the joints. Spacer bars help prevent edge chipping and spalling. Some spacer bars stop short of the top surface, and are known as "blind spacers." They cannot be seen once the pavers have been installed.

Spall: A fragment, usually in the shape of a flake, detached from the edge or surface of a paver by a blow or sudden force, the action of weather, or pressure from adjacent pavers.

Stabilized Base: An aggregate base with cement, asphalt or other material added to increase its structural capacity. The soil subgrade can be stabilized with cement, lime, fly ash or other materials.

Stack Bond: A laying pattern in which the joints in both directions are continuous.

Standing Screed: Aluminum screed with handles allowing one person to pull it across bedding sand while standing (compared to kneeling while screeding).

Storm Water Pollution Prevention Plans (SWPPP): A principal requirement of stormwater permits issued under NPDES that identifies all potential sources of pollution which may reasonably be expected to affect the quality of storm water discharges from the construction site. A SWPPP also describes practices to be used to reduce pollutants in storm water discharges from the construction site and assures compliance with the terms and conditions of the construction permit. SWPPP requirements vary from state to state. (from Construction Industry Compliance Assistance Center)

Strain: The change in length per unit of length in a given direction.

Stress: The force per unit area.

Structural Number (SN): The basis of the flexible pavement design method developed by the AASHTO. It is a dimensionless number expressing the relative strength of a pavement structure. The SN is calculated from an analysis of traffic, roadbed soil conditions, and environment. The SN equals the sum of layer coefficients, with each coefficient quantifying the material strength and thickness of each pavement layer.

Sub-base: The layer or layers of specified or selected material of designed thickness placed on a subgrade to support a base course. Aggregate sub-bases are typically made of stone pieces larger than that in bases.

Subgrade: The soil upon which the pavement structure and shoulders are constructed.

Sustainable Development: Development (including pavement) that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Tactile Pavers: A paver detectable by sight impaired persons due to change in color or texture from surrounding surfaces. Changes in texture are achieved with detectable warnings.

Tensile Strength: Maximum unit stress which a paver is capable of resisting under axial tensile loading, based on the cross-sectional area of the specimen before loading.

Textured or Architectural Finish: Paver surfaces altered by the manufacturing mold or mechanical means, such as shot blasting, bush hammering, tumbling, grinding, polishing, flame treating, or washing. The purpose of such treatments is often to simulate the appearance of stone.

Time of Concentration: The time required for water to follow from the most remote point of a watershed or catchment to an outlet.

Topsoil: Surface soil, usually containing organic matter.

Urban Heat Island: An urban area that, due to denuded landscape, impermeable surfaces, surfaces with low albedo, massive buildings, heat-generating cars and machines, and pollutants, is measurably hotter than surrounding rural areas.

Void Ratio: The volume of voids around the aggregate in an open-graded base divided by the volume of solids.

Water-Cement Ratio: The weight of water divided by the weight of cement in a concrete mixture. Concrete pavers typically have a water-cement ratio of 0.27 to 0.33, lower than ordinary concrete, which contributes to strength and durability.

Wearing course: Pavement surfacing consisting of segmental concrete pavements and joint sand on a sand bedding layer.

Wearing surface: The top surface that contacts traffic.

Weave or Parquet: A laying pattern where two or more pavers are placed side-by-side. Adjacent pavers are placed side-by-side, but turned 90° and alternated 90° throughout the pattern.

Zoning: Using different paver colors, textures, shapes, laying patterns, and surface elevations to delineate pedestrian and vehicular areas or districts.

References

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ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®

Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

TECH SPEC

NUMBER 2

Construction of Interlocking Concrete Pavements

Purpose

This technical bulletin gives construction guidelines to design professionals and contractors of interlocking concrete pavements. The bulletin reviews the steps in constructing an aggregate base, bedding sand and concrete pavers. This pavement structure is commonly used for pedestrian and vehicular applications. Pedestrian areas, driveways, and areas subject to limited vehicular use are paved with units 2 $^{3}/_{8}$ in. (60 mm) thick. Streets and industrial pavements should be paved with units at least 3 $^{1}/_{8}$ in. (80 mm) thick.

It is recommended that ICPI Certified Installers be utilized for the construction of interlocking concrete pavement. These individuals have attended training and have demonstrated their knowledge of the standards, materials and techniques specific to interlocking concrete pavement. ICPI maintains a list of Certified Installer on its web site at www.icpi.org .

Aggregate bases stabilized with asphalt or cement are recommended under very heavy loads, and over weak or saturated soil subgrades. These are sometimes used when adequate aggregates are not available or when a stabilized base is more economical than unstabilized aggregate. Refer to Tech Spec 4–Structural Design of Interlocking Concrete Pavement for Roads and Parking Lots when looking for additional information regarding the structural design of the base and subbase. Tech Spec 4 is based on the design methods detailed in ASCE 58-10 Structural Design of Interlocking Concrete Pavements for Municipal Streets and Roadways.

Concrete pavers made in the U.S. should meet or exceed the requirements established in the American Society for Testing and Materials (ASTM) C 936, Standard Specification for Solid Interlocking Concrete Paving Units. Requirements of this standard include a minimum average compressive strength of 8,000 psi (55 MPa), average absorption no greater than 5%, resistance to at least 50 freeze-thaw cycles with average material loss not exceeding 1%, and conformance to abrasion resistance tests.

Concrete pavers made in Canada are required to meet or exceed requirements set forth by the Canadian Standards Association CSA-A231.2 Precast Concrete Pavers. This standard requires a minimum average cube compressive strength of 7,250 psi (50 MPa) or 5,800 psi (40 MPa) at delivery. There should be no greater than 500 g/m^2 of material lost after 50 freeze thaw test cycles while immersed in water with a 3% saline solution.

Installation steps include job planning, layout, excavating and compacting the soil subgrade, applying geotextiles (optional), spreading and compacting the sub-base and/or base aggregates, constructing edge restraints, placing and screeding the bedding sand, and placing concrete pavers. For larger installations mechanical placement of pavers may be more economical. Refer to Tech Spec 11 –Mechanical Installation of Interlocking Concrete Pavements for additional information.

Job Planning

Prior to excavating, check with the local utility companies to ensure that digging does not damage underground pipes or wires. Many localities have one telephone number to call at least two days before excavation for marking utility line locations. Overhead clearances should be checked so that equipment does not interfere with wires. Site access by vehicles and equipment should be established so that the job can be built without delays.

Figure 1. Excavation of the soil subgrade.

Figure 2. Compacting the soil subgrade.

Figure 3. Application of the geotextile under aggregate base.

Layout

In preparing for excavation, the area to be removed should be marked with stakes. The stakes should be a slight distance away from the area to be removed so that they are not removed during excavation. The stakes should be marked to establish grades, or have string lines pulled and tied to them. Slopes should be a minimum of 1.5%. In the case of roads, the minimum longitudinal slope should be 1% with a minimum cross slope of 2%. Grade stakes should be checked periodically during the job to be sure that they have not been disturbed.

Excavating, Drainage and Compacting the Soil Subgrade

During and after excavation, the soil should be inspected for organic materials or large rocks. If organic materials, roots, debris, or rocks remain, they should be removed and replaced with clean, compacted backfill material. Free-standing water saturating the soil should be removed. After it is removed, low, wet areas can be stabilized with a layer of crushed stone and/or cement.

Typical 4 in. (100 mm) diameter perforated drainage pipes surrounded with minimum 3 in. (75 mm) of No. 57 or similar open-graded stone is wrapped in woven or non-woven geotextile as specified by the designer. The surface of the stone is even with the top of the compacted soil subgrade. The stone and geotextile pipe assembly is placed along the pavement perimeter to remove excess water in the subgrade soil and base. The perforated pipe should be sloped and directed to outlets at the sides or ends of the pavement. The pipe outlets should be covered with screens to prevent animal ingress. Drainage is recommended in clay soils or other slow draining soils subject to vehicular traffic. Soil subgrade drainage extends pavement performance to the extent that the small additional investment is returned many times in additional pavement service years.

Compaction of the soil subgrade is critical to the performance of interlocking concrete pavements. Adequate compaction will minimize settlement. Compaction should be at least 98% of standard Proctor density as specified in ASTM D 698. However, modified Proctor density (ASTM D 1557) is preferred, especially for areas under constant vehicular traffic. This compaction standard may not be achievable in extremely saturated or very fine soils. Stabilization of the soil subgrade may be necessary in these situations.

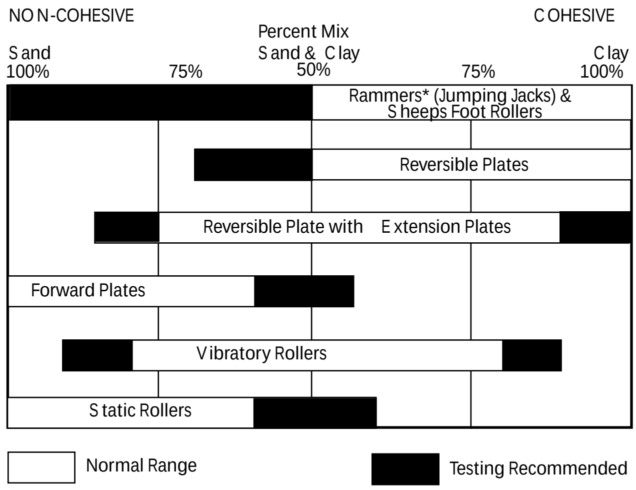
Compaction equipment varies with the type of subgrade soil. Manufacturers of compaction equipment can provide guidance on which machines should be applied to various types of soil. Table 1 gives general guidance on applying the right machines to various soil types.

Monitoring soil moisture content is important to reaching the compaction levels described above. Soil moisture and density measurements should be taken to control and verify the degree of compaction. The moisture content and compacted density of the subgrade soil should be checked for compliance to specifications before installing geotextiles.

Applying Geotextiles (Optional)

Geotextile fabric may be used in areas where soil remains saturated part of the year, where there is freeze and thaw, or over clay and moist silty subgrade soils. As a separation layer, they prevent soil from being pressed

Table 1. Guide to the Application of Compaction Equipment to Various Soils (Courtesy of Vibromax 2000 Co.)



*Rammers work very well in sand if confined, as around abutments, foundations, etc.

Table 2. Geotextile Requirements for Separation

Geotextile Class		Class I [a]		Class II [a]		Class III [a]	
Elongation	AST M D 4632	< 50%	> 50%	< 50%	> 50%	< 50%	> 50%
Grab Strength [b]	ASTM D 4632	315 lb [1400 N]	202 lb [900 N]	247 lb [1100 N]	157 lb [700 N]	180 lb [800 N]	112 lb [500 N]
Sewn Seam Strength [b,c]	ASTM D 4632	283 lb [1260 N]	182 lb [810 N]	223 lb [990 N]	142 lb [630 N]	162 lb [720 N]	101 lb [450 N]
Tear Strength [b]	ASTM D 4533	112 lb [500 N]	79 lb [350 N]	90 lb [400 N] [d]	56 lb [250 N]	67 lb [300 N]	40 lb [180 N]
Puncture Strength [b]	ASTM D 6241	618 lb [2750 N]	433 lb [1925 N]	495 lb [2200 N]	309 lb [1375 N]	371 lb [1650 N]	223 lb [990 N]
Permittivity [b,e]	ASTM D 4491	0.02 sec^{-1}					
Apparent Opening Size	ASTM D 4751	0.024 in [0.60 mm] maximum average roll value					
Ultraviolet Stability	ASTM D 4355	> 50% after 500 hr exposure					

[a] The severity of the installation conditions generally dictates the required geotextile class. Class I is the most severe and Class III is the least severe.
[b] All numeric values represent MARV in the weaker principal direction.
[c] When sewn seams are required.
[d] The required tear strength for woven monofiliment geotextiles if 250 N.
[e] Default Value. Permittivity of the geotextile should be greater than the soil.

into the aggregate base under loads, especially when saturated, thereby reducing the likelihood of rutting. When geotextiles are used they preserve the load bearing capacity of the base over a greater length of time than placement without them. Woven or non-woven fabric may be used under the base with a maximum apparent opening size of 0.60mm as testing using ASTM D 4751. Table 2 lists minumum requirements of geotextiles for soil separation. These requirements are taken from AASHTO M 288-06 Standard Specification for Geotextile Specification for Highway Applications . The minimum down slope overlap should be at least 12 in. (300 mm). Overlap requirements for low strength subgrades are detailed in Table 3.

When the fabric is placed in the excavated area, it should be turned up along the sides of the opening, covering the sides of the base layer. There should be no wrinkles on the bottom. When the aggregate is dumped on the fabric, the tires from trucks should be kept off the fabric to prevent wrinkling.

Spreading and Compacting the Subbase and/or Base Aggregates

Specifications typically used by cities, states, or provinces for aggregate base materials under flexible asphalt pavements are adequate for interlocking concrete pavements. If no specifications are available use the recommended grading for the aggregate base shown in Table 4. Spread and compact the base in 4 to 6 in. (100 to 150 mm) lifts. High force compaction equipment can compact thicker lifts. Consult with compaction equipment manufacturer for guidance. Frozen base material should not be installed, nor should material be placed over a frozen soil subgrade.

The thickness of the base is determined by traffic, soil type, subgrade soil drainage and moisture, and climate.

Table 3. Geotextile Overlap Requirements

Soil C BR	Overlap
> 3.0	1.0 ft [0.3 m] to 1.5 ft [0.45 m]
1.0 to 3.0	2.0 ft [0.6 m] to 3.0 ft [1.0 m]
0.5 to 1.0	3.0 ft [1.0 m] or sewn
< 0.5	Sewn
All roll ends	3.0 ft [1.0 m]

Table 4. Grading Reqirements for Dense Graded Material

Sieve Size (Square Openings)	Design Range[(a)] % Passing		Job Mix Tolerance % Passing	
	Bases	Subbases	Bases	Subbases
2 in. (50 mm)	100	100	–2	–3
1 1/2 in. (37.5 mm)	95-100	90-100	±5	±5
3/4 in. (19 mm)	70-92	—	±8	—
3/8 in. (9.5 mm)	50-70	—	±8	—
No. 4 (4.75 mm)	35-55	30-60	±8	±10
No. 30 (600 μm)	12-25	—	±5	—
No. 200 (75 μm)	0-8 [(b)]	0-12 [(b)]	±3	±5

(a) Job mix formula should be selected with due regard to availability of materials in the area of the project. Job mix tolerances may permit acceptance of test results outside the design range.

(b) Determine by wet sieving. Where frost and free moisture are indicative of site conditions, a lower percentage passing the No. 200 (75 μm) sieve shall be specified.

Note: ASTM D 2940 corresponds closely to this National Stone Association developed specification. While local or state highway specifications may be substituted for the design ranges above, the fraction finer than the No. 200 (75 μm) sieve should be maintained.

Figure 4. Base compaction with a vibratory roller.

Sidewalks, patios and pedestrian areas should have a minimum base thickness (after compaction) of 4 in. (100 mm) over well-drained soils. Residential driveways on well-drained soils should be at least 6 in. (150 mm) thick. In colder climates, continually wet or weak soils will require that bases be at least 2 to 4 in. (50 to 100 mm) thicker.

Local, state or provincial engineering standards for base thickness can be applied to streets constructed with interlocking concrete pavers. Non freeze-thaw areas with well-drained soils should have at least a 6 in. (150 mm) thick base. Minimum base thicknesses for residential streets are 8 to 10 in. (200 to 250 mm). Greater thicknesses are often used in regions with numerous freeze-thaw cycles, expansive soils, or very cold climates. A qualified civil engineer familiar with local soils and traffic conditions should be consulted to determine the appropriate base thickness for streets and heavy-duty, industrial pavements.

Many localities determine base thickness with the 1993 Guide for the Design of Pavement Structures published by the American Association of State Highway and Transportation Officials (AASHTO). The AASHTO procedure calculates the structural number (SN) of the strength coefficients of each base and pavement layer. The SN is determined by assessing the traffic loads, soils, and environmental factors (e.g., drainage, freeze-thaw). The layer coefficient recommended for $3^1/8$ in. (80 mm) thick pavers on 1 in. (25 mm) bedding sand is 0.44 per inch (25 mm), i.e., the SN = $4^1/8$ x 0.44 = 1.82. Base thicknesses can be readily determined by using the charts in ICPI Tech Spec 4, Structural Design of Interlocking Concrete Pavement for Roads and Parking Lots or ICPI Lockpave Software.

Like compaction of the soil subgrade, adequate compaction of the base is critical to minimizing settlement of interlocking concrete pavements. Special attention should be given to achieving compaction standards adjacent to edge restraints, catch basins and utility structures. When spread and compacted, the aggregate base should be at its optimum moisture. Bases for pedestrian areas and residential driveways should be compacted a minimum 98% of standard Proctor density. For vehicular areas, compaction should be at least 98% of modified Proctor density as determined by ASTM D 1557, or AASHTO T180. While the highest percentage compaction (100%) is preferred, it may not be achievable on weak or saturated soils. Density measurements of the compacted base should be made with a nuclear density gauge or other methods approved by the local, state or provincial transportation department. Unless otherwise specified, the compacted thickness of individual lifts and the final base should be $+^3/_4$ in. to $-\ ^1/2$ in. (+19 mm to −13 mm). Maintaining consistent lift thickness during compaction will help achieve consistent density. Variation in final base surface elevations should not exceed $\pm^3/8$ in. (± 10 mm) when tested with a 10 ft. (3 m) straightedge.

The finished surface of a compacted aggregate base should not allow bedding sand to migrate into it. If the surface will allow ingress of bedding sand, a choke course of fine material can be spread and compacted into the surface, or a bitumen tack coat can be applied. The surface of the base course and its perimeter around the edge restraints should be inspected for areas that might allow sand to migrate after installation. Such locations can be joints in curbs, around utility structures or catch basins. These areas should be covered with a geotextile fabric to prevent loss of the bedding sand.

Constructing Edge Restraints

Edge restraints are a key part of interlocking concrete pavements. By providing lateral resistance to loads, they maintain continuity and interlock among the paving units. Aluminum, steel, plastic, or concrete are typical edge restraints. Consult ICPI Tech Spec 3 on edge restraints for recommendations on applications and construction.

Edge restraints must be set at the correct level, especially if the tops of the restraints are used for screeding the bedding sand. Their elevations should be checked prior to placing the sand and pavers. Edge restraints are typically installed before the bedding sand and pavers are laid. However, some restraints can be secured into the base as the laying progresses.

Figure 5. Density testing of the aggregate base with a nuclear density gauge.

Figure 6. Screeding the bedding sand.

Placing and Screeding the Bedding Sand

Bedding sand under concrete pavers should conform to ASTM C 33 or CSA A23.1. This material is often called concrete sand. Masonry sand for mortar should never be used for bedding, nor should limestone screenings or stone dust. The bedding sand should have symmetrical particles, generally sharp, washed, with no foreign material. Waste screenings or stone dust should not be used, as they often do not compact uniformly and can inhibit lateral drainage of moisture in the bedding layer. ICPI Tech Spec 17—Bedding Sand Selection for Interlocking Concrete Pavements in Vehicular Applications provides additional guidance on selecting bedding sand.

Bedding sand should be spread and screeded to a nominal 1 in. (25 mm) thickness. Frozen or saturated sand should not be installed. If there is an uneven base (due to inconsistent compaction or improper grading), the bedding sand should not be used to compensate for it. Over time, unevenness in the bedding sand will reflect through to the surface. Uneven areas on the base surface must be made even prior to placing the bedding sand.

Once the base is complete, screed pipes or rails are placed on it and the bedding sand spread over them. The sand is screeded or smoothed across the pipes with a straight and true strike board. Screed pipes are removed and the resulting void filled with bedding sand. After the sand is screeded it should not be disturbed. Sufficient sand is placed and screeded to stay ahead of the placed pavers. Powered screeding machines that roll on rails and asphalt spreading machines adapted for screeding sand have been successfully used on larger installations to increase productivity.

Placing the Concrete Pavers

Concrete pavers can be placed in many patterns depending on the shapes. Herringbone patterns (45 or 90 degree) are recommended in all street applications, as these interlocking patterns provide the maximum load bearing support, and resist creep from starting, braking and turning tires. Chalk lines snapped on the bedding sand or string lines pulled across the surface of the pavers are used as a guide to maintain straight joint lines. Buildings, concrete collars, inlets, etc., are generally not straight and should not be used for establishing straight joint lines.

Joint widths between the pavers should be consistent and be between $^{1}/_{16}$ and $^{3}/_{16}$ in. (2 and 5 mm). Some pavers are made with spacer bars on their sides. These maintain a minimum joint width, allowing the sand to enter between each unit. Pavers without spacers are generally not placed snug against each other since string lines guide consistent joint spacing.

Cut pavers should be used to fill gaps along the edge of the pavement. Pavers are cut with a double bladed splitter or a masonry saw. A saw gives a smooth cut. Gaps greater than $^{3}/_{8}$ in. (10 mm) should be filled with cut pavers. For street applications do not cut paver to less than $^{1}/_{3}$ their original size. Instead fill void with two cut pavers.

After an area of pavers is placed, it should be compacted with a vibrating plate compactor, which should be capable of exerting a minimum of 5,000 lbs. (22 kN) of centrifugal compaction force and operate at 75-90 hertz. At least two passes should be made across the pavers to seat the pavers in the bedding sand and force it into the joints at the bottom of the pavers.

Dry joint sand is swept into the joints and the pavers compacted again until the joints are full. This may require two or three passes of the plate compactor. If the sand is wet, it should be spread to dry on the pavers before being swept and compacted into the joints. Joint sand may be finer than the bedding sand to facilitate filling of the joints. Bedding sand also can be used to fill the joints, but it may require extra effort in sweeping and compacting. Compaction should be within 6 ft (2 m) of an unrestrained edge or laying face. All pavers within 6 ft (2 m) of the laying face should have the joints filled and be compacted at the end of each day. Excess bed-

Figure 7. Placing the concrete pavers.

Figure 8. Saw cutting pavers.

Figure 9. Compacting the pavers and bedding sand.

Figure 10. Spreading and sweeping joint sand.

Figure 11. Vibrating sand into the joints.

Figure 12. Excess sand swept from the finished surface will make the pavement ready for traffic.

ding sand is then removed. The remaining uncompacted edge can be covered with a waterproof covering if there is a threat of rain. This will prevent saturation of the bedding sand, minimizing removal and replacement of the bedding sand and pavers.

Final surface elevations should not vary more than $\pm^3/_8$ in. ($\pm$10 mm) under a 10 ft (3 m) straightedge, unless otherwise specified. Bond or joint lines should not vary $\pm^1/_2$ in. (13 mm) over 50 ft (15 m) from taut string lines. The top of the pavers should be $^1/_8$ to $^3/_8$ in. (3 to 10 mm) above adjacent catch basins, utility covers, or drain channels, with the exception of areas required to meet ADA design guideline tolerances. The top of the installed pavers may be $^1/_8$ to $^1/_4$ in. (3 to 6 mm) above the final elevations to compensate for possible minor settling. A small amount of settling is typical of all flexible pavements. Optional sealers or joint sand stabilizers may be applied. See ICPI *Tech Spec 5–Cleaning, Sealing and Joint Sand Stabilization of Interlocking Concrete Pavement* for further guidance.

ICPI *Tech Spec 9–A Guide Specification for the Construction of Interlocking Concrete Pavement* helps translate construction methods and procedures described here into a construction document. Tech Spec 9 provides a template for developing project-specific materials and installation specifications for the bedding and joint sand, plus the concrete pavers. Additional guide specifications and detail drawings for varioius applications are available at www.icpi.org as well as ICPI Tech Specs. Other ICPI Tech Specs and technical manuals should be referenced for information on design, detailing, construction and maintenance.

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American Association of State Highway and Transportation Officials, *Standard Specification for Geotextile Specification for Highway Applications M288-06*, Washington, D.C., 2006

Interlocking Concrete Pavement Institute, *Concrete Paver Installer Course Handbook* Eighth Edition, Washington D.C., October 2011.

National Stone Association, *Flexible Pavement Design Guide for Roads and Streets.* Fourth Edition, Washington, D.C., January 1985.

National Stone Association, *Stone Base Construction Handbook,* Second Edition, Washington, D.C., September 1988.

Figures 1,2, 6, 7, 9, 10, 12 are courtesy of the Waterways Experiment Station, U.S. Army Corps of Engineers. Figure 5 is courtesy of the Portland Cement Association.

ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®

Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

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TECH SPEC

NUMBER 3

Edge Restraints For Interlocking Concrete Pavements

Introduction

Edge restraints are an essential component of interlocking concrete pavements. Restraints hold the pavers tightly together, enabling consistent interlock of the units across the entire pavement. They prevent spreading of the pavers from horizontal forces from traffic. Edge restraints are designed to remain stationary while receiving impacts during installation, from vehicles and from freeze-thaw cycles.

The following is a discussion of methods of restraining concrete pavers placed on bedding sand and installed on a base. This is the prevailing method of construction. Edge restraints are needed for concrete pavers joined to a rigid base with bitumen adhesive.

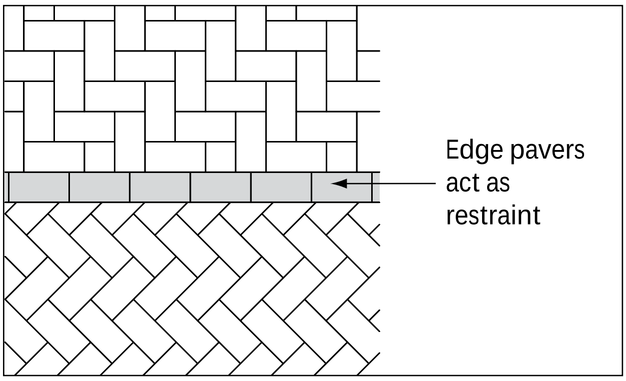


Figure 1. Change in laying pattern direction.

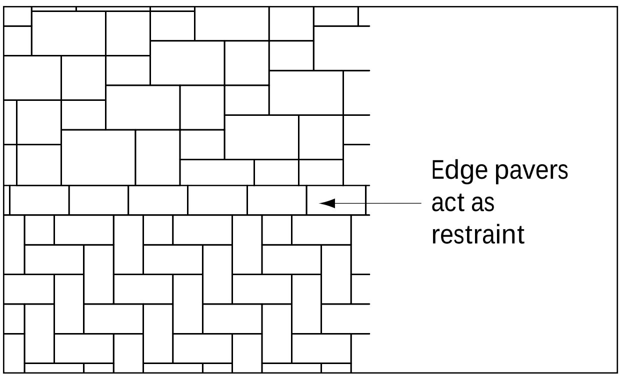


Figure 2. Change in paver shape.

Design Considerations

Restraints are required along the perimeter of interlocking concrete pavements or where there is a change in the pavement material. For example, when a laying pattern changes direction, there may be a need for an edge paver to act as a restraint (Figure 1). When a paver shape changes within an area of paver, the edge paver at the end of each pattern can serve as a restraint (Figure 2). Vertical walls of buildings can also provide a suitable restraint.

Some edge restraints require spiking to an aggregate base. The rule of thumb is the base should extend beyond the restraint at least the same dimension as the thickness of the base material. For example, a 6 in. (150 mm) thick base should extend at least 6 in. (150 mm) beyond the spikes in the restraints. This contributes stability to the restraint especially in soils subject to heaving. Soil backfill is never a suitable edge restraint and edge restraints should never be installed on top of the bedding sand.

If there is a possibility of sand loss from beneath the pavers or between the joints of the edge restraints, geotextile (filter cloth) is recommended to prevent its migration. A 12 in. (0.3 m) wide strip can be applied along the base and turned up along the sides of the restraints. Filter cloth generally is not required across the entire surface of an aggregate base, nor should it be placed on top of the bedding sand.

Types of Edge Restraints

Table 1 shows the types of edge restraints and their application. There are two general types of edge restraints. Those made elsewhere and installed at the site include precast concrete, plastic, cut stone, aluminum and steel. Restraints formed on-site are made of poured in place concrete. Regardless of the material the edge restraint is made of, it should have a smooth vertical surface that will allow the side of the pavers to be in full contact with it.

	Poured Concrete and Walls	Precast Concrete and Cut Stone	Plastic and Aluminum	Troweled and Submerged Concrete
Sidewalks—no vehicular traffic	✓	✓	✓	✓[1]
Plazas—no vehicular traffic	✓	✓	✓	✓[1]
Residential driveways	✓	✓	✓	✓[1]
Commercial/Industrial driveways	✓	✓	✓[2]	
Parking lots	✓	✓	✓[2]	
Crosswalks in asphalt or concrete streets	✓	✓		
Streets—all types	✓	✓		
Utility covers	✓	✓		
Gas stations	✓	✓		
Industrial flooring	✓			
Trucking terminals	✓			
[1]not appropriate for areas with significant freeze thaw cycles [2]only products designed for heavy duty applications				

Table 1. Application guide for edge restraints

Manufactured Edge Restraints

Full depth precast concrete or cut stone edging generally extends the depth of the base material. They can be set on compacted aggregate or concrete backfill (Figure 3).

Partial depth precast concrete edge restraints may be used for residential and light duty commercial applications. (Figure 4). These precast units are anchored on a compacted aggregate base with steel spikes. The spikes are typically 3/8 in. (10 mm) diameter. Depending on the design, the top of the concrete edge can be hidden or exposed.

Plastic edging installs quickly and will not rust or rot. Plastic edging should be specifically designed for use with pavers. It can be used with light duty residential and commercial applications, depending on the design. It should be firmly anchored into the compacted aggregate base course with spikes (See Figure 6). The spikes should penetrate well into the aggregate base. Spikes do not need to penetrate the bottom of the base. Consult the manufacturer's literature for the recommended spacing of the spikes. Edging for planting beds and flower gardens is not an acceptable restraint for interlocking concrete pavements.

Aluminum and steel edging should be selected to provide a smooth vertical surface against the pavers. L-shaped edging provides additional stability. Stakes or spikes fastened to the edging should be below the pavers or on the outside of the restraints. Steel should be painted or galvanized so that rust does not stain the pavers. Consult manufacturer's literature for recommended spacing of the spikes. Spikes to secure steel and aluminum edging should extend well into the base course (Figure 5). Like plastic edging, spikes used for aluminum or steel edging should never be placed into the soil. Aluminum and steel edgings are manufactured in different thicknesses. The thickest edging is recommended when pavers are subjected to vehicular traffic.

Timber is not recommended for an edge restraint because it warps and eventually rots.

Elevations should be set accurately for restraints that rest on the base. For example, 2 3/8 in. (60 mm) thick pavers with 1 in. (25 mm) of bedding sand would have a base elevation set 3 in. (75 mm) below that of the finish elevation of the pavers. This allows 1/4 in. (6 mm) settlement from compaction and 1/8 in. (3 mm) for minor settling over time.

Restraints Formed On-site

Poured in place concrete curbs or combination curb and gutters required by municipalities make suitable restraints for pavers. Exposed concrete edges should have a 1/4 in. to 3/8 (3 to 10 mm) radius edge to reduce the likelihood of chipping. As with precast, the side of the curbs should extend well below the sand bedding course (Figure 7). Complete compaction of the soil subgrade and base next to these curbs is essential to preventing settlement of the pavers.

Troweled concrete from a bag mix or batched on-site can be applied without forms against edge pavers and on the compacted base. When mixed on-site the aggregate (sand and crushed stone)-cement ratio should be at least 5 to 1. If the top of the concrete edge is recessed and slopes away from the pavers, grass can grow next to them (Figure 8). The depth below the surface of the pavers must be sufficient to prevent the concrete from becoming a heat sink that dries the grass and topsoil. This edge restraint is suitable for pavers subjected to pedestrian traffic and for residential driveways. Troweled edges should be at least 6 in. (150 mm) wide and of sufficient thickness to cover at

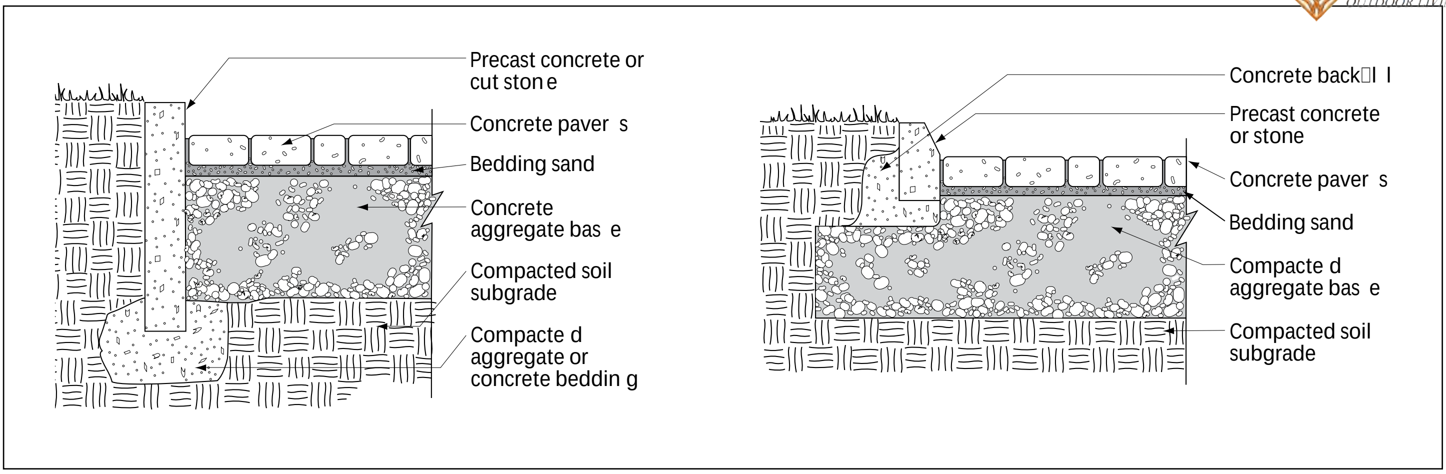


Figure 3. Precast concrete/cut stone.

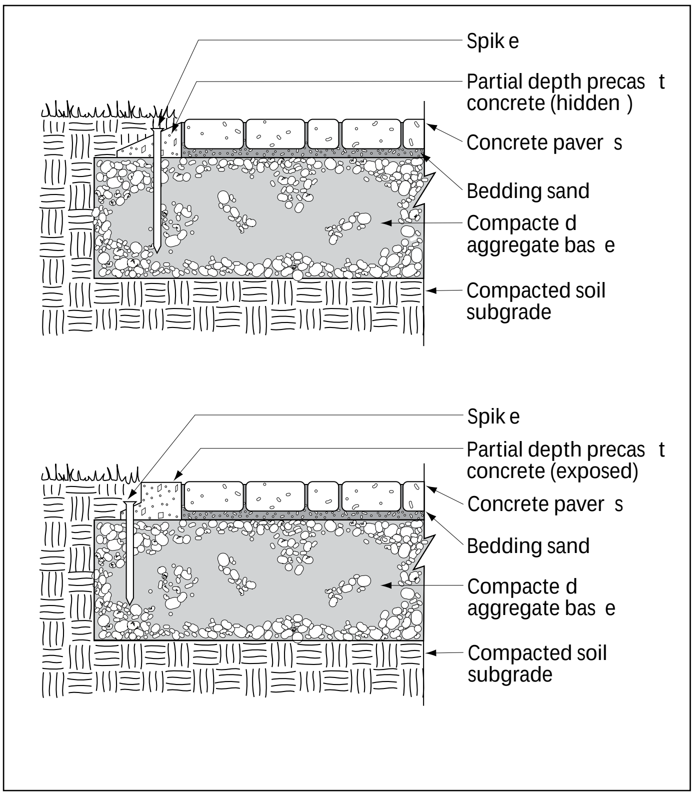


Figure 4. Partial depth precast concrete edge.

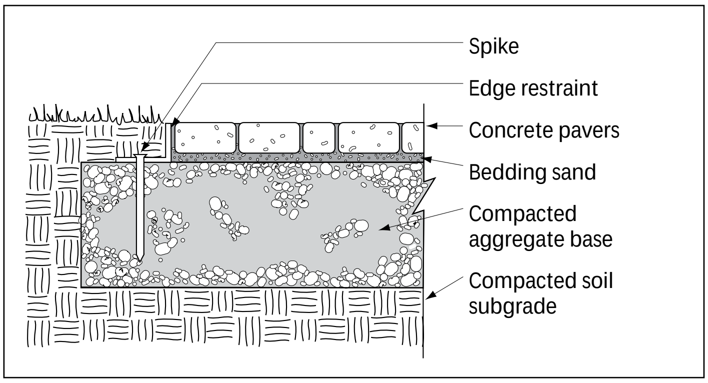


Figure 5. Aluminum and steel edging.

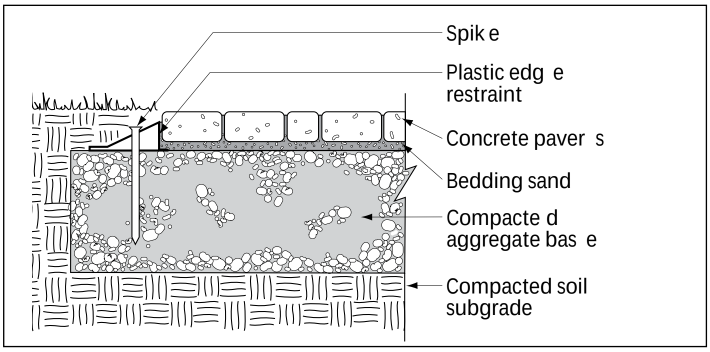


Figure 6. Plastic edge restraint.

least two-thirds of the side of the edge pavers, bedding sand layer, and a minimum of 2 in. (50 mm) into the base. Steel reinforcing can be placed in the concrete to increase service life.

Compacting units against troweled concrete should be done after the concrete has set. Care should be taken to ensure that the plate compactor does not crack the concrete edge or loosen pavers embedded in it. If the concrete is left to cure for a few days prior to compacting the pavers, the edges should be covered with plastic sheeting to prevent water from settling the uncompacted bedding sand. If water is allowed to enter bedding sand of any installation, it will be difficult to compact the pavers into it. The pavers will need to be removed, the saturated bedding sand removed, unsaturated sand installed, and the pavers replaced and compacted.

Troweled concrete edges are not recommended in freezing climates as they may crack and be an ongoing maintenance problem.

A concrete curb or edge that is “submerged” or hidden can be used to restrain concrete pavers. See Figure 9. The top surface of the concrete edge has pavers mortared to it. Acrylic fortified mortar is recommended and pavers exposed to freeze-thaw and deicing salts should be applied with high-strength epoxy mortar materials. The minimum cross section dimensions of the curb should be 8 in. x 8 in. (200 mm x 200 mm). These dimensions apply to residential driveways and low volume streets. Larger sized curbs will be required in higher traffic areas or for support over weak soil. The concrete edge may require a layer of compacted aggregate base as a foundation. The width of concrete

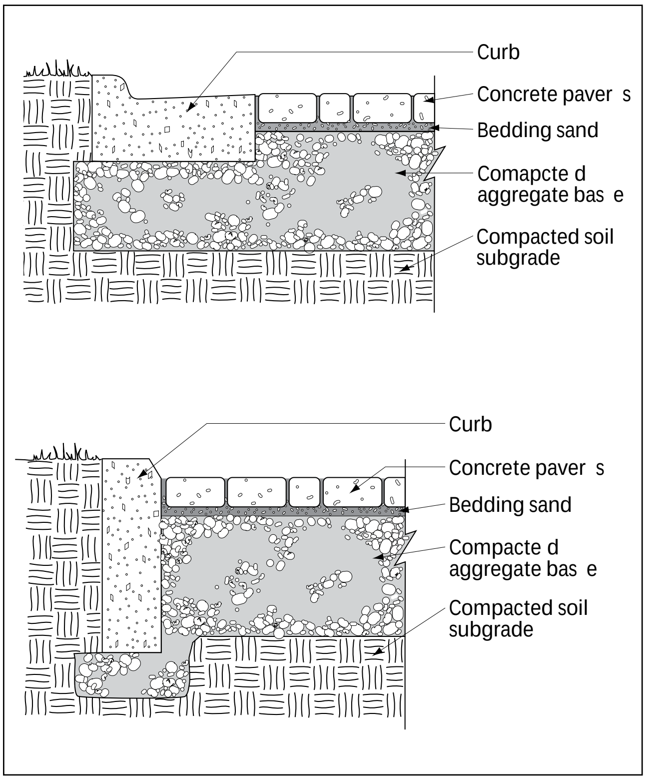


Figure 7. Poured in place concrete curbs.

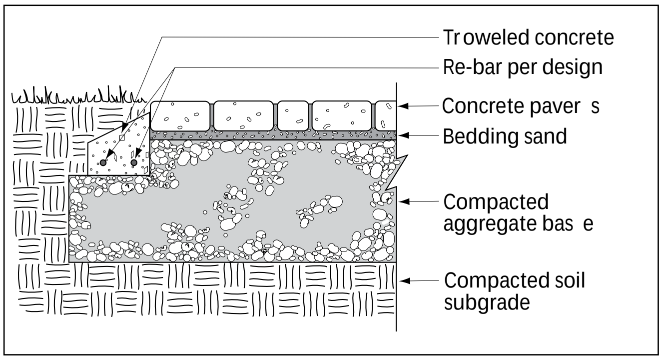


Figure 8. Troweled concrete edges.

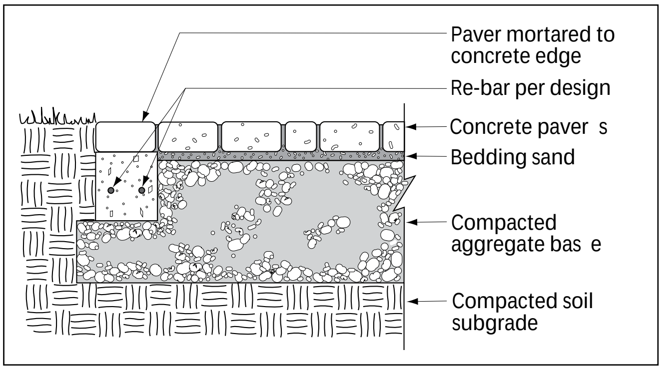


Figure 9. Submerged concrete edge.

will need to be equal to the width of whole pavers mortared to it. This detail should not be used in heavy traffic areas such as major urban streets with regular truck or bus traffic.

Other Design Considerations

Paver sidewalks against curbs —Joints throughout poured in place or precast concrete curbs should allow excess water to drain through joints in them without loss of bedding sand. If there are no joints, weep holes placed at regular intervals will prevent the sand from migrating. A 1 in. (25 mm) diameter hole every 15 ft. (5m) is a recommended spacing. The bottom of the holes should be at the same elevation as the top of the base. They should be covered with filter cloth to prevent loss of bedding sand.

Joints in curbs often have expansion material in them. This material tends to shrink and decompose. Filter cloth placed over these joints will prevent the sand from migrating. Expansion joint materials are not required between the pavers and the curb.

Utility covers in streets and walks (e.g., sewers, water and gas valves, telephone, electrical,) should have concrete collars around them. Consistent compaction of aggregate base against cast iron collars is difficult, so a concrete collar placed around them after base compaction reduces the potential for settlement. Concrete collars should be 1/4 in. (6 mm) below the pavers to prevent catching snowplow blades (Figure 10). Drain and catch basin inlets should have a concrete collar around them if they are not encased in concrete.

When overlaying existing asphalt or concrete streets with pavers and bedding sand, utility covers

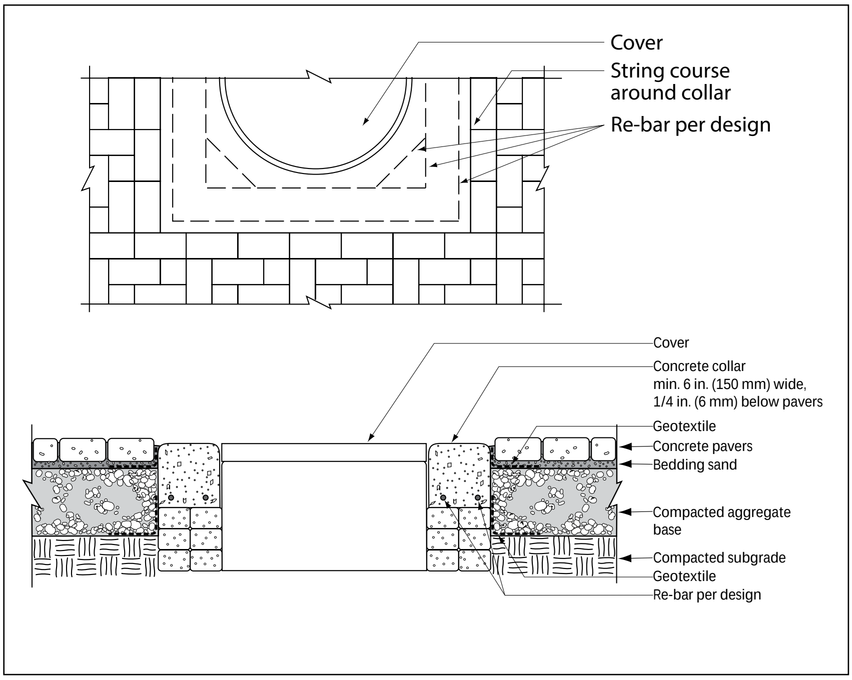


Figure 10. Utility cover.

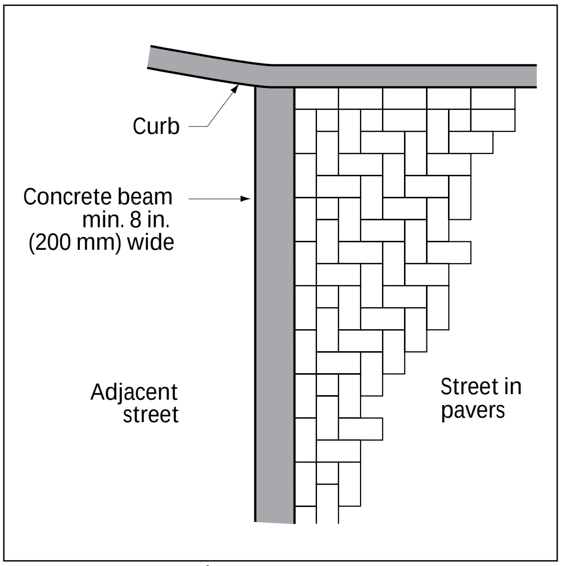


Figure 11. Concrete beam.

are raised and new concrete collars poured around them. When raised, the covers and frames should be inspected for cracks that might allow migration of sand. Cracks should be repaired. Filter cloth should be applied on the base around the concrete collar, turned up against the collar to prevent sand loss.

Catch basins—During the early life of interlocking concrete pavement, there may be a need to drain excess water from the bedding sand. Drain holes may be drilled or cast into the sides of catch basins to facilitate this. The bottom of the holes are at the same elevation as the bottom of the base. Space holes at least 12 in. (0.3 m) apart, and make 1 in. (25 mm) in diameter. The holes should be covered with filter cloth to prevent loss of bedding sand. This drainage detail can prevent pumping and loss of bedding sand around the catch basin.

Crosswalks—Pavers in a crosswalk or abutting another pavement can be placed against a concrete beam (Figure 11), or a beam and slab base combination for pavements subject to heavy vehicular traffic (Figure 12). The beam prevents horizontal creep of the pavers due to braking and turning tires.

Stresses from wheel loads are concentrated at the edge of the pavers and base. They do not interlock and transfer loads to the concrete beam, pavement surfaces or base. Premature rutting can occur at the junction of these materials and can be avoided by using a cement-treated or concrete base. These types of bases are recommended in heavy traffic areas such as thoroughfares. For applications with over 1.5 million ESAL (18-kip (80 kN) equivalent single axle load) design for life or Caltrans Traffic Index > 9.4, refer to ICPI Tech Spec 17—Bedding Sand Selection for Interlocking Concrete Pavements in Vehicular Applications for test methods and acceptance criteria for evaluating bedding sand hardness and degradation.

When cement-treated or concrete bases are used under a crosswalk or plaza, drain holes should be drilled or cast at the lowest elevation(s) (Figure 12). These should be a minimum diameter of 2 in. (50 mm), filled with open-graded aggregate and covered with filter cloth. This drain detail can be applied in areas where the water table is over 3 ft (0.9 m) deep. Otherwise, the drain should be enclosed in a pipe and directed to a sewer or other appropriate outlet.

Drain holes may not be an option due to the expense of directing them to distant storm sewers or catch basins. In addition, local bedding sand may not have sufficient durability after degradation testing or other tests to assess its durability. It may not be able to withstand degradation from repeated, channelized wheel loads without rutting. In such cases, the designer may consider using a sand-bitumen setting bed on a concrete base. This bedding layer is typically ¾ to 1 in. (20 to 25 mm) thick consisting of asphalt and bedding sand. Once the hot material is screeded and compacted on a concrete base, it cools and a thin coat of a neoprene-asphalt adhesive is applied to the bedding. The pavers are placed firmly into the adhesive and rolled with a small hand roller or compactor with rollers to bed them into it. The joints are filled with sand. The joint sand is often stabilized with cement or a joint sand stabilizer. See ICPI Tech Spec 5—Cleaning, Sealing

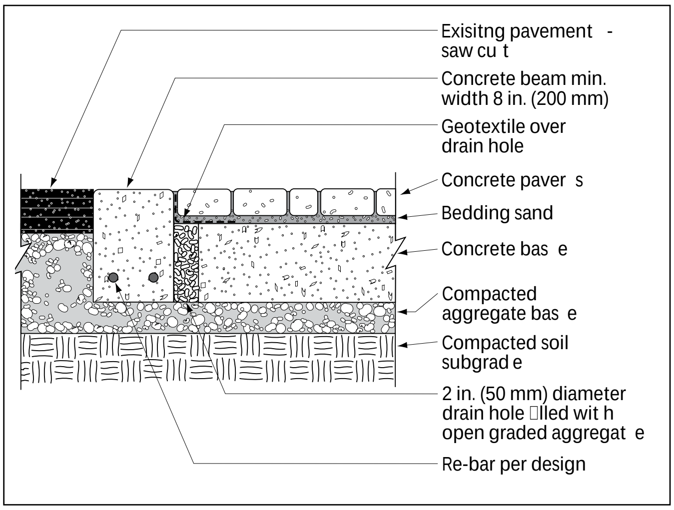


Figure 12. Crosswalk with concrete base.

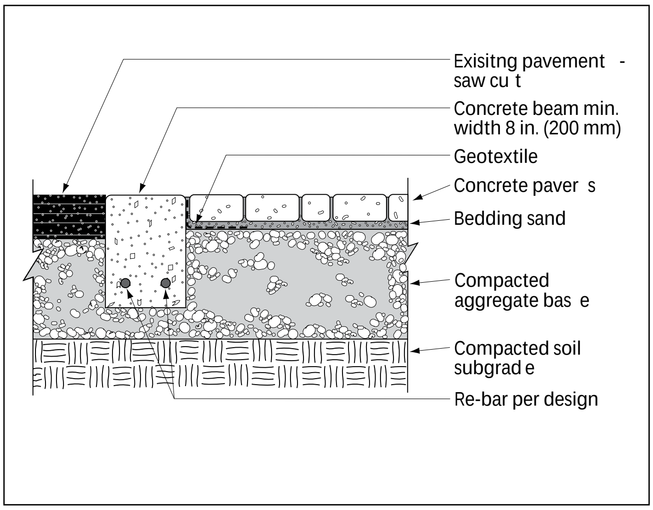


Figure 13. Crosswalk in existing asphalt pavement.

and Joint Sand Stabilization of Interlocking Concrete Pavements for more information.

Figure 13 shows a crosswalk section through an existing saw-cut asphalt pavement. This application is appropriate for residential streets with minimal truck traffic. The existing asphalt should be in good condition with no cracks, raveling or delamination. The concrete beam is constructed on compacted dense graded aggregate and formed directly against the saw cut asphalt. Place re-bar as required by design. A strip of geotextile 12 in. (300 mm) wide placed along the base and the concrete beam can help prevent bedding sand from migrating. The finish elevation of the pavers should be $^{1}/_{4}$ in. (6 mm) above the top of the concrete beam to allow for minor settlement of the pavers and promote surface drainage.

Gutters and drainage channels made with pavers should be embedded in fortified mortar, a bitumen-neoprene bed, or polymer adhesive. The mortar mix should resist degradation from freeze-thaw and salt. Care must be taken in applying the mortar as it can stain the pavers.

Sand is not recommended in joints subject to channelized water flow. The sand will eventually wash out of the paver joints and weaken the pavement. Cement can be dry mixed with joint sand (3% to 4% by weight) to reduce washout in areas subject to channelized drainage or from water draining from roof eaves without gutters. Care must be taken to not let the cement stain the pavers when sweeping the sand and cement into the joints. A more effective method is use of joint sand stabilization materials. Stabilizers are recommended to reduce risk of wash out on steep slopes. See ICPI Tech Spec 5—Cleaning, Sealing and Joint Sand Stabilization of Interlocking Concrete Pavement for more information.

Elevations—When edge restraints are installed before placing the bedding sand and pavers, the restraints are sometimes used to control thickness when screeding the bedding sand. Elevations for screeding should be set from the restraints after their elevations have been verified.

Attention should be given to the elevation of the pavers next to the restraints. Sand-set pavers may require a finish elevation of $^{1}/_{4}$ in. (6 mm) above the top of the restraint. This allows for minor settlement of the pavers and surface drainage. Bitumen-set, mortared or adhesive-set pavers should be at least $^{1}/_{8}$ in. (3 mm) above adjacent curbs or other edge restraints.

Construction tips—Some restraints allow the pavers and bedding sand to be installed prior to placing the edge materials. The field of pavers is extended past the planned edge location. The pavers are marked with a chalk line, or by using the edge material itself as large ruler for marking (Figure 14). The marked pavers are then cut with a powered saw or mechanical splitter. The unused ends and excess bedding sand are removed up to the cut pavers, and the edge restraints installed. This technique is particularly useful for creating curved edges.

When the gap between the pavers and the restraint exceeds $^{3}/_{8}$ in. (10 mm), the space should be filled with cut pavers. Cut pavers exposed to vehicular traffic should be no smaller than one-third of the whole paver. The paving pattern may require shifting to accommodate cut pavers. Stability of cut edge pavers exposed to tire traffic is increased when a running course (string or sailor) of whole pavers is placed between the edge restraint or concrete collar and the cut edge pavers. Pavers are cut to fit against this edge course (see Figures 10 and 11). Other shapes include edge pavers that make a straight, flush edge. This detail can reduce incidental chipping of the cut pavers.

In some situations, site fixtures can be installed after the pavers are placed and vibrated and the joints filled with sand. Openings can be saw cut, the edge restraints placed, and the tree grates, bollards, or other fixtures installed.

Figure 14. Saw cutting marked pavers on bedding sand. The cut pavers are carefully removed and edging is placed against the pavers and spiked in place.

ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®
Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

ICPI INTERLOCKING CONCRETE PAVEMENT INSTITUTE

TECH SPEC

NUMBER 4

Structural Design of Interlocking Concrete Pavement for Roads and Parking Lots

History

The concept of interlocking concrete pavement dates back to the roads of the Roman Empire. See Figure 1. They were constructed with tightly-fitted stone paving units set on a compacted aggregate base. The modern version, concrete pavers, is manufactured with close tolerances to help ensure interlock. Concrete pavers were developed in the Netherlands in the late 1940s as a replacement for clay brick streets. A strong, millennia-old tradition of segmental paving in Europe enabled interlocking concrete pavement to spread quickly. It is now established as a conventional means of paving there with some four billion ft^2 (400 million m^2) installed annually. Concrete pavers came to North America in the 1970s. They have been used successfully in numerous residential, commercial, municipal, port and airport applications. This *Tech Spec* covers the structural design of interlocking concrete pavement over an aggregate base as well as asphalt and cement stabilized bases, asphalt concrete and Portland cement concrete bases.

Figure 1. The Roman Appian Way: early interlocking pavement

Advantages

The paving system offers the advantages of concrete materials and flexible asphalt pavement. As high-strength concrete, the units have high resistance to freeze-thaw cycles and deicing salts, high abrasion and skid resistance, no damage from petroleum products or indentations from high temperatures. Once installed, there is no waiting time for curing. The pavement is immediately ready for traffic. Cracking and degradation of the surface is minimized because of the numerous joints (and sand in them) which act as a means for load transfer without damaging the pavement surface. Like flexible asphalt pavement, an aggregate base accommodates minor settlement without surface cracking. An aggregate base facilitates fast construction, as well as access to underground utilities. Mechanical installation of concrete pavers can further shorten construction time and costs. Pavement reinstatement is enhanced by reusable paving units, thereby minimizing costs and reducing waste.

The Principle of Interlock

Interlock is the inability of a paver to move independently from its neighbors. It is critical to the structural performance of interlocking concrete pavement. When considering design and construction, three types of interlock must be achieved: vertical, rotational, and horizontal interlock. These are illustrated in Figure 2. Vertical interlock is achieved by the shear transfer of loads to surrounding units through sand in the joints. Rotational interlock is maintained by the pavers being of sufficient thickness, meeting recommended plan and aspect ratios, placed closely together, and restrained by a curb from lateral forces of vehicle tires. Rotational interlock can be further enhanced if there is a slight crown to the pavement cross section. Besides facilitating drainage, the crown enables the pavement surface to stiffen and further lock up as the pavement undergoes vehicle loading due to traffic.

Horizontal interlock is primarily achieved through the use of laying patterns that disperse forces from braking, turning and accelerating vehicles. Herringbone patterns are the most effective laying patterns for maintaining interlock (see Figure 3). Testing has shown that these patterns of

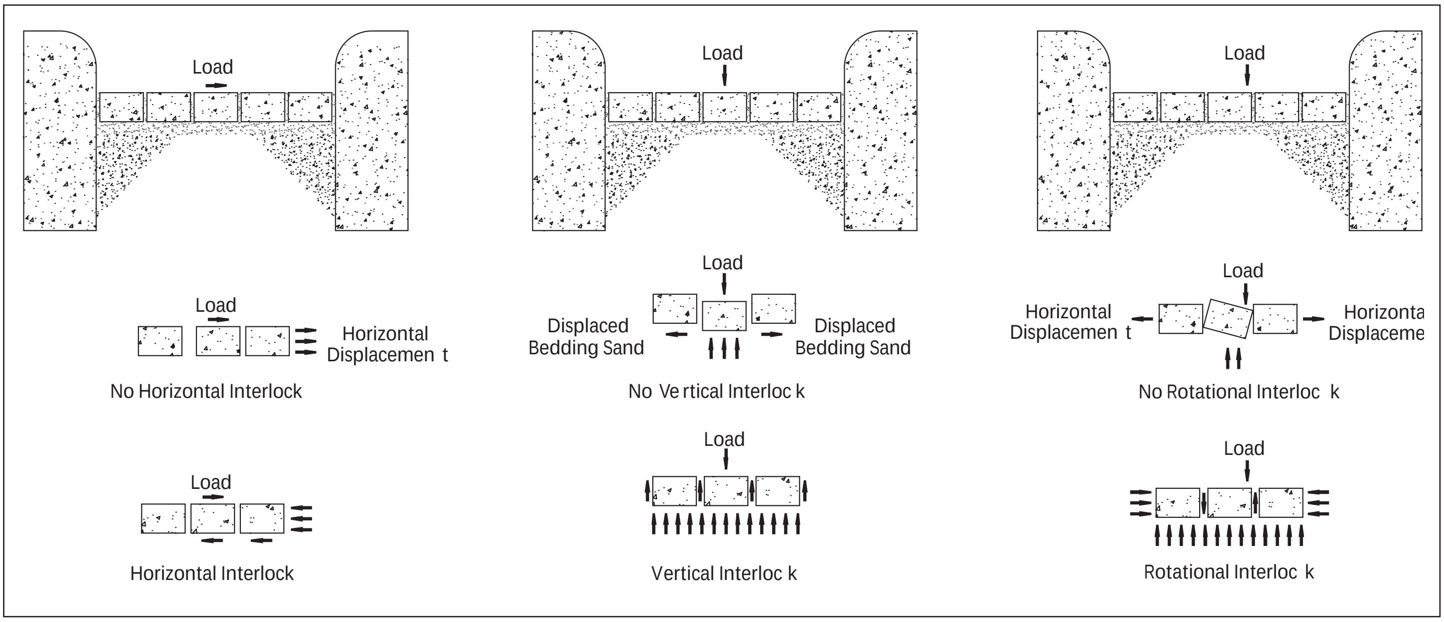


Figure 2. Types of interlock: horizontal, vertical, rotational

fer greater structural capacity and resistance to lateral movement than other laying patterns (Shackel 1979 and 1980). Therefore, herringbone patterns are recommended in areas subject to vehicular traffic. See Figure 3. Stable edge restraints such as curbs are essential. They provide better horizontal interlock among the units while they are subject to repeated lateral loads from vehicle tires. ICPI Tech Spec 3, Edge Restraints for Interlocking Concrete Pavements offers guidance on the selection and detailing of edge restraints for a range of applications.

Typical Pavement Design and Construction

Flexible pavement design uses untreated aggregate, cement- or asphalt-treated aggregates or asphalt under the concrete pavers and bedding layer. Flexible pavements distribute the loads to the subgrade by spreading them through consecutively weaker layers to the compacted soil subgrade. Such pavements are often preferred in colder climates because they can offer greater protection against frost heaving. Figure 4 illustrates typical schematic cross sections for interlocking concrete pavement designed as a flexible system. Both the base and subbase are compacted aggregate. Some road agencies may use open-graded drainage bases as well. Many pavements for city and residential uses do not require an aggregate subbase except for very heavy use or over a weak soil subgrade. In these situations it may be more economical to use asphalt or cement-stabilized base layers. They are often placed over a subbase layer of unbound compacted aggregate.

Construction is covered in ICPI Tech Spec 2, Construction of Interlocking Concrete Pavement. The steps for preparing the soil subgrade and base materials are similar to those required for flexible asphalt pavements. After the base surface is built to specified elevations and surface tolerances, bedding sand is screeded in an even layer, typically 1 in. (25 mm) thick. The units are placed, manually or mechanically, on the even bedding sand constrained by stationary edge restraints.

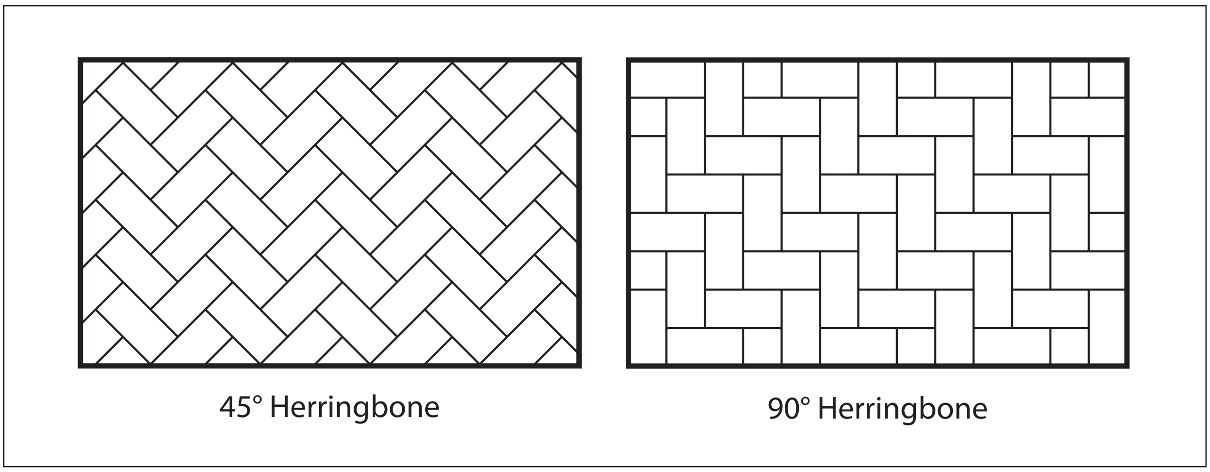


Figure 3. Laying patterns for vehicular traffic

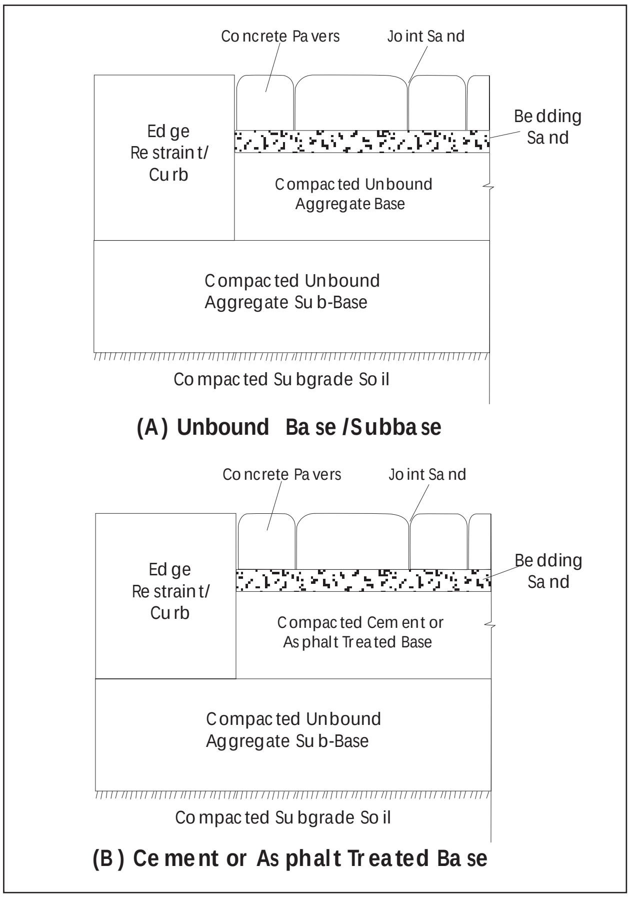


Figure 4. Typical schematic cross sections

The pavers are vibrated with a high frequency plate compactor. This action forces sand into the bottom of the joints of the pavers and begins compaction of the bedding sand. Sand is then spread and swept into the joints, and the process repeated until the joints are filled. Complete compaction of the sand and slight settlement of the pavers tightens them. During compaction, the pavement is transformed from a loose collection of pavers to an interlocking system capable of spreading vertical loads horizontally. This occurs through shear forces in the joints.

Structural Design Procedure

The load distribution and failure modes of flexible asphalt and interlocking concrete pavement are very similar: permanent deformation from repetitive loads. Since failure modes are similar, flexible pavement design procedures are used. The structural design procedures are for roads and parking lots. Base design for crosswalks should consider using stablized aggregate or cast-in-place concrete with sand-set paving units, or bitumen-set paving units over concrete. Stiffer bases will compensate for stress concentration on the subgrade and base where the pavers meet adjoining pavement materials. Design for heavy duty pavements such as port and airport pavements is covered in ICPI manuals entitled, *Port and Industrial Pavement Design for Concrete Pavers* and *Airfield Pavement Design with Concrete Pavers*.

Design Methodology

Structural design of interlocking concrete pavements follows the American Society of Civil Engineers Transportation & Development Institute standard (ASCE/T&DI 58-10), *Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways* (ASCE 2010). This standard applies to paved areas subject to applicable permitted axle loads and trafficked up to 10 million (18,000 lb or 80 kN) equivalent single axle loads (ESALs) with a vehicle speed of up to 45 mph (70 km/h). The standard provides preparatory information required for design, key design elements, design tables for pavement equivalent structural design, construction considerations, applicable standards, definitions and best practices. Readers are encouraged to purchase and review this guideline standard.

The ASCE standard relies on the flexible pavement design method described in the 1993 *Guide for Design of Pavement Structures* published by the American Association of State Highway and Transportation Officials (AASHTO 1993). Future versions of the ASCE standard may include the mechanistic-empirical design methodology as described in the 2004 *Guide for Mechanistic Empirical Design of New and Rehabilitated Pavement Structures* (AASHTO 2004). The level of detailed information required to use this procedure is unavailable for most non-highway applications.

The design process is characterized by the flowchart shown in Figure 5. The following provides information on the key input variables noted in the flowchart.

Design Traffic— When pavement is trafficked, it receives wear or damage usually evidenced as the depth of rutting in flexible asphalt pavements and the extent of cracking in rigid concrete pavements. For interlocking concrete pavements, damage is typically measured by the depth of rutting since it behaves as a flexible pavement similar to asphalt. Cracked paving units are rarely evidence of a pavement damaged by traffic loads and therefore are not typically used as a means to estimate damage or wear of an interlocking concrete pavement.

As with all pavements, the amount of damage from traffic depends on the weight of the vehicles and the number of expected passes over a given period of time. The period of time, or design life, is 20 to 40 years. Design life is the period of time a pavement will last before damage requires major rehabilitation, often complete removal and replacement. The designer or transportation agency selects a design life in years which is influenced by the available budget to construct or rehabilitate a pavement.

Predicting traffic over the life of the pavement is an estimate of various vehicle loads, axle and wheel configurations, and the number of loads (repetitions). The actual amount of traffic loads can often exceed the predicted loads. Therefore, engineering judgment is required in estimating expected sources of traffic and loads well into the future. When future traffic loads are difficult to predict, an engineer will often design a pavement for higher loads

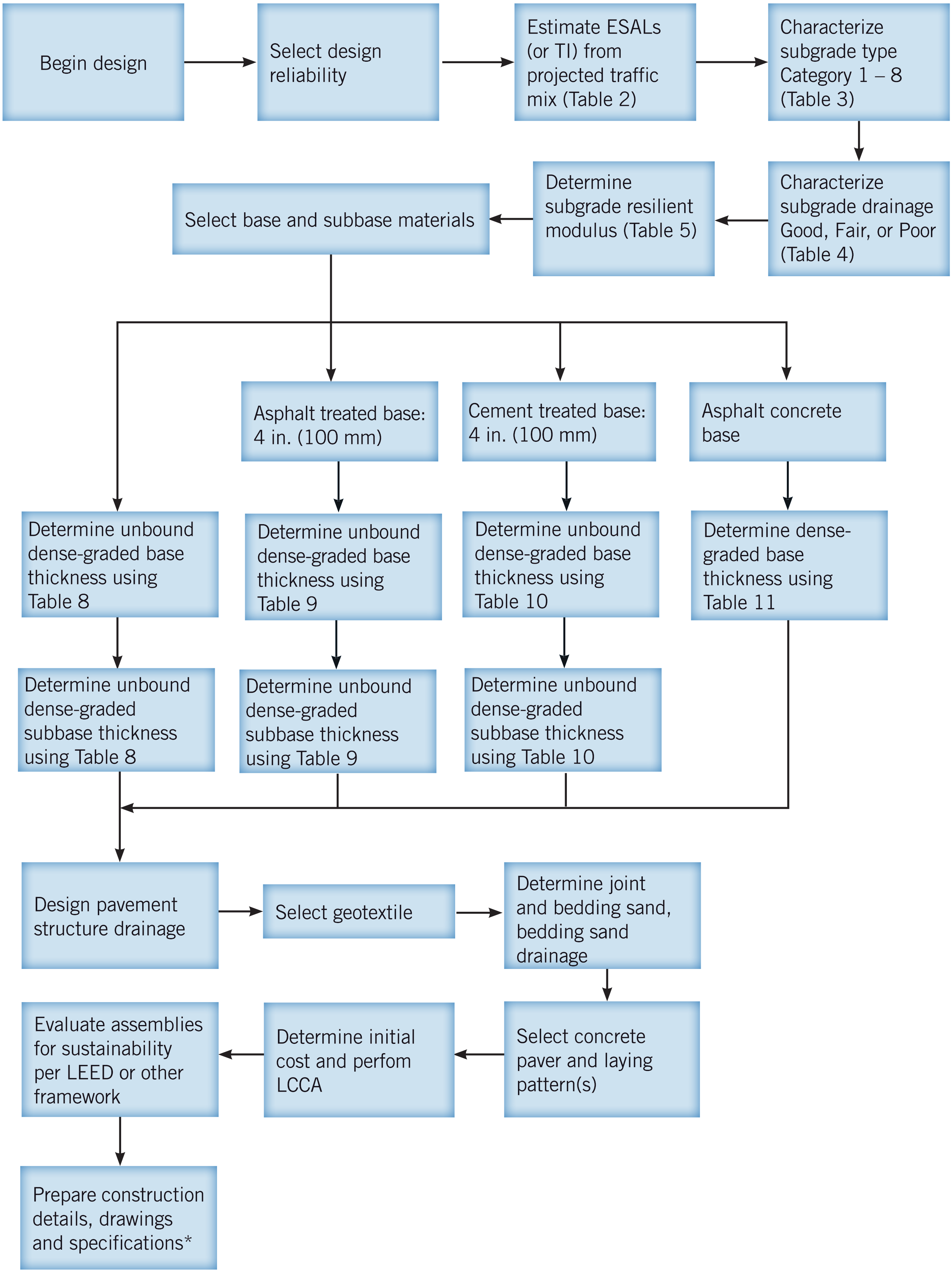


Figure 5. Design Process Flow Chart – *Indicates outside scope of the standard

to ensure that the risk of excessive pavement damage is low over the service life of the pavement.

Compared to cars, trucks and busses do the most damage to pavements because their wheel loads are much higher than cars. One pass of a fully loaded truck will exert more damage to pavement than several thousand cars passing over it. Since there is a range of expected loads (usually expressed as axle loads) over a pavement during its life, AASHTO developed a means to normalize or equalize all axle loads of them into a single axle load exerted repeatedly over the life of the pavement.

The 1993 AASHTO Guide characterizes traffic loads as the number of 80 kN or 18,000 lbs equivalent single axle loads or ESALs. The 18,000 lbs (80 kN) load emerged from AASHTO (then called AASHO) road tests conducted in the 1950s and have remained as a convenient means to quantify a range of different vehicle axle loads. The AASHTO tests demonstrated that loads and resulting damage to pavement is not linear but exponential as loads increase. The tests showed that for every incremental increase in axle load, damage to the pavement increased by roughly the fourth power. This exponential load-damage relationship resulted in determining ESALs by taking the weight of each axle and dividing each by a 'standard' ESAL of 18,000 lbs or 80 kN. Then the quotient is raised to the fourth power.

For example, a five axle tractor-trailer truck has two rear axles on the trailer each exerting 18,000 lbs or 80 kN; two on the back of the truck at 15,800 lbs or 70 kN; and one in the front (steering) at 11,000 lbs or 50 kN. AASHTO uses the following relationships called load equivalency factors or LEFs for each axle to estimate ESALs. These express the exponential relationship between damage and loads. LEF and ESALs for this truck are as follows:

Trailer: LEF = $(80/80)^4$ = 1 (x 2 axles) = 2 ESALs

Truck rear: LEF= $(70/80)^4$ = 0.6 (x 2 axles) = 1.2 ESALs

Truck front: LEF = $(50/80)^4$ = 0.15 ESALs

When added together, all LEFs = 3.35 ESALs. So for every pass across a pavement, this truck exerts 3.35 80 kN (18,000 lbs) ESALs.

To put automobile axle loads into perspective, the axle loads of one passenger car placed into the formula yields about 0.0002 ESALs. Therefore, pavement design primarily considers trucks and busses because they exert the highest loads and most damage. In contrast, thousands of cars are required to apply the same loading and damage as one passage of a truck.

The more axles on trucks the better, since tandem axles spread loads over a wider area and render lower damage for each pass of the vehicle over a pavement. Another way to illustrate this is one single axle load of 36,000 lbs (160 kN) exerts the same damage as 16 passes of a single axle load of 18,000 lbs (80 kN) or $(36/18)^4$ = 16. Therefore, doubling the axle load increases the damage 16 times.

The California Department of Transportation or Caltrans uses Traffic Index or TI rather than ESALs. Converting ESALs to TI is accomplished by using the formula below. Table 1 illustrates the relationships between ESALs and TIs. Table 2 provides AASHTO road classifications and typical lifetime ESALs and TIs.

$$\mathrm{TI} = 9.0 \times \left(\frac{\mathrm{ESAL}}{10^6}\right)^{0.119}$$

For the ASCE standard, ESAL levels are provided for 10

Table 1. Relationship of ESALs to Caltrans TIs

ESAL	TI
5×10^4	6
1×10^5	6.8
3×10^5	7.2
5×10^5	8.3
7×10^5	8.6
1×10^6	9
3×10^6	10.3
5×10^6	10.9
7×10^6	11.3
1×10^7	11.8
2×10^7	12.8
3×10^7	13.5

typical levels of municipal traffic up to a maximum of 10 million ESALs. The designer needs to select the appropriate traffic level and design life. The typical initial design life for municipal pavements is on the order of 20 to 40 years.

Subgrade Characterization— The next step is for the designer to characterize the subgrade soil and drainage for the purpose of selecting a subgrade strength. Typically the resilient modulus or M_r (AASHTO T-274) is used to describe the strength of the subgrade soil. This can be determined directly from laboratory testing. Other means to characterize soil strength include California Bearing Ratio or CBR (ASTM D1883) and R-value (ASTM D2844) tests. The relationship of M_r, CBR and R-value of subgrade soils are illustrated in Figure 6 which also includes strength ranges

Table 2. AASHTO Lifetime ESALs (Caltrans TI)

Road Class	ESAL (TI)			
	Arterial or Major Streets	Major Collectors	Minor Collectors	Commercial/ Multi-Family Locals
Urban	7,500,000 (11.4)	2,800,000 (10.2)	1,300,000 (9.3)	430,000 (8.1)
Rural	3,600,000 (10.5)	1,500,000 (9.4)	550,000 (8.4)	280,000 (7.7)

for soils classified using the Unified (ASTM D2487), and AASHTO methods.

The ASCE standard utilizes eight categories of subgrade quality ranging from good quality gravels and rock with excellent drainage to poor quality clay materials that are semi-impervious to water. Subgrade types are classified according to the Unified Soils Classification method (ASTM D2487). Soil categories in Table 3 are from the standard and are provided to the user for guidance only. Actual laboratory characterization of subgrade properties for each project is recommended. Designers are cautioned against making generalizations.

Once the general subgrade type has been selected, then the drainage quality of the subgrade and pavement structure is characterized (See Table 4). Depending on the type of subgrade, the strength of the pavement may be reduced if there is excess water in the subgrade. The standard includes an adjustment to the resilient modulus of the subgrade based on the overall quality of the pavement drainage, as shown in Table 5.

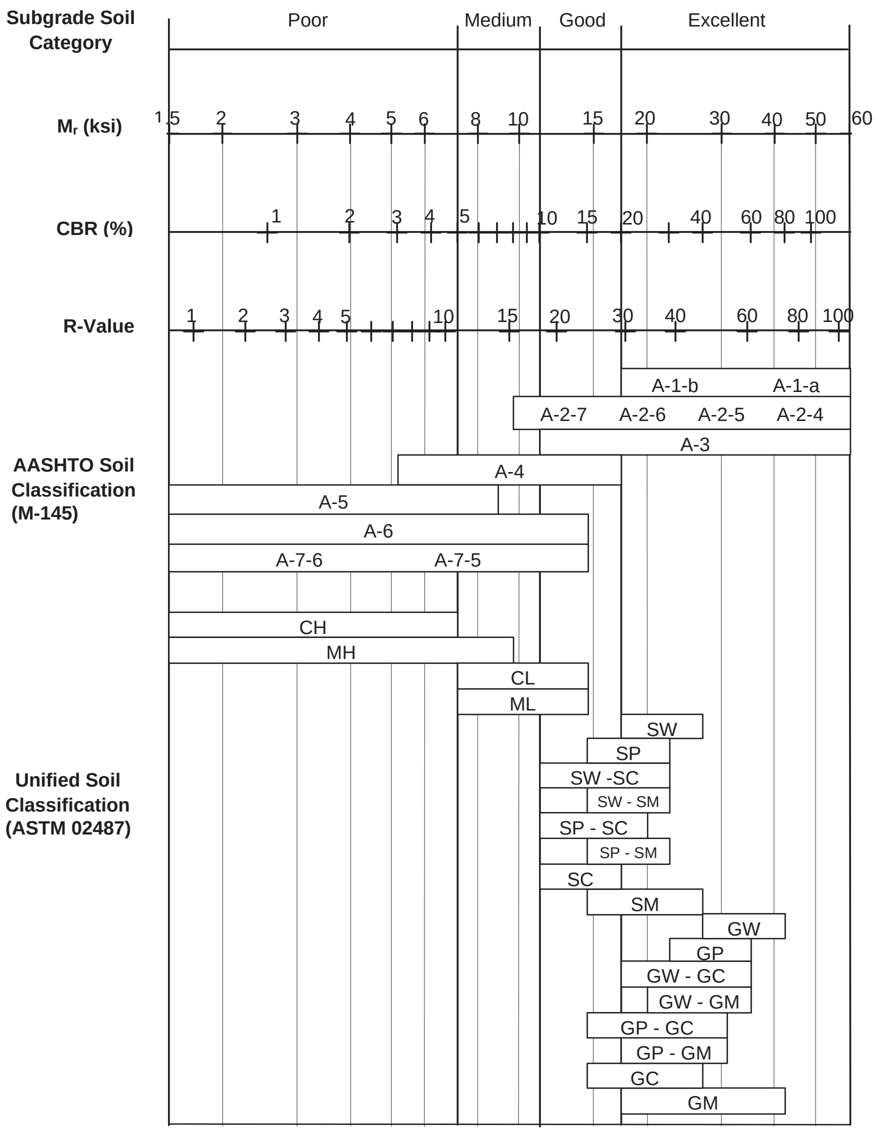


Figure 6. Typical Resilient Modulus Correlations to Empirical Soil Properties and Classification Categories. From Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, Appendix CC-1: "Correlation of CBR Values with Soil Index Properties," National Cooperative Highway Research Program, Transportation Research Board, National Research Council, authored by ARA, Inc., Champaign, Illinois, March 2001. Chart is modified from the National Asphalt Pavement Association Information Series 117, "Guidelines for Use of HMA Overlays to Rehabilitate PCC Pavements," 1994.

Table 3. General Soil Categories and Properties (ASCE 2010)

Category No.	Unified Soil Classification	Brief Description	Drainage Characteristics	Susceptibility to Frost Action
1	Boulders/cobbles	Rock, rock fill, shattered rock, boulders/ cobbles	Excellent	None
2	GW, SW	Well graded gravels and sands suitable as granular borrow	Excellent	Negligible
3	GP, SP	Poorly graded gravels and sands	Excellent to fair	Negligible to slight
4	GM, SM	Silty gravels and sands	Fair to semi-impervious	Slight to moderate
5	GC, SC	Clayey gravels and sands	Practically impervi - ous	Negligible to slight
6	ML, MI	Silts and sandy silts	Typically poor	Severe
7	CL, MH	Low plasticity clays and compressible silts	Practically impervious	Slight to severe
8	CI, CH	Medium to high plasticity clays	Semi-impervious to impervious	Negligible to severe

Table 4. Pavement Drainage According to Soil Category (ASCE 2010)

Quality of Drainage	Time to Drain	Soil Category No. from Table 3
Good	1 day	1,2,3
Fair	7 days	3,4
Poor	1 month	4,5,6,7,8

Selection of Base Material— The next step in the design process is selecting the type of base material for the pavement. The standard supports the use of bound and unbound bases.

For unbound dense-graded bases, the aggregates are required to be crushed, angular materials. Crushed aggregate bases used in highway construction are generally suitable for interlocking concrete pavement, and unbound base materials should meet the local state, provincial or municipal standards governing base materials.

Where local specifications are unavailable, the base material is required to meet the gradation requirements according to ASTM D 2940. Table 6 includes these requirements. The minimum required strength of the unbound base is a CBR of 80% or equivalent bearing strength as described by the test methods in Section 3.6 of the standard. Unbound base materials are required to have a maximum loss of 60% when tested in accordance with CSA A23.2-29A (Micro-Deval abrasion) and a maximum loss of 40% when tested in accordance with ASTM C 131 or CSA A23.2-17A (Los Angeles abrasion).

The required plasticity index is a maximum of 6 and the maximum liquid limit of 25 when tested in accordance with ASTM D4318 and AASHTO T-89 and T-90. For constructability purposes, the minimum design unbound base thickness is 4 in. (100 mm) for traffic less than 500,000 ESALs and 6 in. (150 mm) for 500,000 or higher ESALs. Figure 7 illustrates a typical cross section with an unstabilized, dense-graded base.

For bound or treated bases, asphalt-treated base (ATB) and cement-treated base (CTB) materials and installation are required to conform to provincial, state or local specifications for a dense-graded, compacted, asphalt concrete. ATB material is required to have a minimum Marshall stability

Table 5. Resilient Modulus (M_r), R-Values and CBRs for Subgrade Drainage Conditions (ASCE 2010)

Category	Drainage								
	Good			Fair			Poor		
	M_r (MPa)	R	CBR	M_r (MPa)	R	CBR	M_r (MPa)	R	CBR
1	90	21	13	80	19	11	70	16	9
2	80	19	11	70	16	9	50	11	5
3	70	16	9	50	11	5	35	7	3
4	50	11	5	35	7	3	30	6	2
5	40	8	4	30	6	2	25	4	2
6	30	6	2	25	4	2	18	3	1
7	27	5	2	20	3	1	15	2	1
8	25	4	2	20	3	1	15	2	1

Table 6. ASTM D 2940 Gradation for Unbound Aggregate Bases and Subbases

Sieve Size (square openings)	Design Range* (Mass Percentages Passing)		Job Mix Tolerances (Mass Percentages Passing)	
	Bases	Subbases	Bases	Subbases
2 in. (50 mm)	100	100	-2	-3
1 1/2 in. (37.5 mm)	95 to 100	90 to 100	±5	+5
3/4 in. (19 mm)	70 to 92		±8	
3/8 in. (9.5 mm)	50 to 70		±8	
No. 4 (4.75 mm)	35 to 55	30 to 60	±8	±10
No. 30 (0.600 mm)	12 to 25		±5	
No. 200 (0.075 mm)	0 to 8**	0 to 12**	±3	±5

*Select the Job Mix Formula with due regard to the availability of materials and service requirements of project. Test results outside the design range are not prohibited, provided they are within the job mix tolerances.

**Determine by wet sieving. Where local environmental conditions (temperature and availability of free moisture) indicate that in order to prevent damage by frost action it is necessary to have lower percentages passing the No. 200 (0.075 mm) sieve than permitted in Table 6, appropriate lower percentages shall be specified. When specified, the material having a diameter smaller than 0.020 mm shall not exceed 3% mass.

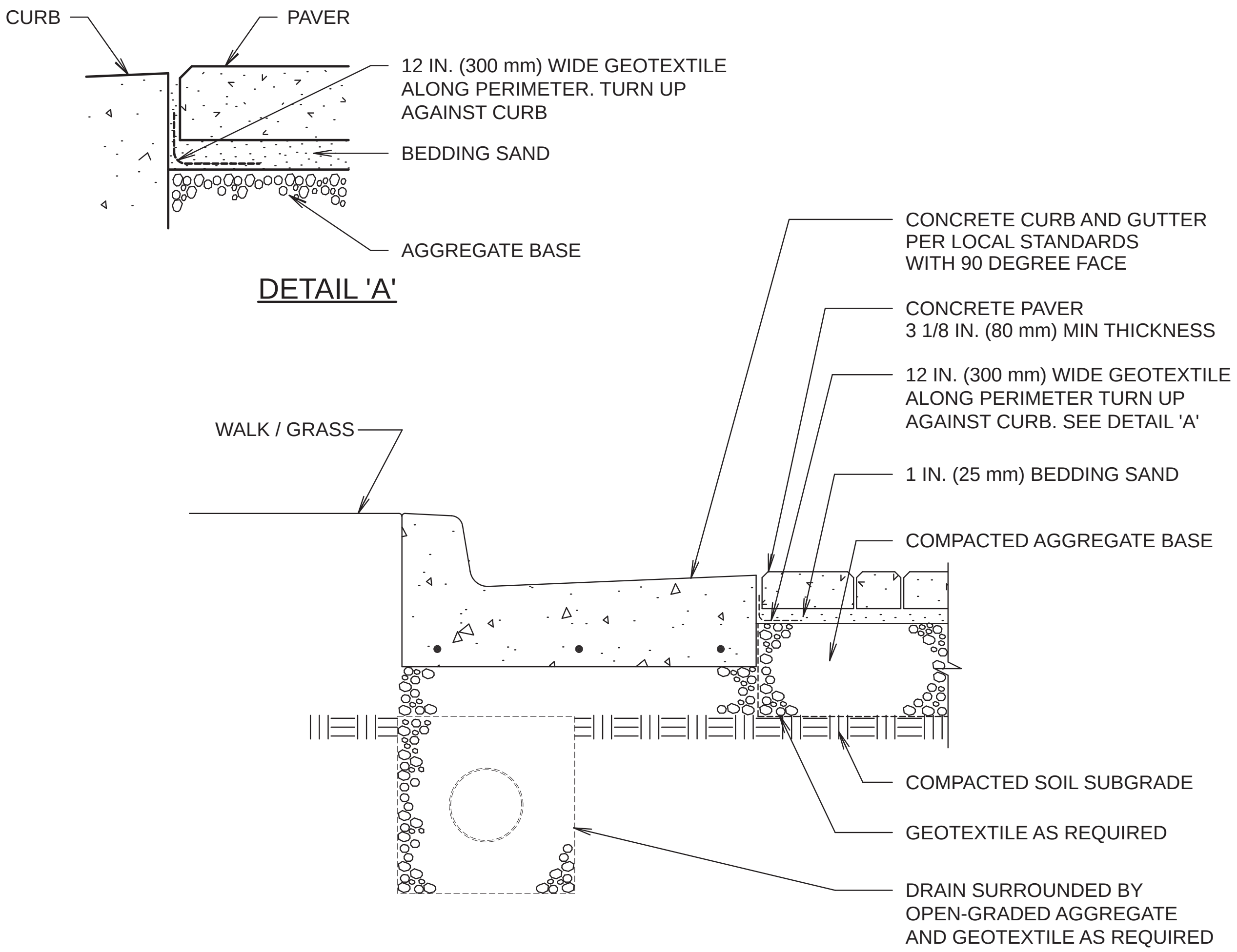


Figure 7: Typical cross section with an unstabilized, dense-graded base

of 1,800 lbf (8000 N) per ASTM D5 or AASHTO T-49. Use of the appropriate asphalt (performance grade) cement binder for local climate conditions is also recommended. For example, a state department of transportation Superpave intermediate binder course mix required for interstate or primary roads may be adequate. Cement-treated base material is required to have a minimum 7-day unconfined compressive strength of 650 psi (4.5 MPa) per ASTM D4320 and D4219. For constructability purposes, the minimum bound base thickness for design purposes is set at 4 in. (100 mm). Figure 8 illustrates a typical cross section with treated bases or an asphalt base and drainage holes.

Asphalt bases should conform to typical provincial, state or municipal material and construction specifications for asphalt pavements. This layer does not require a surface riding layer of fine aggregate and consists of coarser aggregates and asphalt cement. The asphalt base layer thicknesses noted in Table 11 vary between 2 in. (50 mm) and 8.5 in. (220 mm) depending on traffic, soil category and drainage conditions.

Subbase Materials— Aggregates for subbase are crushed, angular materials typically used in highway construction are generally suitable for interlocking concrete pavement. All bound or treated bases are constructed over 4 to 8 in. (100 to 200 mm) unbound dense-graded aggregate base as described above. Unbound subbase materials are required to meet the local state, provincial or municipal standards governing subbase materials. Local road agencies may also use open-graded subbases for drainage. Where local specifications are unavailable, the subbase is required to meet the gradation requirements according to ASTM D2940 noted in Table 6. The required minimum strength of the unbound subbase is a CBR of 40% per ASTM D1883. The required plasticity index is a maximum of 10 and the maximum liquid limit of 25 according to ASTM D4318 and AASHTO T-90.

Compaction Requirements— Compaction of the subgrade soil during construction should be at least 95% Standard Proctor Density as tested using AASHTO T-99 or ASTM D 698 for cohesive (clay) soils and at least 95% Modified Proctor density as tested using AASHTO T-180 or ASTM D 1557 for cohesionless (sandy and gravelly) soils. The higher compaction standards described in T-180 or D 1557 are preferred. The effective depth of compaction for all cases should be at least the top 12 in. (300 mm). Soils having an M_r of 4,500 psi (31 MPa) or less (CBR of 3% or less or R value of 8 or less) should be evaluated for replacement with a higher bearing strength material, installation of an aggregate subbase capping layer, improvement by stabilization or use of geotextiles or geogrids. ATB and CTB density testing should conform to provincial, state or local requirements. In-place density testing of all of the soil subgrade and pavement layers should be included in the project construction specifications and documented with written testing reports. Density tests on the site project as part of construction quality control are critical to pave -

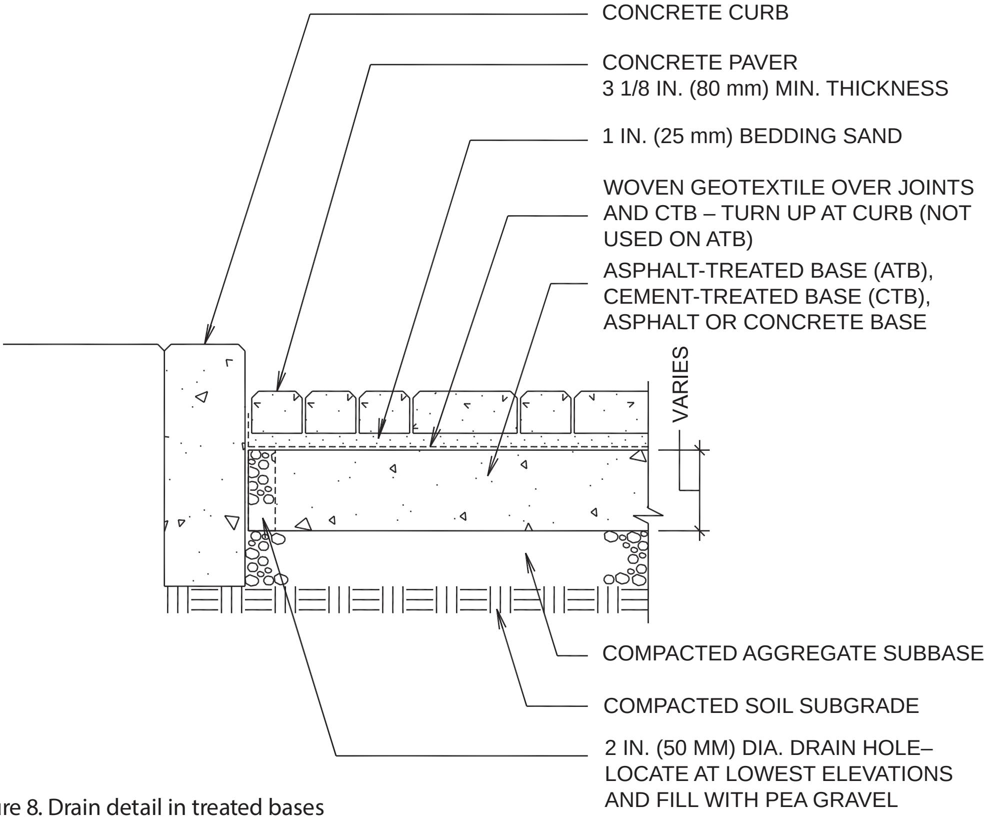


Figure 8. Drain detail in treated bases

Table 7. Recommended Bedding Sand Gradation

Gradation for Bedding Sand			
ASTM C33		CSA A23.1 FA1	
Sieve Size	Percent Passing	Sieve Size	Percent Passing
3/8 in.(9.5 mm)	100	10.0 mm	100
No. 4 (4.75 mm)	95 to 100	5.0 mm	95 to 100
No. 8 (2.36 mm)	80 to 100	2.5 mm	80 to 100
No. 16 (1.18 mm)	50 to 85	1.25 mm	50 to 90
No. 30 (0.6 mm)	25 to 60	630 μm	25 to 65
No. 50 (0.3 mm)	5 to 30	315 μm	10 to 35
No. 100 (0.15 mm)	0 to 10	160 μm	2 to 10
No. 200 (0.075 mm)	0 to 1	80 μm	0 to 1

Note: Bedding sands should conform to ASTM C33 or CSA A23.1 FA1 gradations for concrete sand. For ASTM C33, ICPI recommends the additional limitations on the No. 200 (0.075 mm) sieve as shown. For CSA A23.1 FA1, ICPI recommends reducing the maximum passing the 80 μm sieve from 3% to 1%.

ment performance . Difficult to compact areas can include areas next to curbs, other pavements, and around utility structures. Such areas may require additional compaction or use of manual equipment to achieve specified densities.

Structural Contribution of the Concrete Pavers and Bedding Sand Layer— Research using accelerated traffic studies and non-destructive structural testing in the United States and overseas has shown that the combined paver and sand layers stiffen while exposed to greater numbers of axle loads. The progressive stiffening that results in "lock up" generally occurs early in the life of the pavement, before 10,000 ESALs (Rada 1990). Once this number of loads has been applied, M_r = 450,000 psi (3,100 MPa) for the combined 3 1/8 in. (80 mm) thick paver and 1 in. (25 mm) of bedding sand. Pavement stiffening and stabilizing can be accelerated by static proof-rolling with an 8–10 ton (8–10 T) rubber tired roller.

The above resilient modulus is similar to that of an equivalent thickness of asphalt. The 3 1/8 in. (80 mm) thick pavers and 1 in. (25 mm) thick bedding sand together have an AASHTO layer coefficient at least equal to the same thickness of asphalt, i.e., 0.44 per inch (25 mm). This renders an AASHTO Structural Number or SN of 4.125 in. x 0.44 = 1.82 for this pavement layer. The recommended Caltrans Gravel Equivalency (GE) for the concrete paver layer = 2 and unlike asphalt the GE for concrete pavers does not decrease with increasing TIs. The modulus or stiffness of the concrete paver layer will not substantially decrease as temperature increases nor will they become brittle in cold climates. The surfacing can withstand loads without distress and deterioration in temperature extremes.

Bedding and Joint Sand Selection— Bedding sand thickness should be consistent throughout the pavement and not exceed 1 in. (25 mm) after compaction. A thicker sand layer will not provide stability. Very thin sand layers (less than 3/4 in. [20 mm] after compaction) may not produce the locking up action obtained by sand migration upward into the joints during the initial compaction in construction. The bedding layer should conform to the gradation in ASTM C 33, as shown in Table 7. Do not use screenings or stone dust. The sand should be as hard as practically available and the particle shape should be sub-angular. ICPI Tech Spec 17–Bedding Sand Selection for Interlocking Concrete Pavements in Vehicular Applications provides additional information on gradation and test criteria on selecting bedding sands for pavements subject to 1.5 million lifetime ESALs or higher.

Joint sand provides vertical interlock and shear transfer of loads. It can be slightly finer than the bedding sand. Gradation for joint material should comply with ASTM C144 or CSA A179 with a maximum 100% passing the No. 16 (1.18 mm) sieve and no more than 5% passing the No. 200 (0.075 mm) sieve. Bedding sand may be used for joint sand. Additional effort in filling the joints during compaction may be required due to its coarser gradation.

Concrete Paver Selection— Concrete pavers are required to conform to the product requirements of ASTM C936 Standard Specification for Solid Interlocking Paving Units in the United States and CSA A231.2 Precast Concrete Pavers in Canada. For this ASCE standard, pavers must have an aspect ratio (overall length/thickness) less than or equal to 3:1 and a minimum thickness of 3 1/8 in. (80 mm). A 45 or 90-degree herringbone laying pattern is recommended with sailor courses at the perimeter. No less than one-third of a cut paver should be exposed to tire traffic. The designer is advised that alternative laying patterns may be considered as long as they are functionally and structurally equivalent. Other shapes than rectangular pavers can be considered in the design with the responsibility of the design engineer to confirm that the structural capacity is

Table 8. Design Tables for Granular Base

GRANULAR BASE THICKNESSES (mm) (80 % reliability)												
	Pavement Drainage	ESALs (x 1,000)	10	20	50	100	200	500	1,000	2,000	5,000	10,000
		Caltrans Traffic Index	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
		Layer Type										
Category 1	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	150	225	350
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	100	100	100	150	175	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	150	275	375
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	100	100	100	150	200	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	175	325	450
Category 2	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	100	100	100	150	175	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	150	275	375
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	100	100	100	150	200	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	175	325	450
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	100	100	125	200	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	175	300	450	600
Category 3	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	100	100	100	150	200	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	175	325	450
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	100	100	125	200	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	175	300	450	600
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	100	150	200	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	200	325	450	625	750
Category 4	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	100	100	125	200	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	175	300	450	600
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	100	150	200	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	200	325	450	625	750
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	125	175	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	200	275	375	500	700	825

(Table continues on p. 12)

Table 8—Continued from p. 11

GRANULAR BASE THICKNESSES (mm) (80% reliability)												
	Pavement Drainage	ESALs (x 1,000)	10	20	50	100	200	500	1,000	2,000	5,000	10,000
		Caltrans Traffic Index	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
		Layer Type										
Category 5	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	100	125	175	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	150	275	375	550	700
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	125	175	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	200	275	375	500	700	825
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	150	200	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	275	325	450	600	775	925
Category 6	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	125	175	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	200	275	375	500	700	825
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	150	200	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	275	325	450	600	775	925
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	150	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	175	275	375	475	600	750	950	1100
Category 7	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	150	200	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	250	300	425	550	750	875
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	125	200	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	250	350	425	550	700	875	1050
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	125	175	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	225	350	450	550	700	825	1025	1200
Category 8	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	100	150	200	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	275	325	450	600	775	925
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	100	125	200	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	250	350	425	550	700	875	1050
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Unbound Dense-graded Base	125	175	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	225	350	450	550	700	825	1025	1200

Table 9. Design table for asphalt treated base

ASPHALT TREATED BASE THICKNESSES (mm) (80% reliability)												
	Pavement Drainage	ESALs (x 1,000)	10	20	50	100	200	500	1,000	2,000	5,000	10,000
		Caltrans Traffic Index	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
		Layer Type										
Category 1	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	175
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	0	0
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	200
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	0	0
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	0	150
Category 2	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	200
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	0	0
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	0	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	150	275
Category 3	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	0	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	150	275
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	150	300	450

(Table continues on p. 14)

Table 9—Continued from p. 13

ASPHALT TREATED BASE THICKNESSES (mm) (80% reliability)												
	Pavement Drainage	ESALs (x 1,000)	10	20	50	100	200	500	1,000	2,000	5,000	10,000
		Caltrans Traffic Index	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
		Layer Type										
Category 4	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	150	275
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	150	300	450
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	200	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	200	375	525
Category 5	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	200	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	250	375
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	200	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	200	375	525
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	175	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	150	275	475	625
Category 6	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	200	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	200	375	525
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	175	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	150	275	475	625
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	150	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	150	300	425	625	800

(Table continues on p. 15)

Table 9—Continued from p. 14

ASPHALT TREATED BASE THICKNESSES (mm) (80% reliability)												
	Pavement Drainage	ESALs (x 1,000)	10	20	50	100	200	500	1,000	2,000	5,000	10,000
		Caltrans Traffic Index	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
		Layer Type										
Category 7	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	150	250	425	575
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	125	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	150	250	375	575	725
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	125	200	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	250	375	525	725	900
Category 8	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	175	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	150	275	475	625
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	125	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	150	250	375	575	725
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	125	200	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	250	375	525	725	900

Table 10. Design table for cement treated base

CEMENT TREATED BASE THICKNESSES (mm)		(80% reliability)										
	Pavement Drainage	ESALs (x 1,000)	10	20	50	100	200	500	1,000	2,000	5,000	10,000
		Caltrans Traffic Index	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
		Layer Type										
Category 1	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	0	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	175	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	0	175
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	150	225
Category 2	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	175	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	0	175
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	150	225
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	200	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	225	375
Category 3	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	150	225
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	200	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	225	375
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	150	225	400	525

(Table continues on p. 17)

Table 10—Continued from p. 16

CEMENT TREATED BASE THICKNESSES (mm)		(80% reliability)										
	Pavement Drainage	ESALs (x 1,000)	10	20	50	100	200	500	1,000	2,000	5,000	10,000
		Caltrans Traffic Index	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
		Layer Type										
Category 4	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	200	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	0	225	375
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	150	225	400	525
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	175	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	150	275	475	600
Category 5	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	150	175	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	0	175	325	475
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	175	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	150	275	475	600
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	125	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	150	225	375	550	700
Category 6	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	100	175	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	150	275	475	600
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	125	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	150	225	375	550	700
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	150	200	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	250	375	525	725	875

(Table continues on p. 18)

Table 10—Continued from p. 17

CEMENT TREATED BASE THICKNESSES (mm) (80% reliability)												
	Pavement Drainage	ESALs (x 1,000)	10	20	50	100	200	500	1,000	2,000	5,000	10,000
		Caltrans Traffic Index	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
		Layer Type										
Category 7	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	125	200	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	0	200	325	525	675
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	125	175	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	200	325	475	675	825
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	175	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	250	325	475	600	825	975
Category 8	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	100	125	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	150	225	375	550	700
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	125	175	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	0	200	325	475	675	825
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Cement Treated Base	100	100	100	100	100	100	100	100	100	100
		Unbound Dense-graded Base	100	100	100	175	100	150	150	150	150	150
		Unbound Dense-graded Subbase	0	0	0	0	250	325	475	600	825	975

Table 11. Design table for asphalt concrete base

		ASPHALT CONCRETE BASE THICKNESSES (mm)					(80% reliability)					
	Pavement Drainage	ESALs (x 1,000)	10	20	50	100	200	500	1,000	2,000	5,000	10,000
		Caltrans Traffic Index	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
		Layer Type										
Category 1	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	50	50
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	50	60
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	50	70
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
Category 2	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	50	60
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	50	70
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	80	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
Category 3	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	50	70
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	80	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	70	110	140
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
Category 4	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	50	80	100
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	70	110	140
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	60	90	120	150
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150

(Table continues on p. 20)

Table 11—Continued from p. 19

ASPHALT CONCRETE BASE THICKNESSES (mm) (80% reliability)												
	Pavement Drainage	ESALs (x 1,000)	10	20	50	100	200	500	1,000	2,000	5,000	10,000
		Caltrans Traffic Index	5.2	5.7	6.3	6.8	7.4	8.3	9.0	9.8	10.9	11.8
		Layer Type										
Category 5	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	50	60	100	120
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	60	90	120	150
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	80	100	140	170
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
Category 6	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	60	90	120	150
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	80	100	140	170
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	70	80	110	130	170	210
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
Category 7	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	70	100	130	160
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	60	70	100	120	160	200
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	60	80	90	120	150	190	230
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
Category 8	Good	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	50	50	80	100	140	170
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Fair	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	50	60	70	100	120	160	200
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150
	Poor	Pavers and Bedding	105	105	105	105	105	105	105	105	105	105
		Asphalt Concrete Base	50	50	50	60	80	90	120	150	190	230
		Unbound Dense-graded Base	100	100	100	100	100	150	150	150	150	150

at least equal to the AASHTO structural number layer coefficient (SN) of the 0.44 for the pavers and bedding sand layer used in the standard, either by testing or confirmation from the manufacturer. ICPI takes a conservative approach by not recognizing differences among paver shapes with respect to structural and functional performance. Certain manufacturers may have materials and data that discuss the potential benefits of shapes that impact functional and structural performance in vehicular applications.

Subbase Thickness and Final Pavement Structural Design— The required subbase thickness is determined based on the design reliability, design life, estimated traffic, subgrade soil type, pavement structure drainage and base type selected. Subbase thicknesses are determined from one of the four design tables. The design tables provide structural design thicknesses primarily for unbound bases (granular base), ATB, and CTB. However, a thickness design table is also provided for asphalt concrete (AC) bases to reduce thick pavement structures associated with high traffic/low subgrade strength conditions. In the development of the AC table, an AASHTO structural layer coefficient of 0.44 has been assumed for AC. For AC layer coefficients other than 0.44, the designer is advised to consult the 1993 AASHTO Guide. Tables 8 through 11 show the design tables for unbound granular base, ATB, CTB and AC for 80% reliability factor using the 1993 AASHTO Guide. This reliability factor is slightly higher than the 75% in the ASCE Standard and tables and in some cases can result in slightly thicker subbases, specifically in weak soils.

Design Example

Design examples are given with good soil conditions (subgrade category 4) and, fair drainage, with lifetime traffic of 5,000,000 ESALs. Designs developed for these conditions are shown in Table 12.

Table 12. Material thickness (mm) results for design example

	Unbound Base	ATB	CTB	AC
Pavers and Bedding	105	105	105	105
ATB	n/a	100	n/a	n/a
CTB	n/a	n/a	100	n/a
AC	n/a	n/a	n/a	110
Unbound Base	150	150	150	150
Unbound Subbase	625	300	400	n/a

Other Design Considerations and Construction Details

Guidance is also provided on proper detailing around utility structures, including edge detailing with sailor and soldier courses. Particular emphasis is given to drainage details for unbound aggregate and treated bases. This benefits pavement life and performance for all structural designs and the details are unique to interlocking concrete pavements as shown in Figures 7 and 8. For further details, design considerations, best practices and maintenance procedures designers are directed to the ICPI Tech Spec series and detail drawings available at www.icpi.org. The designer is also encouraged to address how interlocking concrete pavement can contribute to sustainability through applying the Leadership in Energy and Environmental Design (LEED®) credit system. Additional information on LEED® credits can be found in ICPI Tech Spec 16–Achieving LEED® Credits with Segmental Concrete Pavement.

Computerized Solutions

The preceding design example and most interlocking concrete pavement for parking lots and roads can be designed with "Interlocking Concrete Pavement Structural Design Program" that uses Excel-based software. The software is based on the ASCE 58-10 design standard and generates thickness solutions for unbound aggregate base, asphalt- and cement-treated, and asphalt concrete bases.

ICPI Lockpave software is another a computer program for calculating pavement base thicknesses for parking lot, street, industrial, and port applications. User designated inputs include traffic loads, soils, drainage, environmental conditions and a variety of ways for characterizing the strength of pavement materials. Parking lot and street pavement thickness can be calculated using the 1993 AASHTO flexible pavement design procedure (an empirical design method) or a mechanistic, layered elastic analysis that computes projected stresses and strains in the pavement structure modified by empirical factors.

Outputs include pavement thickness using different combinations of unbound and bound bases/subbases. Base thicknesses can be calculated for new construction and for rehabilitated asphalt streets using an overlay of concrete pavers. After a pavement structure has been designed, the user can project life-cycle costs by defining initial and lifetime (maintenance and rehabilitation) cost estimates. Design options with initial and maintenance costs plus discount rates can be examined for selection of an optimal design from a budget standpoint. Sensitivity analysis can be conducted on key cost variables on various base designs. For further information on both software programs, contact ICPI members, ICPI offices or visit the web site www.icpi.org.

Geosynthetics

Geotextiles, geogrids and cellular confinement systems are seeing increased use in pavements. Geotextile selection and use should follow the guidance provided in AASHTO M288. Geotextiles are placed over the top of the compacted soil subgrade and separate the soil from the base materials. These are recommended over silt and clay soils. Geogrids are sometimes used in very soft, wet and slowly draining soils. Cellular confinement systems filled with base materials and placed over the compacted soil subgrade have been used to reduce base thicknesses. Manufacturer's literature should be consulted for guidance on reduction of base thickness given anticipated traffic and soil conditions.

Rigid Pavement Design with Interlocking Concrete Pavers

Rigid pavements consisting of Portland cement concrete (PCC) slabs distribute loads to the compacted soil subgrade through flexure, or bending action. In such pavements the load spreading is primarily a function of the thickness of the slab and the flexural strength of the PCC. Base materials are often placed under the slab to provide additional structural support and drainage.

When PCC slabs are used as a base under concrete pavers, the structural contribution of the concrete pavers is often ignored by designers. The following sections provide a design method that includes some structural contribution by concrete pavers and bedding materials over PCC slabs as well as over roller compacted concrete. This pavement assembly requires consideration of the bedding materials, prevention of bedding sand loss and avoiding discontinuities over slab joints. Detailing that addresses these aspects are also covered in the following sections.

Background to PCC Pavements

There are three main types of PCC pavement; jointed concrete pavements (JCP), jointed reinforced concrete pavements (JRCP) and continuously reinforced concrete pavements (CRCP). Although other types are used, this Tech Spec will only address these three PCC systems. The differences among them are primarily in how environmental effects are controlled such as moisture change and temperature changes, including curing and environmental factors. These factors affect the reinforcement and jointing arrangements with little change in the slab thickness.

As concrete cures and dries, water in small pores within the cement creates surface tension. This force pulls the pore walls closer together causing the volume of the cement paste to shrink. This action reduces the entire paving slab size slightly. As the slabs are partially restrained by friction from the underlying base or soil subgrade, tensile stresses develop that can result in shrinkage cracks. The stress from shrinkage is proportional to the length of the section of pavement. To control the shrinkage it is therefore necessary to provide joints at sufficiently close centers to keep the shrinkage stresses below the tensile strength of the concrete. Alternatively, reinforcement can be used to increase the tensile strength of the pavement so that greater joint spacing can be used.

As concrete pavements heat up the slabs expand, and when they cool the concrete contracts. This movement results in closing and opening of the joints in the pavement. As expansion and contraction are proportional to the length of the slab, the movement range increases with greater joint spacing. Movement is also proportional to the temperature range, so this also requires consideration when designing the joints. Typically concrete can expand or contract by about 1/16 in. (1.5 mm) for every 10 ft (3 m) over an 80°F (27° C) temperature change. Pavement temperatures generally fluctuate over a wider range than air temperatures.

Thickness design for PCC pavements for low-speed roads and parking lots is typically done according to the 1993 AASHTO Guide or to local adaptations. Different equations are used for the design of rigid pavements than those for flexible pavements. The thickness of PCC pavements is determined to resist wheel loads imposed by the predicted traffic. Thickness depends on the soil conditions, the type of subbase, the edge conditions, the reliability requirements and the number of 18,000 lb (80 kN) ESAL repetitions. Some design considerations follow and thickness design is covered in greater detail later.

Jointed Concrete Pavement

In a jointed concrete pavement (JCP) the joints are placed at relatively close centers so that curing shrinkage does not lead to random cracking, and that joint widths are restricted to acceptable limits. The joints may have load transfer devices such as steel dowel bars (doweled JCP), or the interlocking of the aggregate particles on each face of the joint may be sufficient to transfer the loads from one side of the joint to the other (plain JCP).

The joint spacing is dependent upon the thickness of the concrete. A general rule of thumb is that the joint spacing should not exceed thirty times the slab thickness and should in no case exceed 20 ft (6 m). Individual panels should generally have a length of no more than 1.25 times the width. For doweled joints the joint spacings are typically between 10 and 20 ft (3 and 6 m) with joint widths potentially up to 1/8 in. (3 mm). For plain joints, the joint spacings are typically 10 to 15 ft (3 to 4.5 m) with joint widths of up to 1/16 in. (1.5 mm). This type of pavement is the best solution as a base under interlocking concrete pavers.

Jointed Reinforced Concrete Pavement

Jointed reinforced concrete pavements are designed with longitudinal and transverse reinforcement to accommodate the tensile stresses that arise during curing. This enables greater joint spacing to be achieved, but results in wider joint opening. As such, aggregate interlock cannot be relied upon and all joints require load transfer devices such as dowels. The reinforcement is typically located at about mid-depth in the slab so it does not increase the load capacity of the concrete section, As such, the same thickness of slab is required as for jointed concrete pavements. Joint spacings are typically 15 to 60 ft (4.5 to 18 m) with joint widths of up to 1/2 in. (13 mm). Intermediate joints are usually included to enable construction activities and to control warping of the slabs.

Warping occurs when there is a temperature difference between the top and the bottom of the concrete that causes it to curl. The intermediate joints are typically spaced at 10 to 20 ft (3 to 6 m) and include tie bars to keep the two sides of the joint from moving relative to each other. Large joint spacings can be problematic under pavers as joint movement reflects to the surface resulting in bedding sand loss and localized settlement and loosening of the pavers.

Continuously Reinforced Concrete Pavement

Continuously reinforced concrete pavements are designed with a greater amount of longitudinal reinforcement so that they can be constructed without transverse joints. The same thickness of slab is required as for jointed concrete pavements as the reinforcement does not increase the load capacity of the pavement. There is a general acceptance that transverse cracking will occur, however, the cracks are held tightly together by the longitudinal reinforcement. The cracks are initially widely spaced, but with full curing, subsequent traffic and temperature changes, the cracks may develop as closely spaced as 2 ft (0.6 m). Minor opening and closing of these joints are generally considered to accommodate the expansion and contraction of the pavement. Reinforcement in the transverse direction is generally similar to that in jointed reinforced concrete pavements. Longitudinal joints are constructed in a similar fashion to jointed reinforced concrete pavements. They may have tie bars or dowels depending on the pavement width. Excessive spacing of longitudinal movement joints may result in localized issues with the overlying pavers.

Joints

As described above, the joints in a concrete pavement control cracking from curing shrinkage and to permit movement caused by moisture and temperature changes. The joints should be located so that they provide adequate load transfer across each from aggregate interlock or from load transfer devices. Joints are typically laid out in a rectangular grid pattern with joints meeting edges of the pavement at no less than 60 degrees. Joints should not dead-end at another joint. They should be detailed to prevent ingress of moisture and infiltration of foreign mater.

There are three basic joint types that are formed during pouring or induced shortly afterwards. These are contraction joints, expansion joints and isolation joints. Each are described below and how they should be detailed when under interlocking concrete pavement.

Contraction Joints

Contraction joints provide a release for tensile stress in the pavement as the concrete contracts during curing. When they are induced in the interior of a pour of concrete they are often referred to as weakened plane joints as they cause a crack to occur in a defined position. In addition to being formed during pouring, weakened plane joints may be induced by early sawing, or by inserting crack-inducing plastic strips. Their placement controls where the tensile failure will occur so that the resulting cracks are in predefined positions, preventing random cracking. They can be oriented in the transverse and longitudinal directions relative to the pavement. The spacing of the joints is determined based upon the materials used, the thickness of the slab and the local environmental conditions, as described above. Load transfer devices are used when the joint opening is too wide to permit aggregate interlock. Contraction joints should be covered with minimum 12 in. (300 mm) wide woven geotextile strips to prevent bedding sand loss under concrete pavers.

Expansion Joints

Expansion joints perform in the same way as contraction joints but are also used to accommodate any longitudinal or transverse expansion of the pavement that exceeds the drying shrinkage. A compressible filler board absorbs any compressive stresses induced in the concrete by expansion. Where possible, their use is minimized with their most frequent location being at changes in the pavement construction and at intersections or other fixed structures in the pavement surface. In some cases the joint may also need to accommodate lateral movement. Expansion joints should generally be carried through the paver surfacing with the installation of edge restraints on either side.

Isolation Joints

Isolation joints are used in locations where movements in the pavement are to be isolated from an adjacent feature. They may be used against a building, a utility structure or other feature where vertical and horizontal movement could impose unwanted load into that feature. They are normally formed by including a compressible filler board without any load transfer devices. Isolation joints do not generally experience significant movement and they should

Table 13. Approximate relationships among M_r*, CBR and k-value in pounds per cubic inch (MPa/m)

Design M_r, psi (MPa)	Design CBR, %	Design k-value, pci
3,000 (20.6)	1.3	155 (42)
5,000 (34.4)	2.8	258 (70)
7,000 (48.2)	4.8	361 (98)
10,000 (68.9)	8.4	515 (140)
15,000 (103.4)	15.8	773 (210)
20,000 (137.8)	25	1,031 (280)
25,000 (172.3)	35.3	1,289 (350)
30,000 (206.8)	47	1,546 (420)

* $M_r = 2{,}555 \times (CBR)^{0.64}$, M_r is in psi
$M_r = 17.61 \times (CBR)^{0.64}$, M_r is in MPa

be covered with a woven geotextile to prevent bedding sand loss.

Roller Compacted Concrete Background

Roller compacted concrete (RCC) behaves in a similar fashion to jointed concrete pavement and may be used as an alternative base under interlocking concrete pavement. Fresh RCC consists of a semi-dry concrete spread through a modified asphalt paving machine. PCC aggregates are used in the mix and the final strength is similar paving quality concrete.

Mix designs are prepared in the laboratory to determine compressive strength and maximum density. Compressive strengths of 3,000 to 5,000 psi (20 to 35 MPa) may be specified. Compaction is initially done by the paving machine and finally by rollers until the target density is achieved. This is typically 98% of modified Proctor density. RCC may be placed without joints, or joints can be induced on a regular grid. When joints are not planned, the roller compacted concrete develops a network of narrow cracks during curing. The curing shrinkage is far less than for PCC pavements so the joints and cracks transfer loads by aggregate interlock. Design thicknesses are similar to those for PCC pavements.

Traffic

The AASHTO equations for pavement design express serviceability loss as a measure of pavement damage. The damaging effect of axles is different between the flexible and the rigid pavement equations. This is reflected in the AASHTO design method by having a different flexible ESAL values to rigid ESAL values, however the difference is not considered to be significant for design of interlocking concrete pavements over concrete.

Soil Subgrade Support

The AASHTO design method for rigid pavements uses the soil subgrade property known as the Modulus of Subgrade Reaction or k-value. This value is determined using a plate load test that is different than those described above in the flexible pavement section. The test is described in ASTM D1194 or AASHTO T-235. It involves placing a 30 in. (0.76 m) diameter rigid plate on the subgrade and measuring the deflection of the soil as the load on the plate is gradually increased. The k-value is determined as the pressure divided by the deflection at during certain points in the test. The test is rarely carried out and alternative means are generally used to establish the design value.

The design k-value is considered at the underside of the concrete, and includes the effects of any subbase layers. The AASHTO method also includes seasonal changes of subgrade strength and the proximity of rock to the surface to develop a composite k-value for design. This provides a wide range of k-values although the designed thickness has low sensitivity to this property. As such, the design charts in this Tech Spec are simplified to use an approximate relationship between the design resilient modulus (M_r) and the k-value. The design values are listed in Table 13. The values stated assume no subbase is present and that the depth to a rigid rock layer exceeds 10 ft (3 m). Where soils are known to be prone to pumping under concrete pavements, a minimum of 4 in. (100 mm) of compacted aggregate subbase material over the subgrade is recommended prior to casting the concrete. This thickness is also recommended with soils with an $M_r < 7{,}000$ psi (48 MPa) or CBR < 5%.

Pavement Materials

Most states, provinces and municipalities have material and construction standards for concrete pavements. However, material requirements vary among jurisdictions, particularly regarding material strengths. The design tables on the following pages presenting the rigid pavement base layer thicknesses are based upon typical values encountered in many standards.

There are two properties used in the AASHTO design method to characterize PCC pavements; flexural strength and the elastic modulus. Typically pavement quality concrete is specified with a flexural strength, although compressive strength is occasionally substituted. The flexural strength should be determined using beam specimens loaded at third points as described in ASTM C78 or AASHTO T-97. If compressive strength is the only requirement available, the designer can use Table 14 to provide an approximate correlation. The elastic modulus of concrete is rarely specified and so typical relationships to flexural or compressive strengths are required and are provided in Table 14. The AASHTO design equation is based upon the average value of flexural strength, which will be slightly higher than the specified value. When PCC is used as a base under concrete pavers it is usually not necessary to include an air entraining agent. The pavers provide protection against damage from frost action.

Reinforcement is not considered in the AASHTO design equation for determining the PCC pavement thickness. However, the type of reinforcement is important in determining the required bar sizes and centers and the spacing of joints. Typically, reinforcing bars and tie bars are Grade 60 deformed bars in size numbers #4, #5 or #6. However, Grade 40 steel may be used. As jointed concrete pavement is the preferred base condition, no additional guidelines are provided for determining the size and spacing of reinforcement. Dowel bars are typically Grade 60 in sizes ranging from 1/2 to 1 1/4 in. (13 to 32 mm). Table 15 sets out typical recommendations for dowel bars recommended by the American Concrete Institute. All dowel spacings are 12 in. (300 mm) on center.

Joint filler board is used in expansion joints and isolation joint to absorb any compression as the adjacent slabs move or expand. There are several different types including foam and bitumen impregnated fiber board. The thickness is selected dependent on the anticipated movement. Joint sealant is used to prevent the ingress of moisture and intrusion of foreign matter into joints. It may not be required on all joints when the concrete is exposed at the surface of the pavement if the movement range is small and if the lower layers are not moisture susceptible. When jointed concrete pavement is used under pavers the sealant may be left off if the joints are covered by geotextile. Sealant is recommended for joints with wider spacings.

Woven geotextiles are recommended to cover the joints and cracks in the PCC base to prevent bedding sand loss. Since they are manufactured from plastics such as polypropylene and polyester, the materials are stable and resistant to many chemicals encountered in the ground, and also to the deteriorating effects of sunlight. Woven geotextiles are preferred for use directly under the bedding sand as they maintain their integrity under loads exerting abrasion on the concrete. The important property in geotextiles for preventing sand loss is the apparent opening size or AOS. Woven geotextiles with an apparent opening size of 0.300 mm to 0.600 mm are generally suitable. As noted earlier geotextiles are applied to joints in minimum 12 in. (300 mm) wide strips.

Structural Design Procedure

The following structural design procedure is for roads and parking lots. PCC pavements are designed using a simplified version of the method in the AASHTO 1993 Guide . These pavement sections were then analyzed using mechanistic analysis to determine the critical stresses. The pavements were also analyzed considering a concrete paver surface to distribute the loads to a larger area on top of the concrete. The pavements were reduced in thickness incrementally until the same critical stresses were achieved in the concrete. The results of the analyses are presented in the tables. All designs are minimum 3 1/8 (80 mm) thick concrete pavers in a herringbone pattern. Bedding materials are sand or sand-asphalt (bitumen-setting bed). ICPI Tech Spec 17–Bedding Sand Selection for Interlocking Concrete Pavements in Vehicular Applications provides guidance on testing and selecting bedding sands.

Table 14. Approximate correlations among flexural strength, compressive strength and elastic modulus

Flexural Strength, psi (MPa)	Compressive Strength, psi (MPa)	Elastic Modulus, psi (MPa)
550 (3.8)	3,000 (20)	3,700,000 (25,517)
590 (4.1)	3,500 (24)	4,000,000 (27,586)
630 (4.3)	4,000 (28)	4,250,000 (29,310)
670 (4.6)	4,500 (31)	4,500,000 (31,034)
700 (4.8)	5,000 (35)	4,700,000 (32,414)

Table 15. PCC slab thickness and dowel characteristics

Slab Thickness, in. (mm)	Dowel Diameter, in. (mm)	Dowel Length, in. (mm)
4 and 4 1/2 (100 and 115)	1/2 (13)	12 (300)
5 and 5 1/2 (130 and 140)	5/8 (16)	12 (300)
6 and 6 1/2 (150 and 165)	3/4 (19)	14 (350)
7 and 7 1/2 (175 and 190)	7/8 (22)	14 (350)
8 and 8 1/2 (200 and 215)	1 (25)	14 (350)
9 and 9 1/2 (230 and 240)	1 1/8 (32)	16 (400)
10 and 10 1/2 (250 and 265)	1 1/2 (38)	16 (400)

Table 16. PCC base thicknesses under interlocking concrete pavement for a 3,000 psi (20 MPa) or 550 psi (3.8 MPa) flexural strength cement base.

PCC Base Thickness – 3,000 psi (20 MPa) compressive or 550 psi (3.8 MPa) flexural strength										
ESALs (x1,000)	10	20	50	100	200	500	1,000	2,000	5,000	10,000
Caltrans Traffic Index	5.2	5.6	6	6.8	7.4	8.3	9	9.8	10.9	11.8
Subgrade M r psi (MPa)										
30,000 (206)	102	102	102	102	102	102	102	127	127	152
25,000 (172)	102	102	102	102	102	102	102	127	140	165
20,000 (137)	102	102	102	102	102	102	102	127	140	178
15,000 (103)	102	102	102	102	102	102	102	127	152	191
10,000 (68)	102	102	102	102	102	102	102	127	152	191
7,000 (48)	102	102	102	102	102	102	114	140	178	203
5,000 (34)	102	102	102	102	102	102	127	152	178	203
3,000 (21)	102	102	102	102	102	114	140	165	191	216

Table 17. PCC base thicknesses under interlocking concrete pavement for a 4,000 psi (27.5 MPa) or 630 psi (4.3 MPa) flexural strength concrete base

PCC Base Thickness – 4,000 psi (27.5 MPa) compressive or 630 psi (4.3 MPa) flexural strength										
ESALs (x1,000)	10	20	50	100	200	500	1,000	2,000	5,000	10,000
Caltrans Traffic Index	5.2	5.6	6	6.8	7.4	8.3	9	9.8	10.9	11.8
Subgrade M r psi (MPa)										
30,000 (206)	102	102	102	102	102	102	102	127	127	152
25,000 (172)	102	102	102	102	102	102	102	127	127	152
20,000 (137)	102	102	102	102	102	102	102	127	140	165
15,000 (103)	102	102	102	102	102	102	102	127	152	178
10,000 (68)	102	102	102	102	102	102	102	127	152	178
7,000 (48)	102	102	102	102	102	102	114	140	165	191
5,000 (34)	102	102	102	102	102	102	114	140	165	191
3,000 (21)	102	102	102	102	102	102	127	152	178	203

Table 18. PCC base thicknesses under interlocking concrete pavement for a 5,000 psi (34 MPa) or 750 psi (5 MPa) flexural strength concrete base

PCC Base Thickness - 5,000 psi (34 MPa) compressive or 750 psi (5 MPa) flexural strength										
ESALs (x1,000)	10	20	50	100	200	500	1,000	2,000	5,000	10,000
Caltrans Traffic Index	5.2	5.6	6	6.8	7.4	8.3	9	9.8	10.9	11.8
Subgrade M_r psi (MPa)										
30,000 (206)	102	102	102	102	102	102	102	127	127	140
25,000 (172)	102	102	102	102	102	102	102	127	127	140
20,000 (137)	102	102	102	102	102	102	102	127	127	152
15,000 (103)	102	102	102	102	102	102	102	127	140	165
10,000 (68)	102	102	102	102	102	102	102	127	140	165
7,000 (48)	102	102	102	102	102	102	102	127	152	178
5,000 (34)	102	102	102	102	102	102	102	127	152	178
3,000 (21)	102	102	102	102	102	102	114	140	165	191

Structural Design Tables

Tables 16, 17, and 18 establish the PCC base thickness design solutions. Depending on the soil subgrade strength (M_r) and ESALs. The recommended minimum thickness of PCC base is 4 in. (100 mm) at and below 1,000,000 ESALs, and 5 in. (125 mm) above 1,000,000 ESALs.

Use the following steps to determine a pavement thickness:

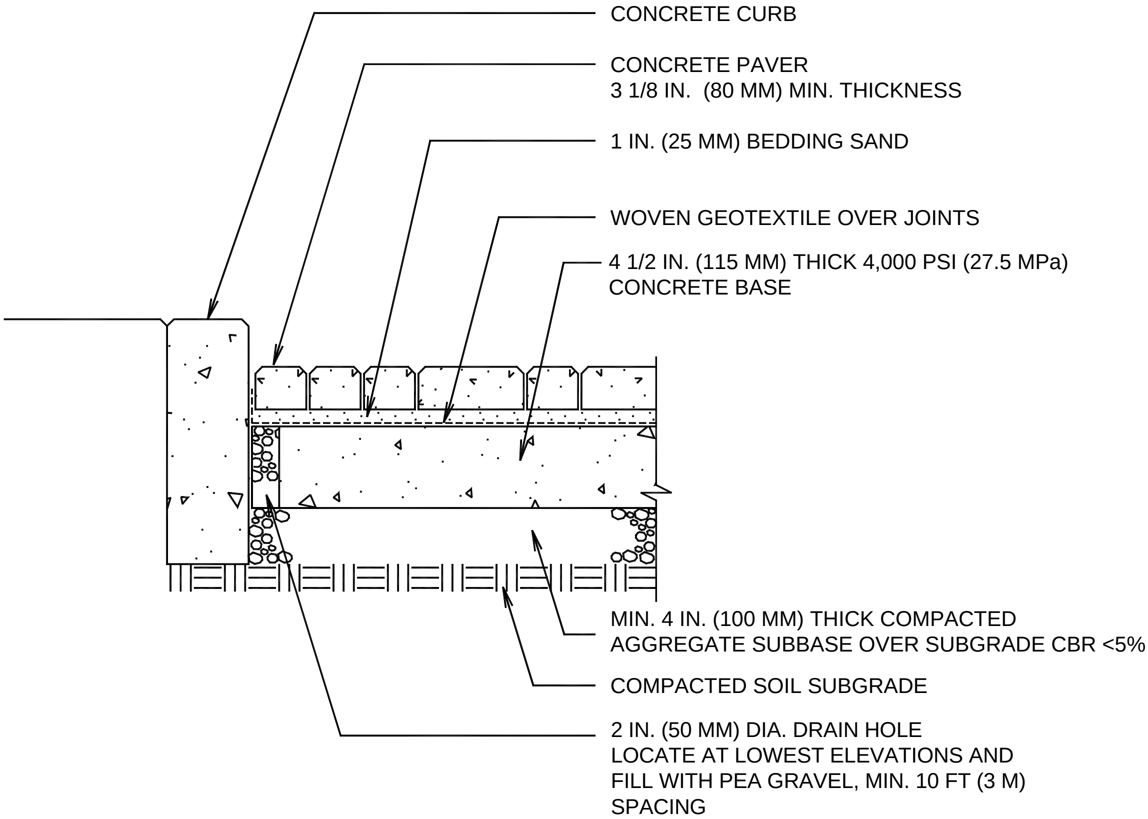
1. Compute design ESALs or convert computed TIs to design ESALs or use the recommended default values given in Table 1 as for flexible base design.
2. Characterize the soil subgrade strength from laboratory test data. If there is no laboratory or field test data, use Tables 3, 4 and 5 to estimate M_r.
3. Select the appropriate table (16, 17 or 18) depending on the compressive strength of the concrete base.
4. Determine the required PCC base thickness. Use M_r for design subgrade strength and design ESALs in the selected tables.

Example Solution and Results

For a given site where the soils are ML, it is assumed that an aggregate subbase will be used to provide a working platform and to protect the pavement from pumping related distress.

1. Estimate design load: 840,000 ESAL. Interpolate between 500,000 and conservatively select 1,000,000 when using Tables 16, 17 or 18.
2. Characterize subgrade M_r: 4,500 psi (31 MPa) from previous example. Conservatively select 5,000 psi (35 MPa) on Tables 16, 17 or 18.
3. Determine concrete strength: Consider 3,000 psi (21 MPa) and 4,000 psi (27.5 MPa) options on Tables 16 and 17.
4. Determine base thickness requirements: the thickness required for 3,000 psi (20 MPa) concrete is 5 in. (125 mm) and for 4,000 psi (28 MPa) concrete is 4 1/2 in. (115 mm).

The final cross section design is shown in Figure 9 on page 28 with 3 1/8 in. (80 mm) thick concrete pavers and a 1 in. (25 mm) thick bedding sand layer over 4 1/2 in. (115 mm) of 4,000 psi (27.5 MPa) PCC base and 4 in. (100 mm) compacted aggregate subbase since the soil M_r < 7,000 psi (48.2 MPa) which is CBR < 5%. Additionally, the concrete slab is jointed at 10 ft (3 m) centers and dowels are 1/2 in. (13 mm) diameter. The joints will be covered with a strip of woven geotextile, minimum 12 in. (300 mm) wide, to prevent bedding sand loss.



NOTES:

1. DRAIN BEDDING SAND OF EXCESS MOISTURE THROUGH PAVEMENT AT LOWEST POINTS AS SHOWN OR AT CATCH BASIN(S).
2. PROVIDE 1" (25 MM) HORIZONTAL DRAIN HOLES IN CATCH BASINS. BOTTOM OF HOLES TO BE EVEN WITH SURFACE OF EXISTING PAVEMENT. COVER HOLES WITH GEOTEXTILE.
3. DO NOT PROVIDE DRAIN HOLES TO SUBGRADE WHEN WATER TABLE IS LESS THAN 2 FT. (0.6 M) FROM TOP OF SOIL SUBGRADE. PROVIDE DRAIN HOLES TO CATCH BASINS.

Figure 9. Interlocking concrete pavers on a concrete base design example solution.

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ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®

Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

DUCON OUTDOOR LIVING

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TECH SPEC

NUMBER 5

Cleaning, Sealing and Joint Sand Stabilization of Interlocking Concrete Pavement

When properly installed, interlocking concrete pavements have very low maintenance and provide an attractive surface for decades. Under foot and vehicular traffic, they can become exposed to dirt, stains and wear. This is common to all pavements. This technical bulletin addresses various steps to ensure the durability of interlocking concrete pavements and to help restore their original appearance. These steps include removing stains and cleaning, plus joint stabilization or sealing if required.

Stains on specific areas should be removed first. A cleaner should be used next to remove any efflorescence and dirt from the entire pavement. A newly cleaned pavement can be an opportune time to apply joint sand stabilizers or seal it. In order to achieve maximum results, use stain removers, cleaners, joint sand stabilizers, and sealers specifically for concrete pavers. These may be purchased from a manufacturer, contractor, dealer or associate member of the Interlocking Concrete Pavement Institute.

Removing Stains

Commercial stain removers available specifically for concrete pavers provide a high degree of certainty in removing stains. Many kinds of stains can be removed while minimizing the risk of discoloring or damaging the pavers. The container label often provides a list of stains that can be removed. If there are questions, the supplier should be contacted for help with determining the effectiveness of the chemical in removing specific stains.

Figure 1. Many sealers enhance the appearance of concrete pavers and protect against staining.

Identify the stains prior to applying the cleaner. A test application should be evaluated in a small, inconspicuous stained area for cleaning effectiveness. Some stains may require repeated applications of the remover to achieve effective cleaning. This is often the case for deep set oil stains. With all stain removers, cleaners, joint sand stabilizers, and sealers, the label directions and warnings should be read and carefully followed for all precautions.

Start removal of stains at the bottom of the pavement and work up the slope in manageable sections. By working up the slope, cleaning fluids will drain down the pavement. This technique assists in uniform removal while allowing the used cleaner to be rinsed away consistently. The surface remains dry ahead of the cleaner-soaked wet areas, allowing better visibility of the stains to be removed.

Take care in selecting and applying cleaning products, as acidic ones may harm vegetation and grass. These cleaners should not run onto vegetation. When using strong acidic stain removers or cleaners that might drain onto vegetation, saturate the vegetation with water prior to using acidic cleaners. This will minimize absorption of cleaner rinse water and reduce risk of damage to vegetation.

Removal of Common Stains

There are proprietary cleaning products specifically designed for concrete pavers. Many have been developed through extensive laboratory and field testing to ensure cleaning effectiveness. These chemicals should be used whenever possible. Using manufactured cleaning chemicals for specific stains relieves the user from the uncertainty of attaining the proper mixture of chemicals.

If no proprietary stain removal products are available, a comprehensive source of information on stain removal is found in *Removing Stains from Concrete* by William H. Kuenning. It describes chemicals, detergents or poultice (scrubbing) materials recommended for removing particular stains, and the steps to be followed in removal. This publication recognizes that some of the treatments involve hazardous chemicals and it advises specific precautions.

Removal of several common stains from *Removing Stains from Concrete* are listed below (1). Most involve typical household chemicals. The information given is the best available at the time of writing. The ICPI disclaims any and all responsibility for the application of the information. The user is advised to use cleaners specifically made to remove stains that commonly occur on concrete pavers. They will likely be more effective.

Asphalt and emulsified asphalt —Chill with ice (if warm outside), scrape away and scrub the surface with scouring or abrasive powder. Rinse thoroughly with water.

Cutback asphalt and roofing tar —Use a poultice made with talc or diatomaceous earth. Mix with kerosene, scrub, let dry and brush off. Repeat as needed.

Blood, candy, ketchup, mustard, grease drippings from food —For stubborn stains, apply liquid detergent full strength and allow it to penetrate for 20 to 30 minutes. Scrub and rinse with hot water. Removal is easier if these stains are treated immediately.

Caulking —Scrape off excess and scrub with a poultice of denatured alcohol. Rinse with hot water and detergent. Acrylic latex caulk—follow guidelines for removal of latex paint.

Chewing gum —Same as caulking, or scrub with naphtha.

Clay soil —Scrape off dry material, scrub and rinse with hot water and strong detergent.

Creosote —Apply a poultice with paint thinner and talc. Scrub and allow to dry. Scrape off, scrub with scouring powder and rinse with water.

Leaf, wood rot, or tobacco stains —apply household bleach and scrub with a stiff bristled brush.

Mortar —Let harden and carefully remove hardened spots with a trowel, putty knife or chisel.

Smoke —Scrub with a poultice of talc with bleach diluted 1:5 with water. Rinse with water.

Oil or grease that has penetrated —Mop up any excess oil with rags. Cover the area with oil absorbent (kitty litter). Talc, fuller's earth, diatomaceous earth can be used. Leave it on the stain for a day then sweep up.

Paint —Fresh paint should be mopped up immediately with rags or paper towels by blotting. Do not wipe as this will spread the paint and extend the job of removal. If the paint is latex and water based, soak and then scrub the area with hot water, scouring powder and a stiff brush until no more improvement is seen. Let the remaining paint dry and remove as described below.

Dried paint —Scrape any excess oil based paint, varnish or water based latex paint off the surface. Apply a commercial paint remover and let it sit for 20 to 30 minutes. Loosen with gentle scrubbing. Do not rub the loosened paint into the surface of the paver. Instead, blot up the loosened paint and thinner. Repeat as necessary.

Tire skid marks —Scrub black area with water, detergent and scouring powder.

In the case of small stained areas, removal and replacement with new pavers may be an option.

Overall Cleaning

Overall cleaning of the pavement can start after stains are removed. In preparation for cleaning, low tree branches, shrubs and vegetation adjacent to the pavement should be tied back or covered to protect from overspray of cleaning solutions or sealers. The area should be inspected for any cracked or broken units. These should be replaced. Badly stained units can be replaced, but it is usually easier to clean stains and less costly than replacing the pavers.

When pavers have stains too difficult to remove, replace them with the same type of units. Refer to ICPI Tech Spec 6, Reinstatement of Interlocking Concrete Pavements, for a full description on replacing pavers. If pavers must be replaced, there may be a difference in color from the surrounding pavers. This variation should eventually disappear. If color variation is unacceptable, controlled use of proprietary cleaners designed to improve the color of concrete pavers can minimize variation.

Removal of accumulated dirt and efflorescence is the objective of cleaning. It is essential in preparing the pavers for sealing as well. Many cleaners effective in removing dirt and efflorescence are a mix of detergent and acid. Cleaners with strong acids will change the color of the pavers slightly. The degree of change can be controlled by the type of acid in the cleaner, its concentration and the length of time on the pavers. Proprietary cleaners will give specific instructions on their application. These directions should be followed. In order to achieve proper results, cleaners should be tried on a small area to test results and any color changes. The concentration and time on the pavement can be adjusted accordingly. Protective clothing and goggles should always be worn when using acidic solutions.

Anticipate where the cleaning fluids will drain, i.e, across the pavement and not onto grass or vegetation. Sediment or cleaners allowed to pond in low spots may stain the pavers. If unsure of the runoff direction, test drainage with ordinary water first to identify any trouble spots. Be sure to rinse these areas thoroughly. Turn off all automatic sprinkler systems during cleaning, sealing and drying.

Professional Cleaning Methods

For most jobs, cleaning should be handled by a professional company experienced in the use of cleaners and spray equipment. Professionals typically use a pressure washer and an applicator to apply efflorescence cleaner (when needed). The various methods for applying joint sand stabilizers and sealers are covered later.

A high pressure sprayer applies cleaner and water between 600 and 2,000 psi (4.1 and 13.8 MPa), and at a rate between 6 and 12 gallons/minute (22 and 45 liters/minute). See Figure 2. The rate of flow is adjusted to ensure sufficient rinsing. The pressure loosens dirt and pushes water from the surface without the need for scrub brushes. The nozzle type and its distance from the paver surface influences the effectiveness of the cleaning as well. A nozzle that creates a wide spray enables a large area to be covered efficiently and prevents sand from being washed from the joints. A low angle of attack from a wide nozzle spray will also reduce the risk of dislodging joint sand.

Cleaners to remove efflorescence are applied with a low pressure pump spray 30 to 100 psi (0.2 to 0.7 MPa). A shower type spray nozzle will help ensure even distribution of the cleaner. Cleaning chemicals are applied, allowed to sit an appropriate time, then rinsed away with a high pressure sprayer. The final rinse should be water only. A large amount of water is more important to rinsing than high pressure.

For small areas, an adequate cleaning job can be achieved without this equipment. Such areas include residential patios, walks, or small driveways. Cleaners can be applied by hand, the pavers scrubbed to remove dirt and efflorescence, then thoroughly rinsed with water from a garden hose. Scrub brushes with steel bristles are not recommended. They will loosen from the brush, rust, and leave stains. Brass or plastic bristles are acceptable. This method of cleaning is for do-it-yourselfers who wish to refurbish a small area of pavers.

The additional time required to clean and seal pavers without the help of a professional should be weighed against investing in a competent company to do the job. Professionals have the equipment and experience with the various chemicals. They can achieve the highest level of results in the least amount of time.

Efflorescence and Its Removal

Efflorescence is a whitish powder-like deposit which can appear on concrete products. When cement hydrates (hardens after adding water), a significant amount of calcium hydroxide is formed. The calcium hydroxide is soluble in water and migrates by capillary action to the surface of the concrete. A reaction occurs between the calcium hydroxide and carbon dioxide (from the air) to form calcium carbonate, then called efflorescence.

Efflorescence does not affect the structural performance or durability of concrete pavers. The reaction that takes place is the formation of water soluble calcium bicarbonate from calcium carbonate, carbon dioxide and water. It may appear immediately or within months following installation. Efflorescence may reach its peak in as short as 60 days after installation. It may remain for months and some of it may wear away. If installation takes place during dry period of the year, the next cycle of wet weather may sometimes be necessary for efflorescence to materialize.

If there is a need to remove deposits before they wear away, best results can be obtained by using a proprietary efflorescence remover. The acid in proprietary cleaning chemicals is buffered and blended with other chemicals to provide effective cleaning without damage to the paver surface. Always refer to the paver supplier or chemical company supplying the chemicals for recommendations on proper dilution and application of chemicals for removal of efflorescence. They are generally applied in sections beginning at the top of slope of the pavement. If the area is large, a sprayer is an efficient means to apply the cleaner. The chemicals are scrubbed on the surface, then rinsed away. Results can be verified after letting the area dry for at least 24 hours. In most instances one application is sufficient. However, in severe instances of efflorescence, a second application may be necessary. Contact the manufacturer of the cleaning product to determine if a second application will not discolor the pavers or expose some aggregates. Note: Protective clothing, chemical resistant rubber boots and gloves, and eye goggles should be worn when applying acid or alkalies.

Figure 2. Pressurized cleaning equipment used by professional cleaning and sealing companies can bring out the best appearance from pavers.

Joint Sand Stabilizers And Sealers

Stabilizer and sealers are two distinct products sometimes with overlapping functions. Joint sand stabilizers help secure sand in the joint after it has been installed. Their primary function reduces the risk of removal of joint sand from flowing water, wind, aggressive cleaning, tire action and intrusion of organic matter, seeds and ants.

Joint sand stabilizers come in liquid and dry applied forms. Some liquid stabilizers are made of the same materials as sealers, but with a higher solids content with additional wetting agents. When applied to the paver surface and joints, stabilizers can make the surface easier to clean and prevent staining in a manner similar to sealers. Depending on the chemical contents, liquid stabilizers may or may not change the appearance of the paver surface.

All surface sealers are applied as liquids. Their primary function is providing additional protection to concrete paver surfaces. Such chemicals can be similar to products used to seal cast-in-place concrete slabs. Sealers are applied to the entire surface of an installation to add further protection from stains, oils, dirt, or water. Occasionally, sealers are applied to pavers during manufacturing. Whether applied in a factory or on a site, most sealers change the appearance of the paver surface by darkening it and enhancing the surface color. Since liquid sealers penetrate the joint sand to some extent during application, they secondarily provide some stabilization.

Joint Sand Stabilizers

Liquid and dry applied stabilizers provide initial protection against joint sand loss. They accelerate joint sealing that can normally occur from a combination of atmospheric dust deposits, dirt and sediment that finds its way to the pavement, and contributions from passing tires. Stain removal, efflorescence removal, and overall surface cleaning should precede application of liquid stabilizers in new construction. None of these preparatory treatments are needed prior to the application of a dry applied stabilizer. It is applied first with the joint sand to complete the paver surface and begin interlock. Stain and efflorescence removal, cleaning and sealing can be done subsequently.

Joint sand stabilization materials are fairly new, so no industry-wide guidelines yet exist on the expected lifetime or reapplication rates. Some stabilized joints in pavements show years of longevity. There is evidence that projects in freeze-thaw climates have performed well for more than six years.

Joint sand stabilization is generally optional and not required for many interlocking concrete pavements. Sand in joints will likely stabilize over time without additional treat

Figure 3. This liquid joint sand stabilizer is applied with a low-pressure sprayer and squeegeed across the surface after allowing some time for soaking into the joints. This helps maintain slip and skid resistance of the paver surface.

Figure 4. Liquid joint sand stabilizers can deepen the surface color slightly and they provide some surface sealing as well. Tumbled pavers shown here have wider joints than other shapes. These type of pavers can require stabilization of the joint sand.

Figure 5. Joint sand can be pre-mixed and delivered to the site (typically in bags), or mixed with stabilizer at the site, then swept into the joints, compacted for consolidation in them to create interlock, and wetted to activate the stabilizer.

ment as a result of silts or other fines working their way into spaces between the sand particles. The rate of stabilization depends on the amount and sources of traffic, plus sources of fines that work their way into the joints from traffic over time.

There are some applications where early stabilization of the joints is important to maintaining functional performance of the paver surface. For example, stabilization is recommended on high slope applications over 7% and on applications where the slope is less than 1.5%. Applications on high slopes will help prevent washout of joint sand. Stabilizers in very low slope or flat areas can help reduce infiltration of standing water.

Stabilization benefits pavements subject to aggressive, regular cleaning. Examples might include amusement parks and restaurant exteriors. Pavements that see regular, heavy rainfall can benefit from stabilization of the joint sand. Surfaces that experience concentrated water flow such as gutters receiving sheet flow from large areas or at the drip lines under the eaves of buildings will better resist erosion of joint sand if stabilized.

Figure 6. Whether using liquid or dry joint stabilization materials, the surface of the pavers should be cleaned with a blower or broom after the joint sand is compacted into the joints.

Figure 7. Dry-applied joint sand with a stabilizer is wetted in order to activate it and stiffen the sand. Once the joints dry, they are stabilized.

Stabilizers have been effective in securing joint sand in places subject to high winds such as in desert climates. They can prevent joint sand displacement from high-speed tire traffic. Like sealers, joint and stabilization materials reduce the potential for weeds and ants in the joints. In residential applications stabilization at downspouts and under eaves helps keep joint sand in place. Tumbled pavers (cobble stone-like units) and circular patterns have wider joints than other paver shapes. Tumbled pavers may require stabilized joint sand between them if they have slightly irregular sides and wide joints.

Studies on the permeability of the surface of interlocking concrete pavements have indicated ranges between 10% and 20% perviousness (2). The rate of permeability depends on several factors. They include the fineness of the joint sand (percent of material passing the No. 200 or 0.075 mm sieve), the joint widths, slope, consolidation of the sand plus the age of the installation. Newly placed pavers have higher permeability (as much as 25%) than installations trafficked for several years. Sealers and joint sand stabilizers can contribute to long-term performance by reducing infiltration of water to the bedding sand and base.

Liquid Penetrating Stabilizers

These are water or solvent-based with the primary resin or bonding agent being an acrylic, epoxy, modified acrylic, or other polymers as solids (by volume) typically 18% to 28%. Solvent or water carries the solids into the joint sand. They will evaporate and leave the solids behind as the binding agent. Modifiers such as epoxy resins may also add to the ability of the product to create a solid matrix in the joint sand. When initially applied, liquid stabilization materials should be allowed to penetrate at least 3/4 inch (20 mm) into the joint sand. A mock-up is beneficial in determining application rates for specific products, joint sands, and for specific job site conditions.

Joint sand gradation can affect the depth of penetration of the liquid stabilizer. The amount of fines or material passing the No. 200 (0.075 mm sieve) can influence the depth of penetration. A joint sand gradation with less than

5% passing the No. 200 (0.075 mm) sieve can allow better penetration of liquid stabilizers. A job site mock-up should be tried to determine the penetration rate. The mock-up also will determine the appropriate application rate.

Prior to applying liquid materials, the surface should be clean and dry and any efflorescence removed from the pavers. Either a broom or leaf blower can efficiently remove excess sand. Some successful methods of application involve applying liquid joint stabilizers with low pressure, high volume spray, followed immediately by a squeegee to move the material into the joints. See Figure 3. Other methods use rollers, watering cans, or hand pumped, garden-type sprayers. Some equipment has multiple spray nozzles and mechanized rollers and/or squeegees. All application methods must provide uniform dispersion and effective penetration.

Liquid stabilizers bind the sand in the joint and secondarily provide sealing of the concrete paver surface. All liquid based stabilizers create some change in the appearance of the pavers. This ranges from a slight color enhancement, a modest sheen, to a high gloss. Like sealers, cured liquid stabilizers that remain on the surface of the pavers enhance their color, inhibit fading, and protect against staining. It also makes the paver surface easier to clean and maintain (Figure 4). However, joint sand stabilization will last significantly longer than the enhancement of the surface appearance.

Dry Joint Sand Stabilizers

These are dry additives mixed with joint sand. The additives are organic, inorganic, or polymer compounds that stiffen and stabilize the joints when activated by water applied to the joint sand. Additives come either pre-mixed with bagged joint sand, or are sold separately as an additive mixed with the joint sand on the job site per the supplier's instructions. The additive is often mechanically mixed for consistency. Dry stabilizers are appropriate for residential settings, parking lots, bike lanes, plazas, and other areas with low velocity wheel loads or areas without concentrated water flow. They are convenient for application by homeowners. Some dry stabilizers have been successfully used in high traffic streets.

The pavers are initially compacted into the bedding sand. Joint sand is applied to the surface with a stabilizer additive mixed in it. See Figure 5. It is then compacted into the joints with a plate compactor like all interlocking concrete pavement installations. After compaction and removal of all sand from the paver surface, the joints are wetted. When dry, the material in the sand stabilizes the full depth of the joint and it helps maintain interlock among the pavers. For either pre-mixed or job site mixed additives, a job site mock-up is beneficial for determining the depth of stabilization. The mock-up will determine the rate and application method of water to ensure full activation of the stabilizer. A mock-up will confirm a consistent method for uniform distribution of the additive in the sand for job site mixed additives in particular.

Prior to application, blowing or sweeping the surface clean is recommended. See Figure 6. Since water activates these products, no moisture should be present on the surface or in the joints until they are ready to be placed in the joints. Once the pavers and joint sand are compacted, the joints are full of sand, and all excess sand is removed from the surface, water is added to activate the bonding agent. The water is applied as a light, wide spray, and allowed to collect and soak into the joints (Figure 7). A narrow spray should not be used because it can dislodge sand from the joints. It is imperative to immediately remove any excess moist joint sand that inadvertently gets on the surface of the pavers. Otherwise, once it is moistened and allowed to cure on the surface, the sand will need to be removed with hot water. Some stabilizers may require removal with a wire brush or a pressure washer. Dry products will not leave a surface sheen like liquid stabilization products. This can be beneficial for a contractor or owner who needs to stabilize isolated areas through selected application of the product.

Installation, Functional and Structural Considerations

Liquid and dry applied joint stabilizers are not a substitute for recommended installation practices. Prior to their application, all liquid stabilization products require that the joint sand be compacted and consolidated in the joints until full. Some dry stabilizers require mixing with joint sand then sweeping, filling, and compacting the sand and pavers until the joints are full. Other stabilizers are premixed in bags and are ready for filling the joints. Stabilizers resist many of environmental conditions that lead to functional deterioration of the paver surface. However, stabilizers do not add to the structural (load bearing) capacity of the pavement. Therefore, structural calculations for base thickness design should not consider a joint sand stabilizer.

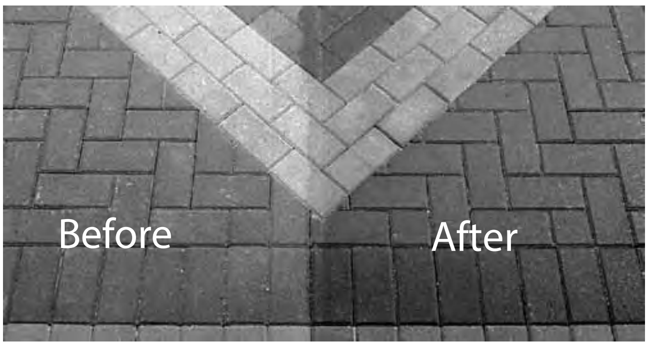

Figure 8. Before and after application of an acrylic sealer shows how it deepens the appearance of concrete pavers.

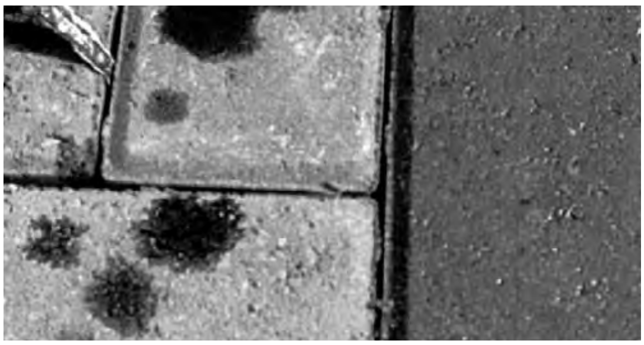

Photo courtesy of Resiblock

Figure 9. Sealers resist stains which makes them ideal for high use areas where they might occur.

Sealers

Uses

Sealers reduce the intrusion of water, stains, oils and dirt into the paver surfaces. Like stabilizers, application of a sealer follows stain removal, efflorescence removal and overall surface cleaning. Sealers are used for visual and functional reasons. They offer visual improvement by intensifying the paver colors. Some will add a glossy sheen or "wet" look to the pavement (see Figure 8). Other sealers offer some color enhancement and produce a low sheen, or a flat finish.

Sealers offer many functional advantages. They can protect pavers from stain penetration. They are useful around trash receptacles, fast food restaurants, driveways, other areas subject to stains, and where oil drippings are not wanted (see Figure 9).

Like stabilizers, sealers are also useful in stopping unwanted insects and weeds. Sealers can stabilize joint sand between pavers cleaned by vacuum sweeping equipment. They can help maintain the sand in the joints under high velocity water flows. Where solvents may be spilled onto pavers, elastomeric urethanes and certain water based sealers have been successfully used to prevent their penetration. Likewise, special urethane sealers have been used to seal and stabilize joint sand subject to propeller wash, jet engine fuels and exhaust in commercial and military airports (2).

Types of Sealers for Concrete Pavers

Table 1 lists the various types of sealer for concrete pavers. The table suggests applications and compares important properties (3). The sealer manufacturer or supplier should be consulted prior to using any sealer to verify that their product will perform in the environment planned for its use. Sealers not recommended for use with pavers are alkyds, esters, and polyvinyl acetates. Epoxies and silicones are generally not used on concrete pavers.

Solvent and Water Based Sealers

Like stabilizers, sealers can be either solvent or water based. Solvent based sealers consist of solids dissolved in a liquid. Solvent based products carry the dissolved solids as deep as the solvent will penetrate into the concrete paver. After the solvent evaporates, the sealer remains.

Water based sealers are emulsions, or very small particles of the sealer dispersed in water. Water based sealers penetrate concrete as far as the size of the particles will permit. After the water evaporates, typically at a slower rate than solvents, the remaining particles bond with the concrete and to each other. These particles cannot penetrate as deeply as those carried by solvents. Water based sealer curing time will vary with the temperature, wind conditions and humidity.

Silanes/Siloxanes

Silanes and siloxanes penetrate concrete well. Silanes are the simpler form that, when exposed to moisture, begin to link up to other silanes. Siloxanes do the same linking together. Both chemicals become a polymer, curing as a film in the capillaries of the concrete. A hydrophobic barrier to moisture is created, preventing moisture from entering but allowing the concrete to "breathe" or release water vapor.

Because silanes and siloxanes reduce moisture from entering the concrete, they can deter efflorescence from appearing on the surface of concrete pavers. They initially enhance colors and produce a flat, no-gloss finish on the paver surface. This makes silanes and siloxanes very suitable on exterior areas for resisting efflorescence when a glossy surface is not desired.

Silanes and siloxanes do not resist penetration of petroleum stains unless they have additives specifically for that purpose. When required, proprietary mixtures with additives can increase petroleum stain resistance. Other additives can ensure greater consistency in the color of pavers and avoid a blotchy appearance.

Silanes have smaller molecules, so they penetrate farther into the concrete than larger siloxane molecules. However, they are more volatile (tend to evaporate) until they bond to the concrete paver. Silane sealers generally require a higher percent of solids to counteract their rate of evaporation. Therefore, silanes tend to be more expensive than siloxanes.

Silanes and siloxanes are typically used as water repellents for concrete bridge decks, parking garages, and masonry walls. Their primary use for reinforced concrete structures is to prevent the ingress of chloride ions from deicing salts (4). This intrusion causes reinforcing steel corrosion in the concrete, and a weakened structure. Their ability to decrease intrusion of chloride materials provides additional protection of pavers subject to deicing salts or salt air, such as walks, streets, parking lots, plaza roof and parking decks. They are also useful around pool decks to minimize degradation from chlorine.

Most silane and siloxane sealers are solvent based. Certain manufacturers offer water based products as well. These products may have a very short shelf life after the silane or siloxane has been diluted with water. The user should check with the manufacturer on the useful life of the product.

Acrylics

Acrylic sealers can be solvent or water based. They enhance paver colors well and create a gloss on the surface. Acrylic sealers provide good stain resistance. Their durability depends on traffic, the quality of the acrylic and the percentage of solids content. They provide longer protection from surface wear than silanes or siloxanes.

Acrylic sealants are widely used in residential and commercial paver applications. They generally last for a few years in these applications before re-coating is required. Acrylics specifically developed for concrete pavers do not yellow over time. When they become soiled or worn, pavers with acrylics can be easily cleaned and resealed without the use of extremely hazardous materials.

Acrylics should not be used on high abrasion areas such as industrial pavements or floors. Water based acrylics perform well for interior applications. They may be allowed by municipalities that regulate the release of volatile organic contents (VOCs) in the atmosphere.

Urethanes

As either solvent or water based, polyurethanes produce a high gloss and enhance the color of pavers. Aromatic ure-

Table 1—Properties of Sealers for Concrete Pavers—Confirm application and properties with supplier.

	Patios, walks, pool decks	Residential/ Com1ercial dri ves	Gas Stations Airports	Areas subject to chlorine &hea vy de-icing salts	Finish	Enhances color	Joint sand stabilizer	UVr esistant	Can be re-coated	Ease of removal	Price
Silane	Yes	Yes		Yes	Flat	*		Yes	Yes	Mod.	++
Siloxane	Yes	Yes		Yes	Flat	*		Yes	Yes	Diff.	++
Acrylic	Yes	Yes			Gloss	Yes	Yes	Varies	Yes	Diff.	+
Urethane	Yes	Yes	Yes	Yes	Gloss	Yes	Yes	Varies	No	V. Diff.	++
Water-based Epoxy	Yes	Yes	Yes	Yes	Semi-Gloss	Yes	Yes	Yes	Yes	Mod.	++

*Initially, then diminishes. Diff.=Difficult V. Diff.=Very Difficult +=Moderate Price ++=Higher price

thanes should contain an ultra-violet (UV) inhibitor to reduce yellowing over time. The product label should state that the sealer is UV stable. Urethanes themselves are more resistant to chemicals than acrylics.

While aliphatic urethanes can be used for coating the surface of pavers, elastomeric (aromatic or aliphatic) urethanes should be used where the primary need is to stabilize joint sand. For airfield and gas station applications, the urethane should have a minimum elongation of 100% per ASTM D 2370, Standard Test Method for Tensile Properties of Organic Coatings. Urethanes resist degradation from petroleum based products and de-icing chemicals. This makes them suitable for heavy industrial areas, as well as airfield and gas station pavements.

Urethanes cannot be rejuvenated simply by re-coating. If urethane sealers must be removed, methylene chloride or sand blasting is often necessary. Methylene chloride is a hazardous chemical, and is not acceptable for flushing into storm drains. It should not be allowed to soak into the soil. Therefore, urethane removal is best handled by professionals.

Water Based Epoxy Sealers

Water based epoxy sealers combine other types of sealers with epoxy. They cure by chemical reaction as well as by evaporation. They have very fine solids allowing them to penetrate deep into concrete while still leaving a slight sheen to enhance the color of the pavers. They generally do not change the skid resistance of the surface. When applied, water based epoxy sealers create an open surface matrix that allows the paver surface to breathe thereby reducing the risk of trapping efflorescence under the sealer should it rise to the surface. They resist most chemicals and degradation from UV radiation. These characteristics make these types of sealers suitable for high use areas such as theme parks and shopping malls. The elasticity and adhesion of these sealers make them appropriate for heavily trafficked street projects and areas subject to aggressive cleaning practices.

Sealing Procedures

All dirt, oil stains and efflorescence must be removed prior to sealing. The cleaned surface must be completely dry prior to applying most sealers. Allow at least 24 hours without moisture or surface dampness before application. The pavers may draw efflorescence to the surface, or the sealer or liquid stabilizer may whiten under any one of these conditions:

- The surface and joints are not dry
- The pavers have not had an adequate period of exposure to moisture
- There is a source of efflorescence under the pavers (i.e, in the sand, base, or soil) moving through the joint sand and/or pavers
- The sealer is not breathable, i.e., does not allow moisture to move through to the surface of the paver and evaporate.

If the base under the pavers drains poorly, the sealer is applied to saturated sand in the joints, or is applied too thick, the sealer can become cloudy and diminish the appearance of the pavers. In this situation, the sealer must be removed or re-dissolved. Consult your sealer supplier for advice on treating this situation.

Cover and protect all surfaces and vegetation around the area to be sealed. For exterior (low-pressure) sprayed applications, the wind should be calm so that it does not cause an uneven application, or blow the sealer onto other surfaces. For many sealers, especially those with high VOC's, wear protective clothing and mask recommended by the sealer manufacturer to protect the lungs and eyes.

Sealers can be applied with a hand roller if the area is small (under 1000 ft^2 or 100 m^2). For larger areas, more efficient application methods include a powered roller, or a low pressure sprayer. Sealers are often applied with a foam roller to dry pavers having clean surfaces and chamfers. However, the use of a squeegee to spread the sealer will avoid pulling joint sand out of the joints. See Figure 10.

Figure 10. Urethane is applied with squeegees to stabilize joint sand between pavers on aircraft pavement.

Sealer should be spread and allowed to stand in the chamfers, soaking into the joints. Penetration into the joint sand should be at least 3/4 inch (20 mm). The excess sealer on the surface is pushed to an unsealed area with a rubber squeegee. The action of a squeegee wipes most of the sealer from the surface of the pavers while leaving some remaining in the chamfers to eventually soak into the joints. Generally only one coat is required.

For other applications, follow the sealer manufacturer's recommendation for application and for the protective gear to be worn during the job. With some sealers that recommend two coats, the first coat is usually applied to saturation. A light second coat, if needed, can be applied for a glossy finish. Be careful not to over apply the sealers such that the surface becomes slippery when cured. For water based sealers requiring two coats, always apply the second coat while the first coat is still very tacky. Prevent all traffic from entering the area until the sealer is completely dry, typically 24 hours.

If spraying sealer on the pavers, care should be taken to prevent the spray nozzle from clogging and causing large droplets to be unevenly distributed on them. This is most important for water based sealers. This can cause a poor appearance and performance.

Sealers normally require reapplication after a period of wear and weather. The period of reapplication will depend on the use, climate, and quality of the sealer.

Safety Considerations

Adequate slip (foot) and skid (tire) resistance of concrete pavers should be maintained with properly applied joint sand stabilizer or surface sealers. See *ICPI Tech Spec 13 – Slip and Skid Resistance of Interlocking Concrete Pavements* for test methods and guidelines. See www.icpi.org to obtain this and all ICPI Tech Spec technical bulletins. The manufacturers of stabilization and sealers should be consulted concerning slip and skid resistance performance characteristics under wet and dry conditions.

Some commercial or industrial pavement use painted pavement markings. Consult with the stabilizer and sealer manufacturers for compatibility of their materials with pavement markings. Where there are pavement markings, applications using high gloss materials should be avoided as they can increase the difficulty of reading pavement markings under certain light conditions.

Federal, state/provincial, and some municipal governments regulate building materials with high volatile organic contents (VOCs). The restrictions usually apply to solvent based sealers. The VOC level of a sealer refers to the pounds per gallon (or grams per liter) of solvent which evaporates from the sealer, excluding the water. VOCs have been regulated since they can contribute to smog. Most water based sealers comply with VOC restrictions and some solvent based products may comply as well. The user should check with the sealer supplier to verify VOC compliance in those areas that have restrictions.

Many solvent based products are combustible and emit hazardous fumes. Therefore, flame and sparks should be prevented in the area to be sealed. Never use solvent based sealers in poorly ventilated or confined areas.

Persons applying joint sand stabilizers and sealers should wear breathing and eye protection as recommended by the manufacturer, as well as protective equipment mandated by local, state/provincial, or federal safety agencies. Follow all label precautions and warnings concerning handling, storage, application, disposal of unused materials, and those required by all government agencies.

The U.S. Federal Government and Canadian Government require that all shipments of hazardous materials by common carrier must be accompanied by a Material Safety Data Sheet (MSDS). All chemical manufacturers must supply sheets to shippers, distributors and dealers of cleaners, joint sand stabilizers, and sealers if the materials are hazardous. The MSDS must accompany all shipments and be available to the purchaser on request. The MSDS lists the active ingredients, compatibility and incompatibility with other materials, safety precautions and an emergency telephone number if there is a problem in shipping, handling or use. The user should refer to the MSDS for this information.

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ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®

Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

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NUMBER 6

Reinstatement of Interlocking Concrete Pavements

Introduction

Concrete pavers can act as a zipper in the pavement. When the need arises to make underground repairs, interlocking concrete pavements can be removed and replaced using the same material. Unlike asphalt or poured-in-place concrete, segmental pavement can be opened and closed without using jack hammers on the surface and with less construction equipment. This results in no ugly patches and no reduction in pavement service life. In addition, no curing means fast repairs with reduced user delays and related costs.

The process of reusing the same paving units is called reinstatement. This Tech Spec covers how to reinstate or "unzip and zip" interlocking concrete pavement. The following step-by-step procedure applies to any interlocking concrete pavement, including pedestrian areas, parking lots, driveways, streets, industrial, port and airport pavements.

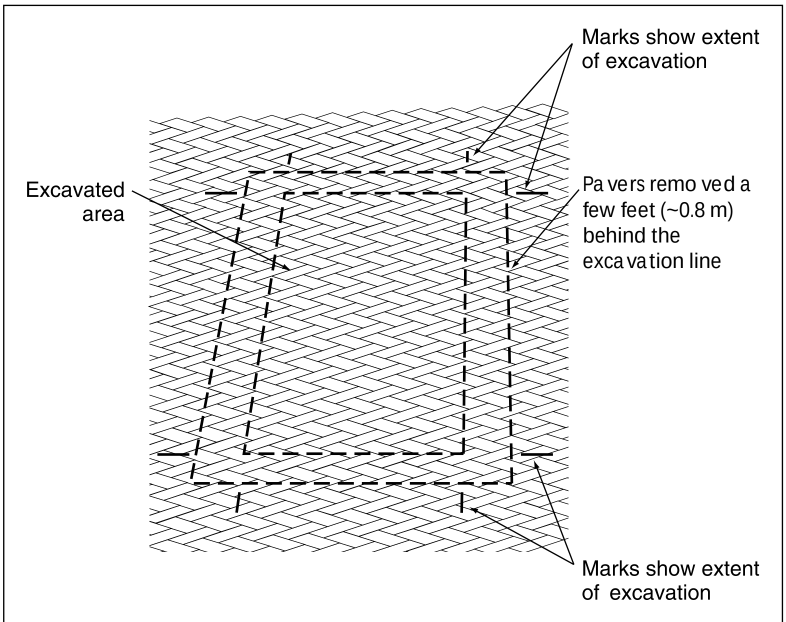

Figure 1. Pavement markings show the extent of paver removal and trench area.

Step 1—Locate Underground Utilities in the Area to be Excavated

The location and depth of existing utilities should be established prior to excavating. Many localities have one telephone number to call for obtaining marked utility locations. Set cones, traffic signs, or barricades around the area to be excavated according to local and state or provincial standards.

Determine and mark the area of pavers to be removed. Remove pavers a few feet (~0.8 m) wider on each side of the trench opening. This shoulder around the opening should consist of undisturbed bedding sand. It will be used as a guide for reinstating the sand and pavers later (Figure 1).

Paint or crayon should be used to mark the area of pavers for removal. The trench area can be marked on the pavers as well. Paint may be necessary to establish a more permanent marking than crayon, especially if there is vehicular traffic, or if there will be an extended period of time between marking and excavation. The same paving units will be reused, so in some instances paint on them may not be desirable, especially if there is little traffic to wear it away over time.

Step 2—Remove the First Paver

Locate the first paver to be removed. This is typically at one end of the marked area. Scrape the sand from the joints around the first paver using a putty knife or small trowel (Figure 2). Carefully pry each side upward with one or two large screwdrivers. Begin prying on the short ends of the paver. The paver will rise a small distance with each prying (Figure 3). When the paver is high enough to grasp, wiggle it loose, pulling upward. If necessary, pry with a screwdriver using one hand while

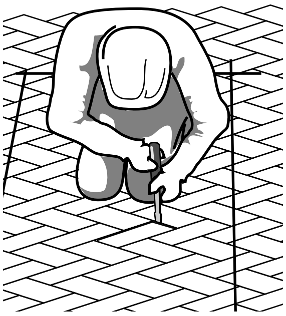

Figure 2. Removing joint sand surrounding the first paver to be removed.

Figure 3. Prying the paver upwards with two large screwdrivers.

Figure 4. Prying with a screwdriver and pulling the paver out.

pulling upward with the other (Figure 4). Sometimes, one end of the paver can be pulled above the others so a pry bar can be inserted under it. The paver can then be pried out.

Paver extractors can also be used to remove the first paver and subsequent ones (Figure 5). They are designed to clamp the paver tightly. These work most efficiently in removing the first paver if some of the joint sand is removed before clamping and pulling. Water can be applied to lubricate the joint sand to facilitate extraction.

If the pavement has been subject to vehicular traffic for a length of time, the first paver may be need to be broken in order to be removed. A small sledge hammer (3 lb. maul) applied to an appropriate chisel will break a paver into small pieces. Protective eye goggles should be worn during this procedure. Remove all broken pieces from the space until the bedding sand is completely exposed. Pneumatic hammers or cutting saws are generally not required to remove the first unit.

Figure 5. Using a paver extractor to remove a paver

Step 3—Remove the Remaining Pavers

After the first one is removed, surrounding pavers can be loosened and pried out (Figure 6). Grab the pavers by the short end, as it offers less resistance than the long side (Figure 7). Remove pavers to the marks on the pavement for the opening.

Sand sticking to the sides and bottoms of pavers can interfere with their reinstatement and compaction into the bedding sand. Scrape off sand from each unit as it is being removed. A small trowel, wide putty knife, wire brush, or another paver works well.

The direction of removal should consider where pavers are going to be stacked. Stack the pavers neatly near the opening, out of the way of excavation equipment such as backhoes or dump trucks. If the pavers need to be re moved from the site, stack them on wooden pallets and secure them tightly so there is no loss during transit.

Equipment used to move pallets with pavers should be capable of lifting at least 3,000 lbs. (1,365 kg). If the pavers need to be moved only a short distance, then stack them directly on a paver cart at the opening and set them nearby. They will then be ready for pick up by the paver cart when reinstated.

For every project, a small stockpile of spare pavers should be stored and used for repairs during the life of the pavement. Weathering, wear and stains may change the appearance of removed pavers compared to spares kept in storage for repairs. When pavers are removed for base or utility repairs, all undamaged units should be retained for future reinstatement. Pavers from the stockpile that replace damaged or broken units should be scattered among the pattern of the existing reinstated pavers. This will reduce the visual impact of color variations.

Step 4—Remove the Bedding Sand

The removed pavers will reveal compacted bedding sand. It may be removed and reused, or removed during excavation of the base. For some projects with time constraints, the sand will probably be removed during excavation and not reused.

Figure 6. Prying out the remaining pavers

Figure 7. Pulling out a paver by the short end provides greater leverage and makes extraction easier.

If the sand is reused, it may need to be loosened with rakes before removal by shoveling. The sand should be neatly stockpiled and kept free from soil, aggregate base, or foreign material. If the sand is mixed with these materials, it should not be reused, and it should be replaced with clean sand.

Whether or not it is reused, always leave an undisturbed area of sand 6 to 12 in. (15 to 30 cm) wide next to the undisturbed pavers. This area will provide a stable support for temporary edge restraints and for screeding the bedding sand after the base is reinstated.

Step 5—Excavate the Base Material and Soil

If aggregate base material is removed, it may be possible to stockpile it near the opening for reuse. Keep the aggregate base material separate from excavated subgrade soil. Any soil removed should be replaced with base material unless local regulations require reinstatement of the native soil. The final shape of the excavated opening should be T-shaped in cross section. (Figure 8). This helps prevent undermining and weakening of the adjacent pavement. Follow local codes on the use of shoring, as it may need to be inserted to prevent collapse of the trench sides.

Figure 9 illustrates temporary bracing with plastic or metal edge restraints around the perimeter of the opening. This is recommended practice. The restraints are pinned to the base using metal spikes. Bracing helps keep the undisturbed pavers in place during excavation and fill activities, and will enable reinstatement of units into the existing laying pattern without cutting them to fit.

Step 6—Replace the Base Material

After the repairs are complete, soil at the bottom of the trench should be compacted prior to placing and compacting the base material. Repairs typically use the same base material that was removed. A crushed stone aggregate base should be placed and compacted in 2 to 4 in. (50 to 100 mm) lifts (Figures 10 and 11). If the excavated base material was stabilized with asphalt or cement, it should be replaced with similar materials.

Monitoring density of the compacted soil subgrade and base is essential to reinstating any pavement, including interlocking concrete pavements. It will help prevent rutting and premature failure. A dynamic cone penetrom-

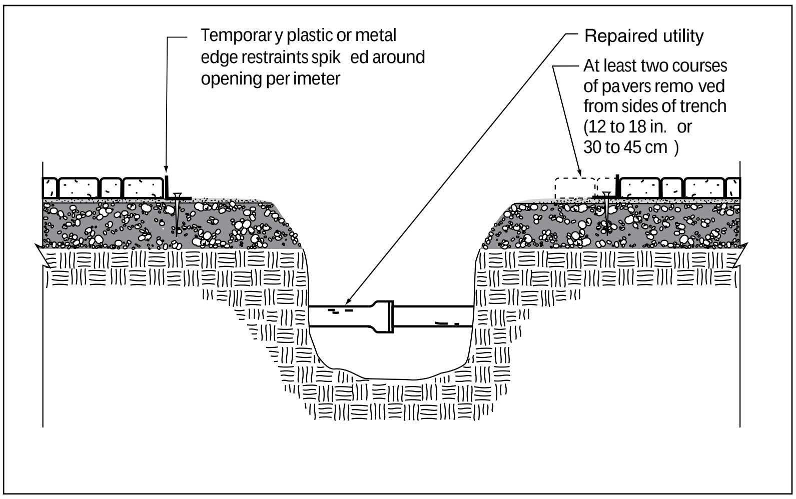

Figure 8. T-shaped cross section of the excavated opening

eter is an effective means for monitoring the density of each lift while working in the opening. If the soil or base material is too dry during compaction, a small amount of water can be sprayed over each lift prior to compacting. This will help achieve maximum density. A nuclear density gauge is recommended for checking the density of the completed compaction of the soil and base layers. A qualified civil engineer should monitor compaction for conformance to local standards.

If there are no local standards for compaction, a minimum of 98% standard Proctor density is recommended for the soil subgrade, and a minimum of 98% modified Proctor density for the base. Compaction equipment companies can provide guidelines on equipment selection and use on the soil and the base. For further guidance on compaction see ICPI Tech Spec 2—Construction of Interlocking Concrete Pavements.

The final elevation of the compacted base at the opening perimeter should match the bottom of the existing undisturbed sand layer that surrounds the opening. The elevation of the middle of the base fill placed in the opening should be slightly higher than its perimeter to compensate for minor settlement.

Controlled low-strength materials (CLSM) (sometimes called slurry mix, flowable fill, or unshrinkable fill) can be used in some applications as a replacement for unstabilized base materials (1). The fill can be made from aggregate bound with fly ash, pozzolans, or cement. Because it is poured from a truck, the fill will form around pipes and underground structures where soil or base backfill and compaction are difficult. Low-strength fill can be poured into undercuts and under pipes where it is impossible to fill and compact aggregate base. The material is also self-leveling.

Low-strength flowable fill requires a short curing time and can be used in freezing weather. It requires no compaction and with some mix designs, can be opened to traffic in 24 hours. Low-strength fill is stiffer than aggregate base and offers higher resistance to settling and rutting. This reduces deterioration of the pavement surface over time. In order to facilitate re-excavation, flowable fill should be made with a small amount of cement. Check with suppliers on the strength of in-place fill that is at least two years old, and on ease of excavation of these sites. The strength of the fill should not exceed 300 psi (2 MPa) after two years of service. Low-strength fill has been used successfully in Toronto and London, Ontario; Colorado Springs, Colorado; Cincinnati, Ohio, Kansas City, Missouri; Peoria, Illinois; and many other municipalities. It is generally more cost-effective than using aggregate base by reducing job time and future pavement repairs. Local ready-mix suppliers can be contacted for available mixes, strengths, installation methods and prices. See ICPI Tech Spec 7—Repair of Utility Cuts with Interlocking Concrete Pavements for further information on low-strength fill.

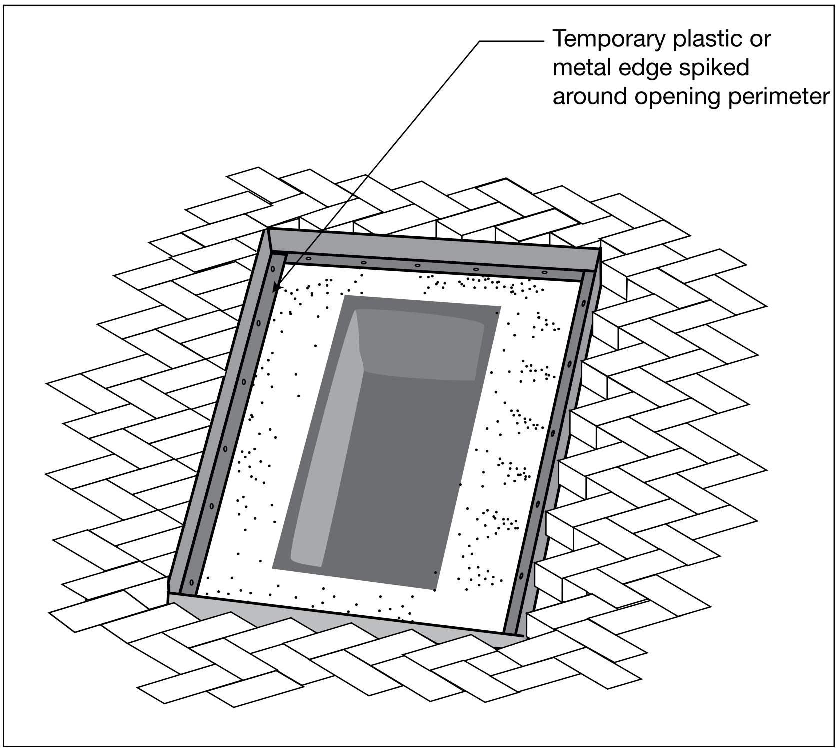

Figure 9. Temporary bracing at the pavement opening will help keep units in place during excavation, repairs and reinstatement.

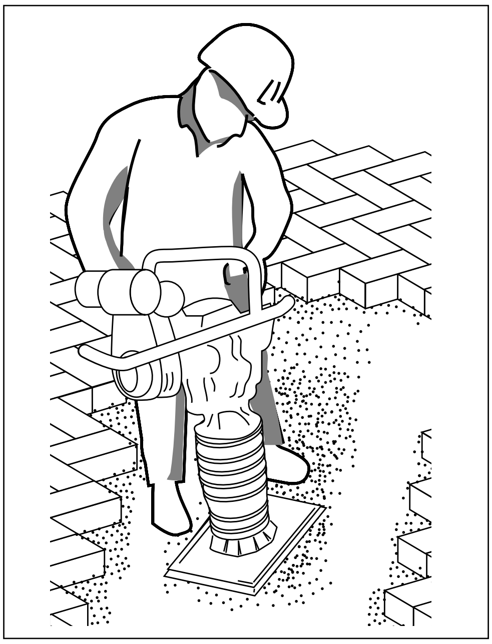

Figure 10. Compaction of the base in 2 to 4 in. (50 to 100 mm) lifts and monitoring density with a dynamic cone penetrometer or a nuclear density gauge are essential to minimizing settlement.

Figure 11. Trench filled with compacted aggregate base. Temporary edge restraints should be used around the opening perimeter.

Figure 12. Screeded bedding sand. Note that a few courses of pavers are removed to create even sides for screeding. Installing temporary edge restraints prior to excavating is preferred practice.

Step 7—Replace the Bedding Sand Layer

During the foregoing procedures, it is likely that the pavers and bedding sand around the opening were disturbed especially if no temporary edge restraints were placed to secure the pavers. If so, then remove an additional two rows of pavers, or back to an undisturbed course. Clean sand from these pavers and set them aside with the others. Be sure there is at least 6 to 8 in. (150 to 200 mm) of undisturbed bedding sand exposed after removal of the course(s) of pavers. This area of undisturbed sand can be used to guide screeding of fresh bedding sand over the compacted and leveled base. Prior to screeding, carefully remove any temporary edge restraints so that adjacent pavers remain undisturbed.

Spread the bedding sand across the base to about two thirds of its full thickness. Do not use the sand to compensate for low places in the surface of the base. Low areas should be filled with base material and compacted. Spread the remaining thickness of sand.

The undisturbed pavers on opposite sides of the opening can be used to guide screeding. It may be necessary to remove a few courses of pavers to straighten the edge of the pavers (Figure 12).

Metal screed pipes are placed on the base and in the bedding sand to control its thickness. The base should have a slight "crown" or rise in the center of the reinstated base. A crown helps compensate for minor settling after the pavers are replaced. Furthermore, as the pavers settle slightly from traffic, the reinstated surface will stiffen, increasing its structural capacity.

Step 8—Reinstate the Pavers

Pull and secure string lines across the opening along the pavement joints every 6 to 10 ft. (2 to 3 m). By following the string lines, joints of reinstated pavers will remain aligned with undisturbed ones. Lay the remaining pavers from the smaller end of the opening, generally working "uphill," i.e., from a lower elevation of the pavement to the higher one. Minor adjustments to the alignment and spacing of joints can be made with pry bars or large screw drivers. Make adjustments prior to compacting the pavers (Figure 13).

Place the pavers in the original laying pattern and compact them with at least two passes of a minimum 5,000 lbf. (22 kN) plate compactor. The path of the plate compactor should overlap onto the undisturbed pavers. Spread joint sand and compact again until the joints can no longer accept sand (Figure 14). Sweep away excess sand. The elevation of the reinstated pavers after compaction should be no higher than 1/8 in. (2 mm) at the edges and 3/16 in. (5 mm) at the center. Traffic and minor settlement will compact the pavers to a level surface. After a short period of time, the repaired area will be undetectable (Figure 15).

Applications such as airports or gas stations require joint sand stabilizers. If an area is reinstated in such uses, then a stabilizer will need to be re-applied to the joints. See ICPI Tech Spec 5—Cleaning and Sealing Interlocking Concrete Pavements for advice on sealers and joint sand stabilizers.

A crew of three or four persons can manually reinstate between 500 and 1,500 sf (50 and 150 m²) per day.

This does not include excavation and replacement of the base material. Crew productivity depends on experience, weather, traffic, site access, a steady flow of materials around the repair site, and the number of pavers to be cut. An experienced crew will reinstate pavers with little or no cutting, aligning reinstated pavers with existing joint lines, pattern, and spacing between the units.

Although existing pavers can be used in reinstatement, there may be projects where it is more cost-effective to remove and replace the area with new pavers. An experienced paver installation contractor can provide guidance on cost-effective approaches for each reinstatement project.

Municipalities, utility companies and other users should use experienced ICPI Certified Installer to reinstate interlocking concrete pavers. Others may use in-house labor which should be trained in the procedures described above. Contact a local Interlocking Concrete Pavement Institute paver installation contractor member to assist with training. Successful reinstatement using experienced contractors will result in successful reinstatement jobs that leave no ugly patches nor do they weaken the pavement. See Figures 15 and 16.

Figure 13 (Left). Adjusting joint spacing and alignment. Figure 14 (Right). Second and final compaction of the pavers. The first compaction occurs after the pavers are placed (no sand in the joints). The second compaction works the sand on pavers into the joints. This process causes the pavers to interlock.

Figure 15 and 16. Reinstated pavers leave no ugly patches nor do they weaken the pavement.

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ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®

Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

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TECH SPEC

NUMBER 7

Repair of Utility Cuts Using Interlocking Concrete Pavers

North American cities have thousands of utility cuts made in their streets each year. Figure 1 shows a daily occurrence in most cities: repairs to underground utility lines for water, sewer, gas, electric, steam, phone, fiber-optic, or cable services. A sample is given below of the number of annual utility cuts in a few cities.

Billings, Montana	650–730
Boston, Massachusetts	25–30,000
Chicago, Illinois	120,000
Cincinnati, Ohio	6,000
Oakland, California	5,000
San Francisco, California	10,000
Seattle, Washington	10–20,000
Toronto, Ontario	4,000

The Costs of Utility Cuts

The annual cost of utility cuts to cities is in the millions of dollars. These costs can be placed into three categories. First, there are the initial pavement cut and repair costs. These include labor, materials, equipment, and overhead for cutting, removing, replacing, and inspecting the pavement, plus repairs to the utility itself. Costs vary depending on the size and location of the cut, the materials used, waste disposal, hauling distances, and local labor rates.

Figure 1. Repairs to utilities are a common sight in cities, incurring costs to cities and taxpayers.

Second, there are user costs incurred as a result of the repair. They include traffic delays, detours and denied access to streets by users, city service and emergency vehicles.

User costs depend on the location of the cut. A repair blocking traffic in a busy center city will impose higher costs and inconvenience from delays than a cut made in a suburban residential street. There are downstream costs to users from utility repairs such as lost productivity due to delays, and damage to vehicles from poor pavement riding quality. While these losses are difficult to quantify, they are very present.

The third cost is subtle and long term. It is the cost of pavement damage after the repair is made. Cuts damage the pavement. Damage can range from negligible to substantial, depending on the quality of the reinstated area and the condition of the surrounding pavement. The damage reduces pavement life and shortens the time to the next rehabilitation. The need to rehabilitate damaged pavements earlier rather than when normally required has costs associated with it.

Several studies have demonstrated a relationship between utility cuts and pavement damage. For example, streets in San Francisco, California, typically last 26 years prior to resurfacing. A study by the City of San Francisco Department of Public Works demonstrated that asphalt streets with three to nine utility cuts were expected to require resurfacing every 18 years (1). This represented a 30% reduction in service life compared to streets with less than three cuts. Streets with more than nine cuts were expected to be resurfaced every 13 years. This represents a 50% reduction in service compared to streets with less than three cuts.

The report concludes that while San Francisco has some of the highest standards for trench restoration, utility cuts produce damage that extends beyond the immediate trench. "...even the highest restoration standards do not remedy all the damage. Utility cuts cause the soil around the cut to be disturbed, cause the backfilled soil to be compacted to a different degree than the soil around the cut, and produce discontinuities in the soil and wearing surface. Therefore, the reduction in pavement service life due to utility cuts is an inherent consequence of the trenching process."

A 1985 study in Burlington, Vermont, demonstrated that pavements with patches from utility cuts required resurfacing more often than streets without patches. Pavement life was shortened by factors ranging between 1.70 and 2.53, or 41% to 60% (2). Research in Santa Monica, California, showed that streets with utility cuts saw an average decrease in life by a factor of 2.75, or 64% (3). A 1994 study by the City of Kansas City, Missouri, notes that "street cuts, no matter how well they are restored, weaken the pavement and shorten the life of the street." It further stated that permit fee revenue does not compensate the city for the lost value resulting from street cuts (4). A 1995 study by the city of Cincinnati, Ohio, showed that damage to the pavement extends up to three feet (1 m) from the edge of properly restored cuts (5).

The cost of pavement damage includes street resurfacing and rehabilitation to remedy damage from cuts. Permit fees charged by cities to those making cuts often do not fully account for pavement damage after the cut pavement is replaced. Some cities, however, are mitigating the long-term costs of pavement cuts by increasing fees or by charging a damage fee. They seek compensation for future resurfacing costs to remedy pavement damage.

$$\text{Annual cost of pavement damage from utility cuts to one category of streets (local, collector thoroughfare, etc.)} = \text{Annual cost of resurfacing streets damaged by utility cuts} - \left[\text{Annual cost of resurfacing streets damaged by utility cuts} \times \left(\frac{\text{Number of years of life remaining before resurfacing streets with utility cuts}}{\text{Expected years of life before resurfacing if there are no utility cuts}}\right)\right]$$

Where the:

$$\text{Annual cost of resurfacing streets damaged by utility cuts} = \left(\text{percent of all resurfaced streets that are damaged by cuts}\right) \times \left[\text{Total annual cost of resurfacing all streets} \times \left(\frac{\text{Total miles (km) of streets resurfaced that year of one category (local, collector thoughfare, etc.)}}{\text{total miles (km) of all streets resurfaced in that year}}\right)\right]$$

A damage fee would be derived by dividing the annual cost of resurfacing a particular category of street damaged by utility cuts by the number of years of life expected from those streets. The fee would be higher if a street to be cut had been recently resurfaced, and lower for a street that is about ready for resurfacing.

Table 1—Annual cost of pavement damage from utility cuts (4).

The rationale for fees to compensate for early resurfacing can be based on the following formula in Table 1.

Pavement damage fees may be necessary for conventional, monolithic pavements (asphalt and cast-in-place concrete) because they rely on the continuity of these materials for structural performance and durability. Cuts reduce performance because the continuity of the pavement surface, base, and subgrade has been broken. Traffic, weather, de-icing salts, and discontinuities in the surface, in the compacted base, and in the soil, shorten the life of the repaired cut. When pavement life is shortened, rehabilitative overlays are needed sooner than normal, thereby incurring maintenance costs sooner than normal.

Figure 2. Removal of concrete pavers for a gas line repair in Dayton, Ohio.

Figure 3. Compaction of the base

Figure 4. Reinstatement of the pavers, bedding and joint sand

Figure 5. The final paver surface is continuous. There are no cuts or damage to the pavement.

Reducing Costs with Interlocking Concrete Pavements

Interlocking concrete pavements can reduce pavement cut and repair costs, and user costs. They can also reduce costs from long term pavement damage, and the fees to rehabilitate them.

Reducing Pavement Cut and Repair Costs— Costs to open interlocking concrete pavements can be competitive with monolithic pavements such as asphalt or poured concrete. Cost savings occur because saw-cutting equipment and pneumatic jack hammers are not required for removal. Since the same paver units are reinstated, additional savings can result from reducing waste and hauling. Minimizing waste material is important in urban street repairs because of compact working conditions and increased landfill costs.

Reducing User Costs— User costs due to traffic interruptions and delays

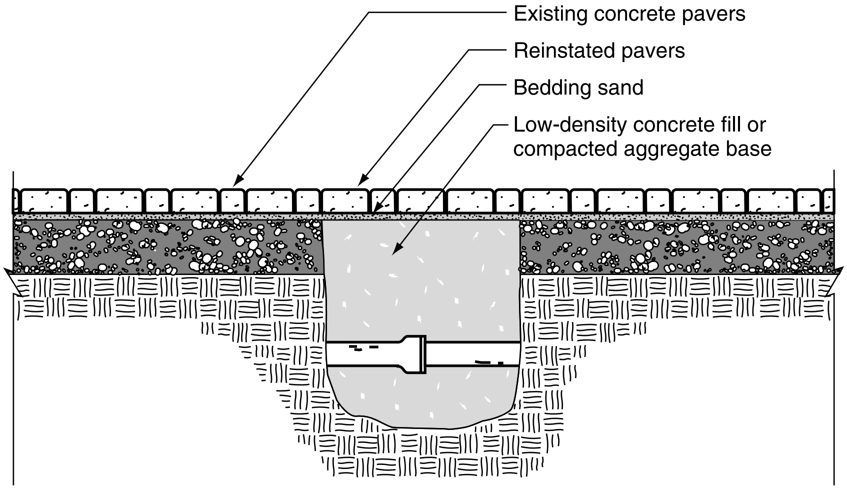

Figure 6. Cross section of reinstated utility cut into interlocking concrete pavement.

of the base and subgrade. This reduces the likelihood of settlement and helps eliminate damage to the pavement.

Therefore, long term costs of pavement damage from utility cuts to interlocking concrete pavement can be substantially lower when compared to monolithic pavements. This makes interlocking concrete pavement very cost effective for streets that will experience a number of utility repairs over their life. Furthermore, lower costs from less damage can mean lower fees for cuts when compared to those for cutting into monolithic pavements.

are reduced because concrete pavers require no curing. They can handle traffic immediately after reinstatement, reducing user delays. Furthermore, reinstated concrete pavers preserve the aesthetics of the street or sidewalk surface. There are no patches to detract from the character of the neighborhood, business district, or center city area. With many projects, concrete pavers help define the character of these areas. Character influences property values taxes. Attractive paver streets and walks without ugly patches can positively affect this character.

Reducing Costs of Pavement Damage— Since interlocking concrete pavements are not monolithic, they do not suffer damage from cuts. The modular pavers and joints are superior to the cracks from cuts that typically result in accelerated wear to monolithic pavements. The role of joints in interlocking concrete pavement is the opposite from those in monolithic pavements. Any break in monolithic pavement, e.g., joints, cuts or cracks, normally shortens pavement life because the continuity of the material is broken. In contrast, the joints of the modular units in interlocking concrete pavements maintain structural continuity.

Figures 2, 3, 4, 5 and 6 show the process of repair and illustrate the continuity of the paver surface after it is completed. The reinstated units are knitted into existing ones through the interlocking paving pattern and sand filled joints. Besides providing a pavement surface without cuts, the joints distribute loads by shear transfer. The joints allow minor settlement in the pavers caused by discontinuities in the base or soil without cracking.

When pavers are reinstated on a properly compacted base, there is no damage to adjacent, undisturbed units. Unlike asphalt, concrete pavers do not deform, because they are made of high strength concrete. The need for street resurfacing caused by repeated utility cuts is eliminated because concrete pavers are not damaged in the reinstatement process. In addition, the use of low density concrete fill can help reestablish the broken continuity

Utility Cut Repairs in Asphalt Pavements Using Interlocking Concrete Pavers

Tech Spec 6, Reinstatement of Interlocking Concrete Pavements, published by the Interlocking Concrete Pavement Institute, provides step-by-step guidance for repairs to vehicular and pedestrian pavements made with concrete pavers. A unique, experimental variation of the techniques in this technical bulletin is demonstrated in London, Ontario, where repairs to utility cuts in asphalt are made with interlocking concrete pavers (6). The local gas company normally reinstates cut pavement in the winter with cold patch asphalt after making repairs to gas lines. In the spring, the cold patch is typically removed and hot mix asphalt is placed in the openings.

Figure 7 shows the result of settlement and shrinkage of the cold patch asphalt in a London, Ontario, utility cut. The change in dimensions causes the edge of the cut asphalt to deteriorate, and settlement decreases riding quality.

Concrete pavers on low density concrete fill have been successfully used as a replacement for cold patch asphalt (Figures 8 and 9). They were first used as a temporary repair with the intent of being removed in the spring. However, the pavers performed so well that the City of London left them in place indefinitely. Several repairs were in streets subject to heavy truck traffic, as well as residential streets. Costs were less than using cold


Figure 7. Pavement damage from settlement and shrinkage of cold patch asphalt.

Figure 8. Utility cut repair in a residential area in London, Ontario.

patch asphalt.

All repairs in London with concrete pavers and low-density concrete have produced a smooth surface transition from the asphalt to the pavers. The riding quality and safety has improved to the extent that the transition from one surface to the next can barely be discerned by the driver. The pavers were colored to match the appearance of the asphalt so there would be no substantial differences in appearance. Figure 10 shows such a patch of pavers blending with the surrounding pavement.

The base material, controlled low-density concrete fill (sometimes called unshrinkable fill), is a low-strength concrete poured from a ready-mix truck into the trench opening. The concrete fill eliminates the need to replace the aggregate base. The concrete cures to a sufficient strength that the repair with concrete pavers can be opened to traffic within 24 hours, even in freezing weather.

Repair Guidelines for Using Concrete Pavers for Utility Cuts in Asphalt Pavement

The experimental repairs in London, Ontario, have been in place since 1994 and have performed well. The gas company and City continue to make repairs using this method. The ongoing repairs using this method demonstrate that it has particular application in cold climates as a substitute for cold patch asphalt. The use of low-density concrete fill has resulted in no settlement. The smooth riding pavement has increased the public image of the utility company and the City, and has reduced liability. By eliminating the need to remove cold patch asphalt in the spring, labor forces can be placed on more urgent work.

The following are guidelines from experience with many utility repairs with concrete pavers and low-density concrete fill in London, Ontario.

Signing such as warnings, arrows, flashers, cones and/or barricades should be placed around the area to be cut, according to local, state, or provincial standards.

Cuts in the asphalt pavement should be done with a saw using straight lines. A pneumatic hammer should not be used to cut the asphalt. The saw cuts must be vertical and made completely through the existing asphalt layer. In order to provide clean corners along the edge of the cut, the asphalt layer should not be fractured, suffer from alligator cracking, or be raveled.

The thickness of the asphalt at the opening should be at least 4 in. (100 mm). The sides of the asphalt provide a restraint for the 3.125 in. (80 mm) thick pavers and approximately 1 in. (25 mm) of bedding sand. The interior of the cut asphalt can be broken with a pneumatic hammer and removed with a front end loader. Pieces along the saw cuts should be removed carefully to prevent damage to the edges.

Excavation of the base and soil must be within the limits of the removed asphalt, and care must be taken to not undermine the adjacent pavement. Trench excavation, bracing, shoring, and/or sheeting should be done in accordance with the local authority. Equipment should be kept from the edges of the opening as loads may crack or break pieces from the cut asphalt edges. Excavated soil and base materials should be removed from the site. The trench should be kept free from standing water.

Unshrinkable fill poured into the trench is shown in Figure 11. The fills flows into undercuts, under the edge of the cut asphalt (providing additional support), and in places where the soil or base has fallen from the sides of the trench. These places are normally impossible to fill and compact with aggregate base or backfill material.

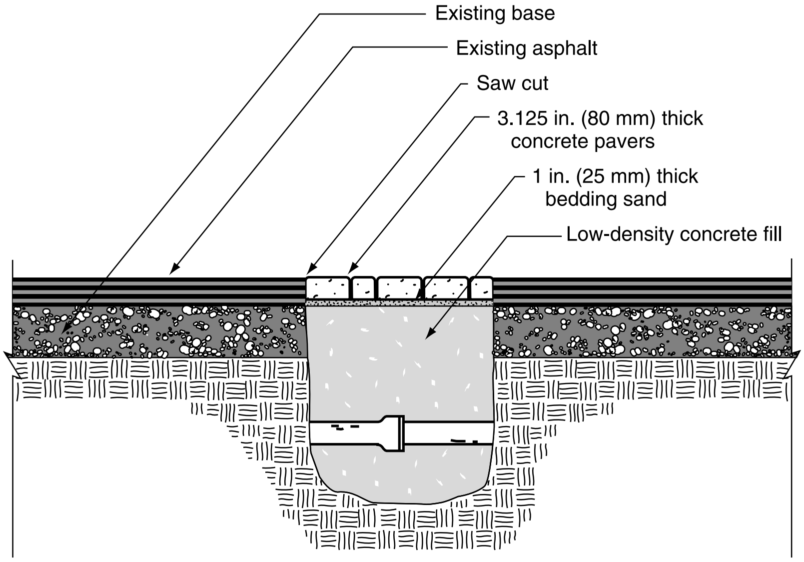

Figure 9. Cross section of utility cut repairs with concrete pavers in London, Ontario

There are many mixes used for low-density concrete fill (7)(8). Proprietary mixtures include those made with fly-ash that harden rapidly. Others are made with cement. A recommended mix can be made with ASTM C 150 (9) Type I Portland cement (or Type 3 for winter repairs), or CAN3-A23.5-M type 10 (or type 30 Portland cement) (10). The slump of the concrete should be between 6 and 8 in. (150 and 200 mm) as specified in ASTM C 143 (11) or CAN3-A23.2.5C (10). When air entrainment is required to increase flowability, the total air content should be between 4 and 6% as measured in ASTM C 73 (11) or CAN3-A23.2-4C (10). Air content greater than 6% is not recommended as it may increase segregation of the mix.

A strength of 10 psi (0.07 Mpa) should be achieved within 24 hours. The maximum 28 day compressive strength should not exceed 50 psi (0.4 Mpa) as measured by ASTM C 39 (11) or CAN3-A23.2-9C (10). Cement content should be no greater than 42 lbs/cy (25 kg/m^3). The low maximum cement content and strength enables the material to be excavated in the future. Mixes containing supplementary cementing materials should be evaluated for excessive strength after 28 days.

Figure 10. A patch of barely discernable pavers in a heavily trafficked intersection in London, Ontario


Figure 11. Low density concrete fill (unshrinkable fill) poured into a utility trench from a ready-mix concrete truck.

Repaired utility lines are typically wrapped in plastic prior to pouring the low density fill. This keeps the concrete from bonding to the lines and enables them to move independently. When the fill is poured, it is self-leveling. It should be poured to within 4 in. (100 mm) of the riding surface of the asphalt.

Bedding sand can be installed when the concrete is firm enough to walk on, generally within a few hours after placement. The bedding sand should be as hard as available and should conform to the grading requirements of ASTM C 33 (11) or CSA A23.1 (10). Mason sand, limestone screenings or stone dust should not be used. The sand should be moist, but not saturated or frozen. Screed the bedding with 1 in. (25 mm) diameter screed pipe. Remove excess sand from the opening.

Since the low-density concrete fill is self-leveling, it will create a flat surface for the bedding sand. In most cases, there will be a slope on the surface of the street. Adjustments to the thickness of the bedding sand may be necessary for the finished elevation of the pavers to follow the slope on the surface of the street. This can be accomplished by adjusting the height of the screed pipes.

Concrete pavers should be at least 3.125 in. (80 mm) thick and meet the standards in ASTM C 936 (12) or CSA A231.2 (13). They should be delivered in strapped bundles and placed around the opening in locations that don't interfere with excavation equipment or ready-mix trucks. The bundles should be covered with plastic to prevent water from freezing them together. The bundles need to be placed in locations close to the edge of the opening. Most bundles have several rows or bands of pavers strapped together. These are typically removed with a paver cart. The paver bundles should be oriented so that removal of the bands with carts is done away from the edge of the asphalt.

Rectangular concrete pavers [nominally 4 in. by 8 in. (100 mm x 200 mm)] should be placed against the cut asphalt sides as a border course. They should be placed in a sailor course, i.e., the long side against the asphalt. No cut paver should be smaller than one third of a unit.

Place pavers between the border course in a 90 degree herringbone pattern (Figure 12). Joints between pavers should not exceed $^1/_{16}$ in. (2 mm). Compact the pavers with a minimum 5,000 lbf (22 kN) plate compactor. Make at least two passes with the plate compactor. A small test area of pavers may need to be compacted to check the amount of settlement. The bedding sand thickness should be adjusted in thickness to yield pavers no higher than $^1/_8$ in. (3 mm) above the edge of the asphalt.

Spread, sweep and compact sand into the joints. The joint sand is typically finer than the bedding sand, and should conform to the grading requirements of ASTM C 144 (11) or CSA A179 (10). The joints must be completely full of sand after compaction. Remove excess sand and other debris. The pavers may be painted with the same

Figure 12. Pavers are laid in a 90 degree herringbone pattern between the border courses.

Figure 13. Concrete pavers in utility cuts can be painted as any other pavement.

lane, traffic, or crosswalk markings as any other concrete pavements (Figure 13).

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Sources for additional information on low-density flowable fill include the Cement Association of Canada, 1500-60 Queen Street, Suite 609, Ottawa, Ontario K1P 5Y7, tel: 613-236-9471 and the National Concrete Ready-Mix Association, 900 Spring Street, Silver Spring, Maryland, 20910, tel: 301-587-9419. The American Concrete Institute offers publication 229R-94, "Controlled Low Strength Materials (CLSM)" at P.O. Box 9094, Farmington Hills, Michigan 48333-9094, tel: 810-848-3700.

Figures 8, 9, 10 and 11 are courtesy of Gavigan Contracting, Ltd., London, Ontario.

ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®

Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

TECH SPEC

NUMBER 8

Concrete Grid Pavements

Background

As cities grow, man-made surfaces contribute to urban heat and stormwater runoff. Heat is generated by the high concentration of pavements and buildings. It forms a dome of warm air, or an urban heat island, over cities that can be as much as 12° F (7°C) higher than outlying areas. The urban heat island also inceases electricity consumption for air conditioning. This dome of heat traps dust and gases, increasing the concentrations of air pollution from automobile exhaust and industrial sources (1).

A high concentration of pavements and buildings, or impervious surfaces, generates additional runoff during rainstorms. Washed from the air and pavements, excess runoff carries pollutants that enter water courses. The runoff generated by impervious surfaces erodes streams, degenerating riparian environments, and pollutes sources of drinking water. Increased runoff volumes and velocities deprive ground water from recharging, decreasing the amount of available water in many communities.

Concrete grid pavements or "green parking lots" originated from the need to reduce the urban heat island and stormwater runoff from impervious surfaces. Perforated concrete units as pavement were introduced when hollow concrete building blocks were placed in the ground to support cars. They first appeared in 1961 to handle overflow parking at a major cultural center near Stuttgart, Germany (2). They were a replacement for temporary steel runway matting. Figure 1 shows the genesis of grids.

Since then, concrete grids developed in Europe were applied in North America as a method for reducing lakeside and streambank erosion, as well as for ditch liners. Concrete grids were later used for driveways, main and overflow parking areas, shoulders along airfields and highways crossovers on medians, boat launching ramps, emergency fire lanes and for access roads adjacent to buildings. See Figure 2. Figures 3-13 illustrate many uses of concrete grid pavers. This technical bulletin provides guidance on the design, specification, construction, and maintenance of concrete grid pavements for a wide range of applications. Concrete grids are an environmentally friendly technology that can help earn credits under green building rating systems such as LEED® and Green Globes. For more information on how grids can earn credits see ICPI Tech Spec 16 – Achieving LEED® Credits with Segmental Concrete Pavement.

Properties of Concrete Grid Paving Units

The properties of concrete grid units are defined in ASTM C 1319, Standard Specification for Concrete Grid Paving Units (3). This specification defines concrete grids as having maximum dimensions of 24 in. long by 24 in. wide (610 mm by 610 mm) and a minimum nominal thickness of 3 $^1/_8$ in. (80 mm). The minimum required thickness of the webs between the openings is 1 in. (25 mm). Dimensional tolerances should not differ from approved samples more than $^1/_8$ in. (3.2 mm) for length, width, and height.

The minimum compressive strength of the concrete grid units should average 5,000 psi (35 MPa) with no individual one less than 4,500 psi (31 Mpa). Their average water absorption should not exceed 10 lb/ft^3 (160 kg/m^3). Freeze-thaw durability is based on three

Figure 2. A typical grid pavement for occasional vehicular traffic

Figure 1. Grids first used in Germany in 1961 for overflow parking were building blocks placed in the ground. They emerged from the need to cool cities and decrease stormwater runoff.

Figure 3. Residential driveway

Figure 4. Lakeside stabilization

Figure 5. Streambank stabilization

Figure 6. Roadway median crossover

Figure 7. Service access lane

years of proven field performance of units that conform to the above web thickness, compressive strength and absorption criteria.

Concrete grid unit designs fall into two categories: lattice and castellated as shown in Figure 14. Lattice pavers have a flat surface that forms a continuous pattern of concrete when installed. Castellated grids include protruding concrete knobs on the surface making the grass appear continuous when installed. Concrete grid pavers range in weight from 45 lbs. (20 kg) to 90 lbs. (40 kg). The open area generally ranges between 20% and 50%.

Design, Construction, and Maintenance Guidelines for Vehicular Pavements

Guidelines are provided for a dense-graded, crushed stone, aggregate base under bedding sand, topsoil and grass or aggregate in the grid openings. The choice of grass or aggregate in the openings depends on the expected intensity of use. Most grasses require at least five hours of sunlight each day to survive. Grass can be placed in the grid openings in intermittent or overflow parking areas, as well as in fire lanes. If a parking area is covered by cars all day for consecutive days, aggregate should be used in the openings as constant shade and engine heat will kill the grass.

Before a parking lot is constructed, existing pedestrian paths across the lot should be studied and defined. Parking spaces and pedestrian paths as well as spaces for disabled persons can be delineated with solid concrete pavers. Paths with solid units will make walking more comfortable, especially for pedestrians with high-heeled shoes. Likewise, parking spaces accessible to disabled persons and bicycles should be marked with solid pavers (Figure 15).

Design with a dense-graded, crushed stone base

A typical grid pavement installation consists of compacted soil subgrade, a dense-graded base of compacted crushed

Figure 8. Emergency access lane for fire trucks

Figure 9. Overflow parking

Figure 11. Fence

Figure 12. Picnic area

Figure 10. Embankment stabilization

Figure 13. Air for tree roots and a warning for drivers

stone, 1/2 to 1 in. (13 to 25 mm) thick bedding sand, and grids. The openings in the grids are filled with topsoil and grass (Figure 16), or aggregate.

Thicknesses required under conventional asphalt pavements are generally sufficient under concrete grids. A minimum of 8 in. (200 mm) of compacted aggregate base is recommended for emergency fire lanes supporting fire trucks, and truck axle loads, defined by AASHTO H20 and HS20 as well as for parking lots and driveways. Thicker bases may be required when extremely heavy vehicular loads are expected.

Thicker bases may also be required when the soil subgrade is weak (California Bearing Ratio < 4%) or when it has high amounts of clay or silt. Likewise, thicker bases or those stabilized with cement will be required over a high water table, in low-lying areas subject to flooding, or over continually saturated soils. For unstabilized aggregate bases, geotextile is recommended to separate the compacted soil subgrade from the base material for these situations.

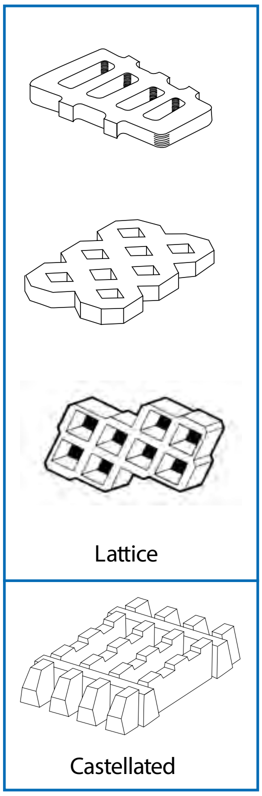

Figure 14. Types of Grid Pavement Units

Construction of dense-graded bases – Prior to placing a dense-graded base, the soil subgrade should be uniformly compacted to at least 95% of standard Proctor density per ASTM D 698 (4). Dense-graded aggregate bases should be compacted to a minimum of 98% standard Proctor density (4). A well-compacted base is essential to shedding water and remaining stable in freeze-thaw conditions. Specifications for crushed stone aggregate base materials typically used under asphalt pavements are suitable under concrete grid pavements. If no local standards exist, gradation of the base material should conform to ASTM D 2940, Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports (5). Figure 17 illustrates a typical cross-section with a dense-graded aggregate base.

For bases over poorly draining soils, perforated plastic, geotextile wrapped drain pipe is recommended for removing excess water. The pipe should be directed to a drainage swale, storm sewer, or stream. If draining soils is impractical, aggregate bases can be stabilized with 4 to 6 percent (by weight) of cement to increase strength during drainage or freeze-thaw.

The maximum surface tolerance of the compacted base should be ± 3/8 in. (±10 mm) over a 10 ft (3 m) straight-edge. The base should extend beyond the perimeter of the grids a minimum of 12 in. (300 mm) when there is no building or curb to restrain them. The extended perimeter increases the stability of the grids and facilitates installation of staked edge restraints.

The gradation of the bedding sand should conform to ASTM C 33 (6) or CSA A23.1-FA1 (7). These gradations are given in the guide specification at the end of this bulletin. Limestone screenings, stone dust or masonry sand should not be used. The thickness of the bedding sand should be between 1/2 and 1 in. (13–25 mm), and screeded to a consistent thickness. If No. 8 stone is used for bedding and openings, this should be screeded to 1 in. (25 mm) thickness. This is typically accomplished with screed rails or bars placed on the compacted base. The bedding sand over the bars is pulled across them with a screed board to establish a consistent sand thickness. The sand should have a consistent moisture content but not be saturated. It should not be disturbed prior to placing the grids.

The grids are placed on the screeded bedding sand with the maximum joint spacing of 3/16 in. (5 mm). The units shouldn't be pushed or hammered such that they touch each other. If the grids touch, they may crack, chip or spall under repeated traffic.

The units should be cut to fill any spaces along the edges prior to compaction. All installed units should be compacted into the bedding sand at the end of each day. Rainfall settles uncompacted sand, preventing the grids from pressing into the sand when compacted. If bedding sand is left uncompacted, it should be covered with plastic to protect it from rain. Otherwise, bedding sand saturated with rainfall prior to compaction will need to dry, be raked and re-screeded or be replaced. If left uncorrected, the grids will settle unevenly and move under traffic.

After the grids are placed, topsoil is spread across them and swept into the openings. Fertilizer may be mixed with the topsoil as well. Quantities should account for the concrete surface.

The grids are vibrated into the sand with a high-frequency (75-90 Hz), low-amplitude plate compactor. It should have a minimum centrifugal compaction force of 4,000 lbs (18 kN). Rollers or a mat should be attached to the plate of the compactor to protect the grids from cracking and chipping. The primary purpose of compaction is to create a level surface among the units. An occasional cracked unit from compaction will not compromise performance. Extensive cracking should be addressed on a job-by-job basis.

The openings should be seeded and completely filled with topsoil. Adding topsoil to the entire surface can assist in germination. Straw can be applied to protect the grass while it is growing. While labor-intensive, sod plugs can be inserted into the openings as an alternative to topsoil and seeding. Sod plugs require a reduced amount of topsoil in the openings so space is available for them.

The choice of grass variety is important to longevity under tires and drought. A limited amount of research on concrete grid pavers has shown that Merion Kentucky bluegrass, Kentucky 31 tall fescue, and Manhattan perennial ryegrass have a high tolerance to wear, a high potential for recuperation from damage, and a low tendency toward thatch build-up (8). Turfgrass specialists may have further recommendations on species and seeding rates.

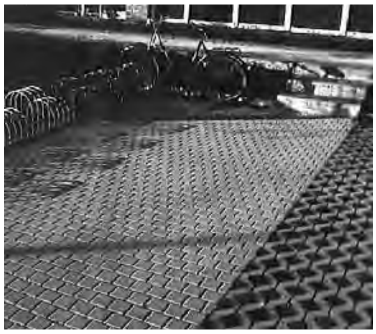

Figure 15. Solid pavers used for bicycle parking and pedestrian access.

Figure 16. A parking lot with a dense-graded, crushed stone base.

Sediment from runoff and dust from adjacent areas must be kept from entering the openings during and after establishment of the grass. Sediment clogs the topsoil and prevents grass from growing. The grass should not be exposed to tires until it is well established. A period of time for establishing grass should be part of the construction contract and schedule. This is typically three to four weeks.

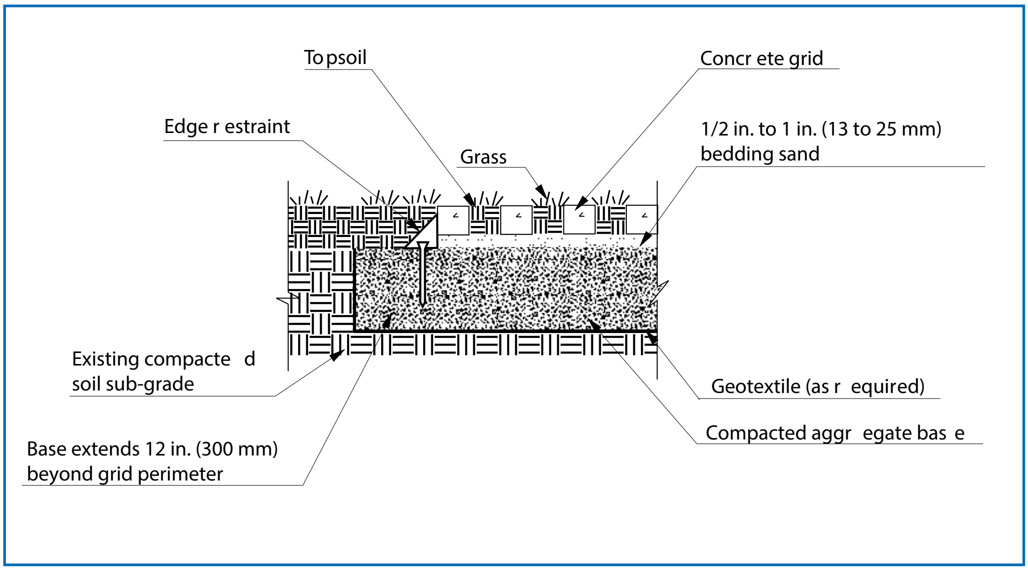

Figure 17. Typical concrete grid pavement over dense-graded base

Edge restraints are required for containing concrete grid pavements and preventing them from shifting under tire traffic. Concrete, plastic, or metal edge restraints are recommended where automobile tires could loosen and damage the edge units. ICPI Tech Spec 3 Edge Restraints for Interlocking Concrete Pavements provides further guidance on their selection (9). For parking applications, tire stops are recommended to help prevent lateral movement of perimeter units. Tire stops should be anchored into the base at least 2 ft. (0.6 m) from the outside edge of the units.

Maintenance – Concrete grids with grass will require maintenance ordinarily required for lawns such as watering, mowing, removal of weeds and occasional fertilizing. If grass in grid pavements can not be maintained by the project owner or tenant, then crushed stone aggregate should be placed in the openings. Aggregate also should be used if sediment from the site or adjacent areas is expected to wash onto the grids or be deposited on them by vehicles.

Snow can be plowed from grids if the plow blade is set slightly above their surface. Rotary brushes for snow removal are not recommended. De-icing salts should never be used on grass because salt will kill it. Re-establishing grass in openings with contaminated soil is difficult without removing and replacing the soil in each opening.

Due to their slab-like shape, concrete grids may crack during compaction or while in service. In most situations, one or two cracks in a unit will not diminish structural or functional performance. If units crack from soil or base settlement, they can be removed and replaced. Likewise, the same units can be reinstated after repairs to the base or to underground utilities.

Design for Runoff and Pollutant Reduction

Concrete grid pavements with an open-graded stone in their openings and bedding can store storm water and allow for partial treatment of pollutants (Figure 18). Grids designed as an infiltration area can improve water quality by reducing sediment and pollutants that enter lakes and streams (10). Because of their hydrologic and pollution abatement benefits, concrete grid pavements are considered by state and federal agencies to be a best management practice (BMP) for reducing stormwater runoff and non-point source pollution. They are one of many techniques that can be used in a system of watershed-wide measures to control excess runoff and nonpoint pollution of storm water. Other techniques can include infiltration trenches, surface or underground retention/detention ponds, roof top/parking lot ponding, street sweeping, filtering systems, permeable interlocking concrete pavement, etc.

Many municipalities regulate the quantity and/or rate of stormwater released into sewers and streams. Others regulate both the water quantity and quality of the runoff by controlling the amount of impervious cover. To control water quantity, municipal regulations strive to meet one or more design objectives. Several municipal stormwater objectives are presented on the following page, with ways that concrete grid pavements contribute to meeting them (11). These objectives benefit water quality since the amount of runoff and pollutants in it are decreased.

Figure 18. Concrete grids with aggregate in the openings

• Capture and infiltrate the entire stormwater volume so there is no discharge from the drainage area. This requires a large area of concrete grid pavement. The high cost of capturing all runoff can be offset by reducing or eliminating pipes, inlets, and other drainage appurtenances.

• Infiltrate the increased runoff generated by development and impervious surfaces. This results in runoff volumes equal to or near those prior to development. The runoff volume before and after development are estimated and the difference in volume is stored or infiltrated. Places for storage include gutters, swales, pipes, rooftops, and infiltration areas covered with concrete grid pavements.

• Infiltrate a fixed volume of runoff from every storm. This helps control the "first flush" of concentrated pollutants in the initial inch (25 mm) or so of runoff. The first inch (25 mm) of infiltrated water often represents a large percentage of storms. Concrete grid pavements with No. 8 stone bedding and fill in the openings can be designed to infiltrate the first inch (25 mm) or more of runoff.

• Infiltrate sufficient water to control the peak rate of discharge. Many municipalities establish a maximum rate of peak discharge (in cubic feet/second or liters/second) into specific storm sewers or water courses. The maximum rate can be based on the carrying capacity of the drainage ways, or by rates prior to development. This approach favors detention ponds rather than infiltration as a means to control downstream flooding and can help reduce detention storage requirements and costs.

Peak runoff calculations for storm sewers and water courses are typically determined using the Rational Method. For drainage calculations an average runoff coefficient of 0.25 to 0.4 can be used for grids with established grass on a dense-graded aggregate base (12) (13). These coefficients are substantially lower than the 0.9 to 1.00 for conventional pavements. The runoff coefficient of 0.25 to 0.3 is similar to that for natural grassed areas. Runoff coefficients will be 0.2 to 0.25 when No. 8 stone is used to fill the openings and used as bedding over a dense-graded aggregate base. This open-graded aggregate material provides additional runoff storage.

Concrete grids can be placed on a No. 8 bedding layer and open-graded, crushed stone aggregate base such as No. 57 stone. No. 8 stone is placed in the openings. A No. 2 stone subbase under the No. 57 stone can add additional structural support and water storage capacity in its voids. For a detailed design discussion using open-graded aggregate bases for stormwater management, see the ICPI manual, Permeable Interlocking Concrete Pavements .

Day, et al. (14) reported substantial reductions in nonpoint source runoff pollutants in simulated laboratory experiments with concrete grids with grass over bedding sand, No. 57 open-graded aggregate base, and clay soils. Field studies by Goforth et al. (10) also demonstrated the reduction of pollutants from concrete grid pavement. Likewise, data reported by Claytor and Scheuler (15) illustrate the benefits of infiltration trenches, as well as filtering systems. Some systems are similar to concrete grid pavements.

The type of soil subgrade affects the pollution reduction capabilities of infiltration areas. Clay soils with a high cation exchange capacity will capture more pollutants than sandy soils. Debo and Reese (13) recommend that for control of runoff quality, the storm water should infiltrate through at least 18 in. (0.45 m) of soil (typically clay) which has a minimum cation exchange capacity of 5 milliequivalents per 100 grams of dry soil. Some heavy clay soils that are effective pollutant filters do not have a sufficiently high infiltration rate or bearing capacity when saturated, and may not be suitable under infiltration areas subject to vehicular loads.

Concrete grid pavement is not rec-

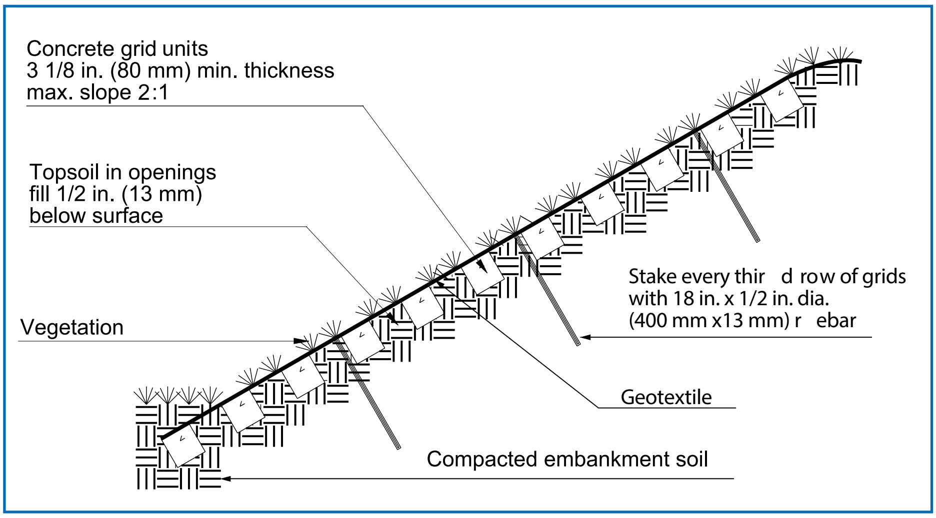

Figure 19. Embankment stabilization with concrete grids

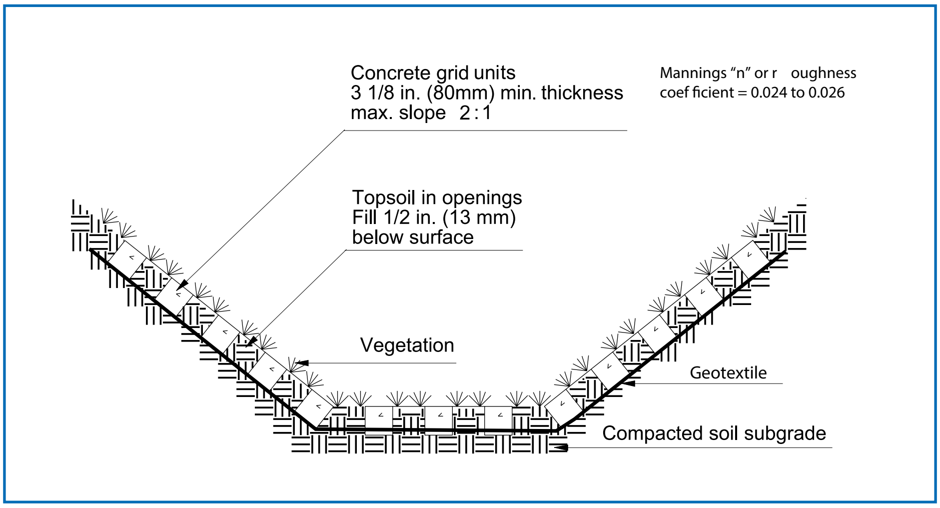

Figure 20. Ditch lined with concrete grid pavers for intermittent flow (17)

ommended in places where grease or oil loads are high. Filter areas such as settling basins should be used to remove grease and oil, as well as sediment before they enter concrete grid pavements.

Urban Heat Island Control Through Urban Microclimates

Besides abating runoff pollution, concrete grids generate lower temperatures than asphalt. Solid pavements and buildings hold heat, thereby contributing to the urban heat island and capturing urban air pollution. Research has shown that grid pavements have 2° to 4° F (1° to 2° C) lower local air temperatures than asphalt and 4° to 6° F (2° to 4° C) lower radiometric than asphalt (12). Lower temperatures create more comfortable microclimates for pedestrians in urban surroundings. Concrete grid pavements can be an integral part of cooling the urban climate and reducing air pollution. They can be incorporated with tree-lined streets, a managed urban forest, fountains, roof top gardens, vegetation on building walls, plus park spaces to cool areas and filter urban air pollutants. The result is more comfortable, cleaner and livable cities.

Design Guidelines for Erosion Control

Grid pavements provide immediate stabilization of embankments until grass or other vegetation is established. The recommended maximum angle for stabilization is 27° (2:1). Grids can be placed directly on graded and compacted soil, working from the bottom to the top of the embankment. The grids should be staked every third row to secure them while vegetation establishes. Stakes should be steel (Figure 19). Grids are also effective liners for ditches with intermittent flows of water (Figure 20). The grids protect ditches from erosion while the openings accommodate vegetation to increase stability.

Preparing the lake sides for concrete grids includes grading and compacting the area above the water prior to placing the units. Aggregate is often placed under grids on banks to further prevent erosion. This layer should be at least 4 in. (100 mm) thick. Geotextile should be placed prior to installing the grids and anchored with large aggregate at the "toe" (bottom) and sides of the installation (Figure 21).

Aggregate should be placed in the openings of the submerged grids. Topsoil and riparian vegetation can be planted along the banks in areas subject to high water levels. Grass can be used in areas not subject to frequent inundation. The maximum recommended slope is 18° (3:1) for grids stabilizing slopes.

Boat ramps in recreation facilities can be made from concrete grids. They can be installed without partitioning the area and removing the water prior to construction. The design guidelines above for lake sides apply except that a minimum of 8 in. (200 mm) of open-graded aggregate should be compacted to provide a base for the grid pavers (Figure 22). This provides a base for the vehicles and boat trailers. The maximum recommended slope is 12% (5:1) for grid boat ramps.

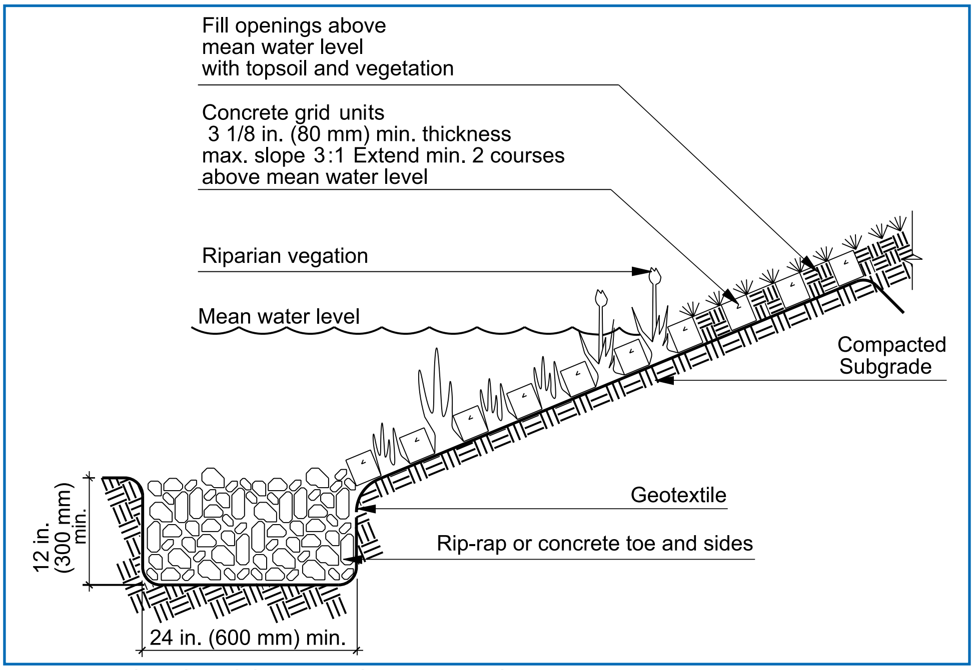

Figure 21. Lake side stabilization with concrete grids

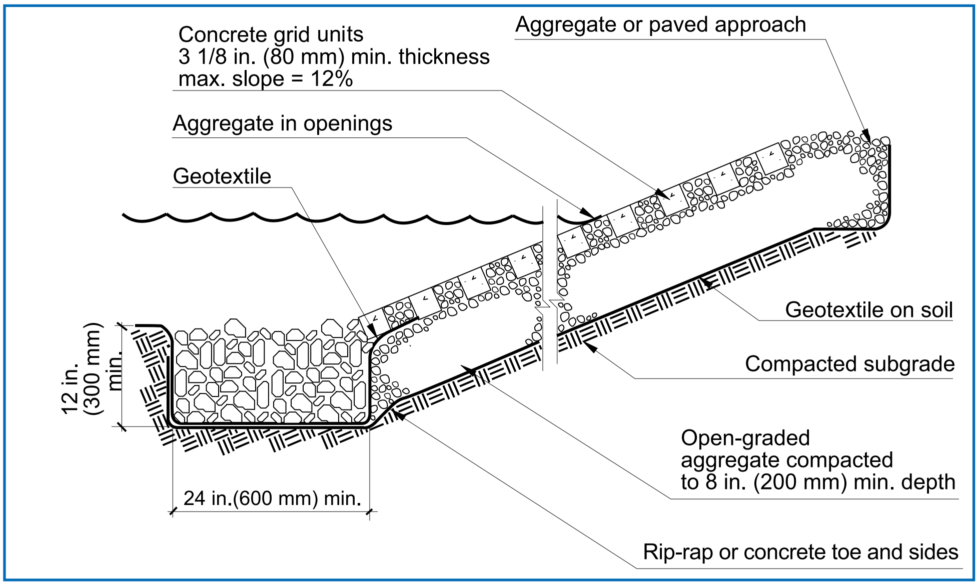

Figure 22. Typical cross-section for boat ramp

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SECTION 32 14 13.19 CONCRETE GRID PAVEMENTS

(1995 MasterFormat Section 02795)

Note: This guide specification is for concrete grid units placed on a sand bedding course over a compacted dense-graded aggregate base. The text allows an option of topsoil and grass in the grid openings over bedding sand or No. 8 open-graded aggregate in the grid openings and for the bedding course. This specification is for limited vehicular applications such as access roads and emergency fire lanes, as well as intermittently used overflow parking areas. This text must be edited to suit specific project requirements for projects. This Section includes the term "Architect." Edit this term as necessary to identify the design professional in the General Conditions of the Contract. Use U.S. or Canadian references as appropriate.

If the area is exposed to recurring vehicular traffic and additional stormwater storage in the base is desired, the specifier should consider using permeable interlocking concrete pavements, as they provide additional structural support to vehicles while providing runoff storage in an open-graded, crushed stone base. In such cases, the specifier should refer to the ICPI manual, *Permeable Interlocking Concrete Pavements.*

PART 1 GENERAL

1.01 SUMMARY

A. Section includes:
   1. Concrete grid units.
   2. Bedding sand.
   3. Edge restraints.
   4. Geotextiles.
   5. [Topsoil and grass for the grid openings.]
   6. [Open-graded aggregate for the grid openings.]
   7. [Open-graded aggregate bedding course].

B. Related Sections:
   1. Section [______]: Curbs and drains.
   2. Section [______]: Dense-graded aggregate base.
   3. Section [______]: Open-graded aggregate base.

1.02 REFERENCES

A. American Society of Testing Materials (ASTM)
   1. C 33, Specification for Concrete Aggregates.
   2. C 136, Method for Sieve Analysis for Fine and Coarse Aggregate.
   3. C 140, Standard Test Methods of Sampling and Testing Concrete Masonry Units.
   4. C 979, Standard Specification for Pigments for Integrally Colored Concrete.
   5. C 1319, Standard Specification for Concrete Grid Paving Units.

6. ASTM D 698, Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,000 ft-lbf/ft ^{3} (600 kN-m/m ^{3})).
7. D 2940, Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports.
8. D 5268, Specification for Topsoil Used for Landscaping Purposes.

B. Canadian Standards Association (CSA)
1. CSA A23.1, Concrete Materials and Methods of Concrete Construction

C. Interlocking Concrete Pavement Institute (ICPI)
1. Tech Spec technical bulletins.

1.03 SUBMITTALS

A. In accordance with Conditions of the Contract and Division 1 Submittal Procedures Section.

B. Manufacturer's drawings and details: Indicate perimeter conditions, relationship to adjoining materials and assemblies, expansion and control joints, paving slab [layout,] [patterns,] [color arrangement,] installation [and setting] details.

C. Sieve analysis per ASTM C 136 for grading of bedding and base materials.

Note: Include D below if the grid openings will be filled with topsoil and grass seed, or sod plugs.

D. Source and content of topsoil and grass seed [sod].

E. Concrete grid units:
1. Color selected by Architect.
2. [Four] representative full-size samples of each grid type, thickness, color, finish that indicate the extremes of color variation and texture expected in the finished installation.
3. Accepted samples become the standard of acceptance for the work.
4. Test results from an independent testing laboratory for compliance of grid paving unit requirements to ASTM C 1319.
5. Manufacturer's certification of concrete grid units by ICPI as having met applicable ASTM standards.
6. Manufacturer's catalog literature, installation instructions, and material safety data sheets for the safe handling of the specified materials and products.

1.04 QUALITY ASSURANCE

A. Paving Subcontractor Qualifications:
1. Engage an experienced installer who has successfully completed grid pavement installations similar in design, material, and extent indicated for this Project.
2. Hold a current certificate from the Interlocking Concrete Pavement Institute Concrete Paver Installer Certification program.

B. Single-source Responsibility: Obtain each color, type, and variety of grids, joint materials and setting materials from single sources with resources to provide products and materials of consistent quality, appearance and physical properties without delaying progress of the Work.

C. Regulatory requirements and approvals: [Specify applicable licensing, bonding or other requirements of regulatory agencies.]

D. Mock-up
1. Locate where directed by the Architect.
2. Notify Architect in advance of dates when mock-ups will be erected.
3. Install minimum [100] sf ([10] m ^{2}) of concrete grid units.
4. Use this area to determine the quality of workmanship to be produced in the final unit of Work including surcharge of the bedding sand layer, joint sizes, lines, pavement laying pattern(s), color(s), and texture.
5. This area shall be used as the standard by which the work is judged.
6. Subject to acceptance by the owner, mock up may be retained as part of the finished work.
7. If mock up is not retained, remove and properly dispose of.

1.05 DELIVERY, STORAGE, AND HANDLING

A. General: Comply with Division 1 Product Requirement Section

B. Deliver concrete grid units to the site in steel banded, plastic banded, or plastic wrapped packaging capable of transfer by forklift or clamp lift. Unload grids at job site in such a manner that no damage occurs to the product or existing construction.

C. Cover sand with waterproof covering to prevent exposure to rainfall or removal by wind. Secure the covering in place.

D. Coordinate delivery and paving schedule to minimize interference with normal use of buildings adjacent to paving.

1.06 ENVIRONMENTAL CONDITIONS

A. Do not install bedding materials or grid units during heavy rain or snowfall.

B. Do not install bedding materials and grid units over frozen base materials.

C. Do not install frozen bedding materials.

1.07 GRID PAVER MAINTENANCE MATERIALS:

A. Supply [ ] sf [(m 2)] of [each type and color of grid unit] in unopened pallets with contents labeled. Store where directed.

B. From the same production run as installed materials.

PART 2 PRODUCTS

2.01 CONCRETE GRID UNITS

A. Manufacturer: [Specify ICPI member manufacturer name.].
 1. Contact: [Specify ICPI member manufacturer contact information.].

B. Concrete grid paver units, including the following:
 1. Grid unit type: [Specify name of product group, castellated, lattice, etc.]
  a. [Material standard: Comply with material standards set forth in [ASTM C 1319.].
  b. Color [and finish]: [Specify color.] [Specify finish].
  c. Color Pigment Material Standard: Comply with ASTM C 979.
  d. Size: [Specify.] inches [([Specify.] mm)] x [Specify.] inches [([Specify.] mm)] x [Specify.] inches [([Specify.] mm)] thick.

C. Manufactured in a plant where paving products are certified by ICPI as having passed ASTM requirements in this specification.

2.02 PRODUCT SUBSTITUTIONS

A. Substitutions: No substitutions permitted.

2.03 BEDDING MATERIALS

Note: If openings are filled with topsoil, use sand bedding. If the openings are filled with open-graded aggregate for additional runoff storage, the same aggregate should be used for the bedding. Edit 2.03 and 2.04 accordingly.

A. General – Sieved per ASTM C 136.

B. Bedding Sand

Note: The type of sand used for bedding is often called concrete sand. Sands vary regionally. Contact contractors local to the project and confirm sand(s) successfully used in previous similar applications. Bedding sand is not used in ditch liner applica - tions, slope protection, riparian stabilization or with boat ramps constructed with concrete grid units.

 1. Washed, clean, hard, durable crushed gravel or stone, free from shale, clay, friable materials, organic matter, frozen lumps, and other deleterious substances.
 2. Conforming to the grading requirements in Table 1 below.
 3. Do not use limestone screenings.

Table 1. Grading Requirements for Bedding Sand

ASTM C33 – Gradation for Bedding Sand		CSA A23.1 FA1 – Gradation for Bedding Sand	
Sieve Size	Percent Passing	Sieve Size	Percent Passing
3/8 in.(9.5 mm)	100	10.0 mm	100
No. 4 (4.75 mm)	95 to 100	5.0 mm	95 to 100
No. 8 (2.36 mm)	80 to 100	2.5 mm	80 to 100
No. 16 (1.18 mm)	50 to 85	1.25 mm	50 to 90
No. 30 (0.6 mm)	25 to 60	630 μm	25 to 65
No. 50 (0.3 mm)	5 to 30	315 μm	10 to 35
No. 100 (0.15 mm)	0 to 10	160 μm	2 to 10
No. 200 (0.075 mm)	0 to 1	80 μm	0 to 1

Note: Bedding sands should conform to ASTM C33 or CSA A23.1 FA1 gradations for concrete sand. For ASTM C33, ICPI recom - mends the additional limitations on the No. 200 (0.075 mm) sieve as shown. For CSA A23.1 FA1, ICPI recommends reducing the maximum passing the 80 μm sieve from 3% to 1%.

-OR-

B. Washed, open-graded stone.

Note: Finer gradations such as ASTM No. 89 stone may be used.

 1. Conforming to the grading requirements in Table 2 below.

Table 2. Gradation for fill or Bedding Course

ASTM No. 8	
Sieve Size	Percent Passing
1/2 in.(2.5 mm)	100
3/8 in.(9.5 mm)	85 to 100
No. 4 (4.75 mm)	10 to 30
No. 8 (2.36 mm)	0 to 10
No. 16 (1.18 mm)	0 to 5

2.04 FILL MATERIALS FOR GRID OPENINGS

A. Topsoil: Conform to ASTM D 5268.

Note: Consult with local turf grass specialists for recommendations on grass seed mixture or sod materials.

B. Grass seed [Sod]: [mixture and source].

-OR-

A. Open-graded aggregate.

B. Conforming the gradation requirements in Table 2. Do not use gravel.

Note: Local, state or provincial standards for aggregate base materials for roads should be used for the gradation and quality of dense-graded aggregate base materials under concrete grid pavements. If no standards exist, follow ASTM D 2940, Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports. The gradation for base material from this standard is given in Table 3 below. This material should be compacted to a minimum of 95% standard Proctor density.

Table 3

ASTM D 2940

Gradation for Dense-Graded, Crushed Stone Base

Sieve Size		Percent Passing
2 in.	(50 mm)	100
1 1/2 in.	(37.5 mm)	95 to 100
3/4 in.	(19.0 mm)	70 to 92
3/8 in.	(9.5 mm)	50 to 70
No. 4	(4.75 mm)	35 to 55
No. 30	(0.600 mm)	12 to 25
No. 200	(0.075 mm)	0 to 8

2.05 EDGE RESTRAINTS

A. Provide edge restraints installed around the perimeter of all concrete grid paving unit areas as follows:

1. Manufacturer: [Specify manufacturer].
2. Material: [Plastic] [Concrete] [Aluminum] [Steel] [Precast concrete] [Cut stone].
3. Material standard: [Specify material standard].

2.06 ACCESSORIES

A. Provide accessory materials as follows:

1. Geotextile fabric:
   a. Material Type and Description: [Specify material type and description].
   b. Material Standard: [Specify material standard.].
   c. Manufacturer: [Acceptable to concrete grid unit manufacturer] [Specify manufacturer.].

PART 3 EXECUTION

3.01 ACCEPTABLE INSTALLERS

A. [Specify acceptable paving subcontractors.].

3.02 EXAMINATION

Note: Compaction of the soil subgrade is recommended to a minimum of 95% standard Proctor density per ASTM D 698 for pedestrian and lightly trafficked vehicular areas. Stabilization of the subgrade and/or base material may be necessary with weak or saturated subgrade soils.

Note: Local aggregate base materials typical to those used for highway flexible pavements are recommended, or those conforming to ASTM D 2940. Compaction of aggregate is recommended to not less than 95% Proctor density in accordance with ASTM D 698 is recommended for pedestrian and vehicular areas. Mechanical tampers are recommended for compaction of soil subgrade and aggregate base in areas not accessible to large compaction equipment. Such areas can include that around lamp standards, utility structures, building edges, curbs, tree wells and other protrusions. The recommended base surface tolerance should be ± 3/8 in. (±10 mm) over a 10 ft. (3 m) straight edge.

Note: The elevations and surface tolerance of the aggregate base determine the final surface elevations of concrete grids. The installation contractor cannot correct deficiencies in the base surface with additional bedding materials. Therefore, the surface elevations of the base should be checked and accepted by the General Contractor or designated party, with written certification to the paving subcontractor prior to placing bedding materials and concrete grids.

A. Acceptance of site verification conditions:
   1. Contractor shall inspect, accept and verify in writing to the grid installation subcontractor that site conditions meet specifications for the following items prior to installation of bedding materials and concrete grid units:
      a. Verify that drainage and subgrade preparation, compacted density and elevations conform to specified requirements.
      b. Verify that geotextiles, if applicable, have been placed according to drawing and specifications.
      c. Verify that base materials, thickness, [compacted density,] surface tolerances and elevations conform to specified requirements.
      d. Provide written density test results for the soil subgrade, base materials to the Owner, Contractor, and grid installation subcontractor.
   2. Do not proceed with installation of bedding materials and concrete grids until [subgrade soil and] base conditions are corrected by the Contractor or designated subcontractor.

3.03 PREPARATION

A. Verify that base is dry, certified by Contractor as meeting material, installation and grade specifications [and geotextile] are ready to support sand, [edge restraints,] grids and imposed loads.

B. Edge Restraint Preparation:
   1. Install edge restraints per the drawings [and manufacturer's recommendations] [at the indicated elevations.].
   2. Mount directly to finished base. Do not install on bedding sand.
   3. The minimum distance from the outside edge of the base to the spikes shall be equal to the thickness of the base.

3.04 INSTALLATION

A. Spread the sand [No. 8 stone] evenly over the compacted, dense-graded base course and screed uniformly to ½ to 1 in. (13 to 25 mm). Place sufficient sand [stone] to stay ahead of the laid grids.

B. Ensure the grid units are free from foreign materials before installation.

C. Lay the grid units on the bedding sand in the pattern(s) shown on the drawings. Maintain straight joint lines.

D. Joints between the grids shall not exceed [3/16 in. (5 mm)].

E. Fill gaps at the edges of the paved area with cut grid pavers or edge units.

F. Cut grid pavers to be placed along the edge with a double-bladed splitter or masonry saw.

G. Sweep [top soil][No. 8 aggregate] into the joints and openings until full.

H. Sweep the grid surface clear prior to compacting.

I. Compact and seat the grids into the screeded [bedding sand] [No. 8 aggregate] using a low-amplitude, 75-90 Hz plate compactor capable of at least 4,000 lbs. (18 kN) centrifugal compaction force. Use rollers or a rubber or neoprene pad between the compactor and grids to prevent cracking or chipping. Do not compact within 6 ft (2 m) of the unrestrained edges of the grid units.

J. All work to within 6 ft (2 m) of the laying face must be left fully compacted at the completion of each day.

K. [Broadcast grass seed at the rate recommended by seed source.][Place sod plugs into openings.] [Add topsoil to the surface to cover the seeds.]

L. Remove excess [topsoil][No. 8 aggregate] on surface when the job is complete.

M. [Distribute straw covering to protect germinating grass seed [sod]. Water entire area. Do not traffic pavement for [30] days.] if seeded.

3.05 FIELD QUALITY CONTROL

A. After removal of excess top soil/aggregate, check final elevations for conformance to the drawings. Allow 1/8 to 1/4 in. (3 to 6 mm) above specified surface elevations to compensate for minor settlement.

B. The final surface tolerance from grade elevations shall not deviate more than ± 3/8 in. (10 mm) over a 10 ft (3 m) straightedge.

C. The surface elevation of grid units shall be 1/8 to 1/4 in. (3 to 6 mm) above adjacent drainage inlets, concrete collars or channels.

D. Lippage: No greater than 1/8 in. (3 mm) difference in height between adjacent grid units.

3.06 PROTECTION

A. After work in the section is complete, the Contractor shall be responsible for protecting work from damage due to subsequent construction activity on the site.

END OF SECTION

ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®
Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

ICPI INTERLOCKING CONCRETE PAVEMENT INSTITUTE

TECH SPEC

NUMBER 9

Guide Specification for the Construction of Interlocking Concrete Pavement

SECTION 32 14 13.13 (02780)
INTERLOCKING CONCRETE PAVERS

Note: This guide specification for manually installed concrete paver applications in the U.S. and Canada. Contact ICPI for current information and guide specifications for mechanical installation. This document should be edited to fit project conditions and location. Brackets [ ] indicate text for editing. Notes are provided on the use of a compacted aggregate base under the bedding sand and pavers. Other bases can be used such as cement or asphalt-treated aggregate, concrete or asphalt, as well as other setting materials. The user should refer to Interlocking Concrete Pavement Institute (ICPI) Details & Specifications for Interlocking Concrete Pavement at www.icpi.org for various guide specifications and detail drawings. This Section includes the term "Architect." Edit this term as necessary to identify the design professional in the General Conditions of the Contract. Coordinate all Sections with the General Conditions as well.

PART 1 GENERAL

1.01 SUMMARY

A. Section Includes:
1. Interlocking Concrete Paver Units (manually installed).
2. Bedding and Joint Sand.
3. Edge Restraints.

B. Related Sections:
1. Section: [ ]-Curbs and Drains.
2. Section: [ ]-Aggregate Base.
3. Section: [ ]-Cement Treated Base.
4. Section: [ ]-Asphalt Treated Base.
5. Section: [ ]-Pavements, Asphalt and Concrete.
6. Section: [ ]-Roofing Materials.
7. Section: [ ]-Geotextiles.

Note: Pavements subject to vehicles should be designed in consultation with a qualified civil engineer, in accordance with established flexible pavement design procedures, ICPI Lockpave software, and in accordance with the ICPI Tech Spec technical bulletins. Use the current year reference. Edit ASTM and CSA references below and throughout this Section according to project location.

1.02 REFERENCES

A. American Society for Testing and Materials (ASTM):
1. ASTM C 33, Standard Specification for Concrete Aggregates.
2. ASTM C 136, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.
3. ASTM C 140, Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units.
4. ASTM C 144, Standard Specification for Aggregate for Masonry Mortar.
5. ASTM C 936, Standard Specification for Solid Concrete Interlocking Paving Units.
6. ASTM C 979, Pigments for Integrally Colored Concrete.
7. ASTM D 698, Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,000 ft-lbf/ft^3 (600 kN-m/m^3)).
8. ASTM D 1557, Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3)).
9. ASTM D 2940, Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports.

B. Canadian Standards Association (CSA):
1. A231.2, Precast Concrete Pavers.
2. A23.2A, Sieve Analysis of Fine and Coarse Aggregates.
3. A23.1-FA1, Concrete Materials and Methods of Concrete Construction.
4. A179, Mortar and Grout for Unit Masonry.

C. Interlocking Concrete Pavement Institute (ICPI):
1. ICPI Tech Spec technical bulletins.

1.03 SUBMITTALS

A. In accordance with Conditions of the Contract and Division 1 Submittal Procedures Section.

B. Manufacturer's drawings and details: Indicate perimeter conditions, relationship to adjoining materials and assemblies, [expansion and control joints,] concrete paver [layout,] [patterns,] [color arrangement,] installation [and setting] details.

C. Sieve analysis per [ASTM C 136][CSA A23.2A] for grading of bedding and joint sand.

D. Concrete pavers:
1. [Four] representative full-size samples of each paver type, thickness, color, finish that indicate the range of color variation and texture expected in the finished installation. Color(s) selected by [Architect] [Engineer] [Landscape Architect] [Owner] from manufacturer's available colors.
2. Accepted samples become the standard of acceptance for the work.
3. Test results from an independent testing laboratory for compliance of paving unit requirements to [ASTM C 936] [CSA A231.2].
4. Manufacturer's certification of concrete pavers by ICPI as having met applicable [ASTM][CSA] standards.
5. Manufacturer's catalog product data, installation instructions, and material safety data sheets for the safe handling of the specified materials and products.

E. Paver Installation Subcontractor:
1. A copy of Subcontractor's current certificate from the Interlocking Concrete Pavement Institute Concrete Paver Installer Certification program.

Note: ICPI certifies that installers have passed an exam on installation knowledge and does not certify or guarantee the quality of installation. Job references should be carefully reviewed and verified to assist in identifying competent contractors.

2. Job references from projects of a similar size and complexity. Provide Owner/Client/General Contractor names and phone numbers.

1.04 QUALITY ASSURANCE

A. Paving Subcontractor Qualifications:
1. Utilize an installer having successfully completed concrete paver installation similar in design, material, and extent indicated on this project.
2. Utilize an installer holding a current certificate from the Interlocking Concrete Pavement Institute Concrete Paver Installer Certification program.

B. Regulatory Requirements and Approvals: [Specify applicable licensing, bonding or other requirements of regulatory agencies.].

C. Mock-Ups:

Note: A site visit and approval by the owner's representative during the first day of paving may substitute for a mock-up.

1. Install a 7 ft x 7 ft (2 x 2 m) paver area.
2. Use this area to determine surcharge of the bedding sand layer, joint sizes, lines, laying pattern(s), color(s) and texture of the job.
3. Evaluate the need for protective pads when compacting paving units with architectural finishes.
4. This area will be used as the standard by which the work will be judged.
5. Subject to acceptance by owner, mock-up may be retained as part of finished work.
6. If mock-up is not retained, remove and properly dispose of mock-up.

1.05 DELIVERY, STORAGE & HANDLING

A. General: Comply with Division 1 Product Requirement Section.

B. Refer to manufacturer's ordering instructions and lead- time requirements to avoid construction delays.

C. Delivery: Deliver materials in manufacturer's original, unopened, undamaged containers packaging with identification labels intact.
1. Coordinate delivery and paving schedule to minimize interference with normal use of buildings adjacent to paving.
2. Deliver concrete pavers to the site in steel banded, plastic banded or plastic wrapped packaging capable of transfer by fork lift or clamp lift.
3. Unload pavers at job site in such a manner that no damage occurs to the product.

D. Storage and Protection: Store materials protected such that they are kept free from mud, dirt, and other foreign materials. [Store concrete paver cleaners and sealers per manufacturer's instructions.]

1.06 PROJECT/SITE CONDITIONS

A. Environmental Requirements:

1. Do not install sand or pavers during heavy rain or snowfall.
2. Do not install sand and pavers over frozen base materials.
3. Do not install frozen sand or saturated sand.
4. Do not install concrete pavers on frozen or saturated sand.

1.07 MAINTENANCE

A. Extra Materials: Provide [Specify area] [Specify percentage] additional material for use by owner for maintenance and repair.

PART 2 PRODUCTS

2.01 INTERLOCKING CONCRETE PAVERS

Note: In addition to ASTM or CSA conformance, ICPI recommends a maximum 3:1 aspect ratio (length ÷ thickness) and a minimum 3 $^{1}/_{8}$ in. (80 mm) thickness for vehicular applications. Residential driveways and pedestrian applications should use a minimum 2$^{3}/_{8}$ in. (60 mm) thick units with a maximum 4:1 aspect ratio.

A. Manufacturer: [Specify ICPI member manufacturer name.].
   1. Contact: [Specify ICPI member manufacturer contact information.].
B. Interlocking Concrete Paver Units, including the following:
   1. Paver Type: [Specify name of product group, family, series, etc.].
      a. Material Standard: Comply with material standards set forth in [ASTM C 936][CSA A231.2].
      b. Color [and finish]: [Specify color.] [Specify finish].
      c. Color Pigment Material Standard: Comply with ASTM C 979.

Note: Concrete pavers may have spacer bars on each unit. Spacer bars are recommended for mechanically installed pavers and for those in heavy vehicular traffic. Manually installed pavers may be installed with or without spacer bars. Verify with manufacturers that overall dimensions do not include spacer bars.

      d. Size: [Specify.] inches [({Specify.}mm)] x [Specify.] inches [({Specify}mm)] x [Specify.] inches [({Specify.} mm)] thick.

Note: If 3 $^{1}/_{8}$ in. (80 mm) thick pavers are specified, their compressive strength test results per ASTM C 140 should be adjusted by multiplying by 1.18 to equate the results to that from 2 $^{3}/_{8}$ in. (60 mm) thick pavers. Contact ICPI for adjustment factors for pavers exceeding 3 $^{1}/_{8}$ in. (80 mm) thickness.

Note: For ASTM C 936 use the following material characteristics:

      e. Average Compressive Strength: 8,000 psi (55 MPa) with no individual unit under 7,200 psi (50 MPa).
      f. Average Water Absorption (ASTM C 140): 5% with no unit greater than 7%.
      g. Freeze/Thaw Resistance (ASTM C 67): Resistant to 50 freeze-thaw cycles with no greater than 1% loss of material. Freeze-thaw testing requirements shall be waived for applications not exposed to freezing conditions.

Note: For CSA A231.2 use the following material characteristics:

      h. Minimum average cube compressive strength of 7,250 psi (50 MPa) for laboratory cured specimens or 5,800 psi (40 MPa) for unconditioned field samples.
      i. Resistance to 28 freeze-thaw cycles while immersed in a 3% saline solution with no greater mass lost than 225 g/m² of surface area after 28 years, or 500 g/m² after 49 cycles.

2.02 PRODUCT SUBSTITUTIONS

A. Interlocking concrete pavers: as specified or approved equal.

2.03 BEDDING AND JOINT SAND

A. Provide bedding and joint sand as follows:
   1. Clean, non-plastic, free from deleterious or foreign matter, symmetrically shaped, natural or manufactured from crushed rock.
   2. Do not use stone dust.
   3. Do not use limestone screenings or sand for the bedding that does not conform to the grading requirements of [ASTM C 33][CSA A23.1-FA1].
   4. Do not use mason sand, or sand conforming to [ASTM C 144][CSA A179] for the bedding sand.

Note: If the pavement will be exposed to heavy traffic with trucks, i.e., a major thoroughfare with greater than 1.5 million 18-Kip (80 kN) equivalent single axle loads, see ICPI Tech Spec 17–Bedding Sand Selection for Interlocking Concrete Pavements in Vehicular Applications for test methods and criteria for assessing bedding sand durability. Limestone screenings will typically not meet the durabulity requirements outlined in Tech Spec 17 . However, there are some granite materials that meet these requirements. Tech Spec 17 recommends using concrete sand as a first preference.

   4. Where concrete pavers are subject to vehicular traffic, utilize sands that are as hard as practically available.
   5. Sieve according to [ASTM C 136][CSA A23.2A].
   6. Bedding Sand Material Requirements: Conform to the grading requirements of [ASTM C 33][CSA A23.1-FA1] with modifications as shown in Table 1.

Table 1. Grading Requirements for Bedding Sand

Gradation for Bedding Sand			
ASTM C33		CSA A23.1 FA1	
Sieve Size	Percent Passing	Sieve Size	Percent Passing
3/8 in.(9.5 mm)	100	10.0 mm	100
No. 4 (4.75 mm)	95 to 100	5.0 mm	95 to 100
No. 8 (2.36 mm)	80 to 100	2.5 mm	80 to 100
No. 16 (1.18 mm)	50 to 85	1.25 mm	50 to 90
No. 30 (0.6 mm)	25 to 60	630 μm	25 to 65
No. 50 (0.3 mm)	5 to 30	315 μm	10 to 35
No. 100 (0.15 mm)	0 to 10	160 μm	2 to 10
No. 200 (0.075 mm)	0 to 1	80 μm	0 to 1

Note: Bedding sands should conform to ASTM C33 or CSA A23.1 FA1 gradations for concrete sand. For ASTM C33, ICPI recommends the additional limitations on the No. 200 (0.075 mm) sieve as shown. For CSA A23.1 FA1, ICPI recommends reducing the maximum passing the 80 μm sieve from 3% to 1%.

Table 2. Grading Requirements for Joint Sand

Gradation for Joint Sand			
ASTM C144		CSA A179	
Sieve Size	Percent Passing	Sieve Size	Percent Passing
No. 4 (4.75 mm)	100	5.0 mm	100
No. 8 (2.36 mm)	95 to 100	2.5 mm	90 to 100
No. 16 (1.18 mm)	70 to 100	1.25 mm	85 to 100
No. 30 (0.6 mm)	40 to 75	630 μm	65 to 95
No. 50 (0.3 mm)	10 to 35	315 μm	15 to 80
No. 100 (0.15 mm)	2 to 15	160 μm	0 to 35
No. 200 (0.075 mm)	0 to 5	80 μm	0 to 10

Note: Coarser sand than that specified in Table 2 above may be used for joint sand including C 33 or A23.1 material as shown in Table 1. Use material where the largest sieve size easily enters the smallest joints. For example, if the smallest paver joints are 2 mm wide, use sand 2 mm and smaller in particle size. If C 33 or A23.1 sand is used for joint sand, extra effort may be required in sweeping material and compacting the pavers in order to completely fill the joints.

7. Joint Sand Material Requirements: Conform to the grading requirements of [ASTM C 144][CSA-A179] as shown with modifications in Table 2 or meet the requirements for bedding sand in Table 1.

Note: Specify specific components of a system, manufactured unit or type of equipment. See ICPI Tech Spec 3–Edge Restraints for Interlocking Concrete Pavements for guidance on selection and design of edge restraints.

2.04 EDGE RESTRAINTS

A. Where not otherwise retained, provide edge restraints installed around the perimeter of all interlocking concrete paving unit areas as follows:
   1. Manufacturer: [Specify manufacturer.].
   2. Material: [Plastic] [Concrete] [Aluminum] [Steel] [Pre-cast concrete] [Cut stone] [Concrete].
   3. Material Standard: [Specify material standard.].

2.05 ACCESSORIES

A. Provide accessory materials as follows:

Note: Delete article below if geotextile is not used.

   1. Geotextile:
      a. Material Type and Description: [Specify material type and description.].
      b. Material Standard: [Specify material standard.].
      c. Manufacturer: [Acceptable to interlocking concrete paver manufacturer] [Specify manufacturer.].

Note: Delete article below if cleaners, sealers, and/or joint sand stabilizers are not specified.

   2. [Cleaners] [Sealers] [Joint sand stabilizers]
      a. Material Type and Description: [Specify material type and description.].
      b. Material Standard: [Specify material standard.].
      c. Manufacturer: [Specify manufacturer.].

PART 3 EXECUTION

3.01 ACCEPTABLE INSTALLERS

A. [Specify acceptable paving subcontractors.].

3.02 EXAMINATION

A. Acceptance of Site Verification of Conditions:
   1. General Contractor shall inspect, accept and certify in writing to the paver installation subcontractor that site conditions meet specifications for the following items prior to installation of interlocking concrete pavers.

Note: Compaction of the soil subgrade is recommended to at least 98% standard Proctor density per ASTM D 698 for pedestrian areas and residential driveways. Compaction to at least 98% modified Proctor density per ASTM D 1557 is recommended for areas subject to heavy vehicular traffic. Stabilization of the subgrade and/or base material may be necessary with weak or saturated subgrade soils.

      a. Verify that subgrade preparation, compacted density and elevations conform to specified requirements.
      b. Verify that geotextiles, if applicable, have been placed according to drawings and specifications.

Note: Local aggregate base materials typical to those used for highway flexible pavements are recommended, or those conforming to ASTM D 2940. Compaction of aggregate is recommended to not less than 98% Proctor density in accordance with ASTM D 698 is recommended for pedestrian areas and residential driveways. Minimum 98% modified Proctor density according to ASTM D 1557 is recommended for vehicular areas. Mechanical tampers are recommended for compaction of soil subgrade and aggregate base in areas not accessible to large compaction equipment. Such areas can include that around lamp standards, utility structures, building edges, curbs, tree wells and other protrusions.

Note: Prior to screeding the bedding sand, the recommended base surface tolerance should be ± 3/8 in. (10 mm) over a 10 ft. (3 m) straight edge. See ICPI Tech Spec 2 – Construction of Interlocking Concrete Pavements for further guidance on construction practices.

Note: The elevations and surface tolerance of the base determine the final surface elevations of concrete pavers. The paver installation contractor cannot correct deficiencies in the base surface with additional bedding sand or by other means. Therefore, the surface elevations of the base should be checked and accepted by the General Contractor or designated party, with written certification to the paving subcontractor, prior to placing bedding sand and concrete pavers.

      c. Verify that [Aggregate] [Cement-treated] [Asphalt-treated] [Concrete] [Asphalt] base materials, thickness, [compacted density], surface tolerances and elevations conform to specified requirements.
      d. Provide written density test results for soil subgrade, [aggregate] [cement-treated][asphalt-treated][asphalt] base materials to the Owner, General Contractor and paver installation subcontractor.
      e. Verify location, type, and elevations of edge restraints, [concrete collars around] utility structures, and drainage inlets.
   2. Do not proceed with installation of bedding sand and interlocking concrete pavers until [subgrade soil and] base conditions are corrected by the General Contractor or designated subcontractor.

3.03 PREPARATION

A. Verify base is dry, certified by General Contractor as meeting material, installation and grade specifications.
B. Verify that base [and geotextile] is ready to support sand, [edge restraints,] and, pavers and imposed loads.
C. Edge Restraint Preparation:
   1. Install edge restraints per the drawings [and manufacturer's recommendations] [at the indicated elevations].

Note: Retain the following two subparagraphs if specifying edge restraints that are staked into the base with spikes.

   2. Mount directly to finished base. Do not install on bedding sand.
   3. The minimum distance from the outside edge of the base to the spikes shall be equal to the thickness of the base.

3.04 INSTALLATION

A. Spread bedding sand evenly over the base course and screed to a nominal 1 in. (25 mm) thickness. Spread bedding sand evenly over the base course and screed rails, using the rails and/or edge restraints to produce a nominal 1 in. (25 mm) thickness, allowing for specified variation in the base surface.
   1. Do not disturb screeded sand.
   2. Screeded area shall not substantially exceed that which is covered by pavers in one day.
   3. Do not use bedding sand to fill depressions in the base surface.

Note: When initially placed on the bedding sand, manually installed pavers often touch each other, or their spacer bars if present. Joint widths and lines (bond lines) are straightened and aligned to specifications with pry bars as paving proceeds.

B. Lay pavers in pattern(s) shown on drawings. Make horizontal adjustments to laid pavers as required.

Note: Contact manufacturer of interlocking concrete paver units for recommended joint widths.

C. Provide joints between pavers between [1/16 in. and 3/16 in. (2 and 5 mm)] wide. No more than 5% of the joints shall exceed 1/4 in. (6 mm) wide to achieve straight bond lines.
D. Joint (bond) lines shall not deviate more than ± 1/2 in. (15 mm) over 50 ft. (15 m) from string lines.

E. Fill gaps at the edges of the paved area with cut pavers or edge units.
F. Cut pavers to be placed along the edge with a [double blade paver splitter or] masonry saw.

Note. Specify requirements for edge treatment in paragraph below.

G. [Adjust bond pattern at pavement edges such that cutting of edge pavers is minimized. All cut pavers exposed to vehicular tires shall be no smaller than one-third of a whole paver.] [Cut pavers at edges as indicated on the drawings.]
H. Keep skid steer and forklift equipment off newly laid pavers that have not received initial compaction and joint sand.
I. Use a low-amplitude plate compactor capable of at least minimum of 5,000 lbf (22 kN) at a frequency of 75 to 100 Hhz to vibrate the pavers into the sand. Remove any cracked or damaged pavers and replace with new units.
J. Simultaneously spread, sweep and compact dry joint sand into joints continuously until full. This will require at least 4 to 6 passes with a plate compactor. Do not compact within 6 ft (2 m) of unrestrained edges of paving units.
K. All work within 6 ft. (2 m) of the laying face must be left fully compacted with sand-filled joints at the end of each day or compacted upon acceptance of the work. Cover the laying face or any incomplete areas with plastic sheets overnight if not closed with cut and compacted pavers with joint sand to prevent exposed bedding sand from becoming saturated from rainfall.
L. Remove excess sand from surface when installation is complete.

Note: Excess joint sand can remain on surface of pavers to aid in protecting their surface especially when additional construction occurs after their installation. If this is the case, delete the article above and use the article below. Designate person responsible for directing timing of removal of excess joint sand.

M. Allow excess joint sand to remain on surface to protect pavers from damage from other trades. Remove excess sand when directed by [Architect].
N. Surface shall be broom clean after removal of excess joint sand.

3.05 FIELD QUALITY CONTROL

A. The final surface tolerance from grade elevations shall not deviate more than ± 3/8 in. (10 mm) over 10 ft (3 m). Use a straightedge, flexible straightedge or transit depending on surface slope and contours.
B. Check final surface elevations for conformance to drawings.

Note: For installations on a compacted aggregate base and soil subgrade, the top surface of the pavers may be 1/8 to 1/4 in. (3 to 6 mm) above the final elevations after compaction. This helps compensate for possible minor settling normal to pavements.

C. The surface elevation of pavers shall be 1/8 in. to 3/8 in. (3 to 10 mm) above adjacent drainage inlets, concrete collars or channels.

Note: For pedestrian access routes maximum elevation should not exceed 1/4 in. (6 mm).

D. Lippage: No greater than 1/8 in. (3 mm) difference in height between adjacent pavers.

Note: Cleaning and sealing may be required for some applications. See ICPI Tech Spec 5–Cleaning and Sealing Interlocking Concrete Pavements for guidance on when to clean and seal the paver surface, and when to stabilize joint sand. Delete article below if cleaners, sealers and or joint sand stabilizers are not applied.

3.06 [CLEANING] [SEALING] [JOINT SAND STABILIZATION]

A. [Clean] [Seal] [Apply joint sand stabilization materials to concrete pavers in accordance with the manufacturer's written recommendations.]

3.07 PROTECTION

A. After work in this section is complete, the General Contractor shall be responsible for protecting work from damage due to subsequent construction activity on the site.

END OF SECTION

ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®
Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

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TECH SPEC

NUMBER 10

Application Guide for Interlocking Concrete Pavements

This technical bulletin provides an overview of interlocking concrete pavements for a range of applicatons. The Interlocking Concrete Pavement Institute (ICPI) publishes other technical bulletins, brochures, design manuals, and software that address many of the applications in greater detail.

Product Description

Applications: Interlocking concrete pavements are appropriate for any application that requires paving. These areas include patios, driveways, pool decks, sidewalks, parking lots, pedestrian plazas, roof plaza decks, roof ballast, roof parking decks, embankment stabilization, gas stations, medians, streets, industrial pavements, ports, and airports.

Composition and Materials: Interlocking concrete pavers are composed of portland cement, fine and coarse aggregates. Color is often added. Admixtures are typically placed in the concrete mix to reduce efflorescence. These materials are combined with a small amount of water to make a "zero slump" concrete. Pavers are made in factory-controlled conditions with machines that apply pressure and vibration. The result is a consistent, dense, high strength concrete that can be molded into many shapes. Special surface finishes can be produced to give an upscale architectural appearance. These include unique aggregates, colors, tumbling, shot blasting, bush hammering, and polishing.

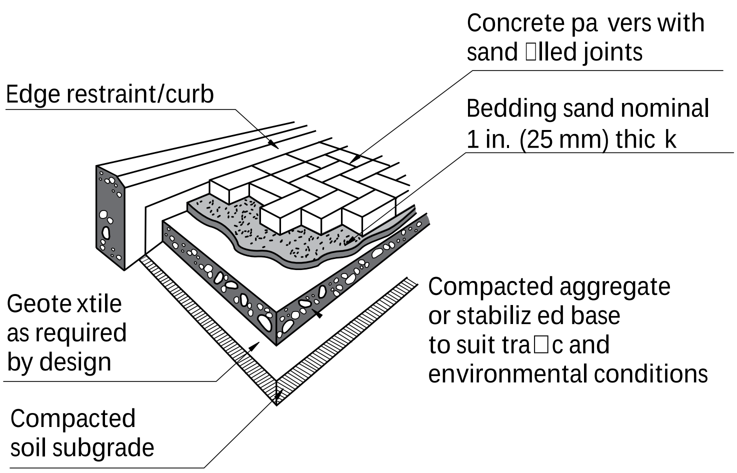

Figure 1. Typical components of an interlocking concrete pavement system

Technical Data

Visit icpi.org for guide specifications and detail drawings for a range of applications.

Physical Characteristics: When manufactured in the U.S., interlocking concrete pavers made by ICPI members typically meet the requirements in ASTM C 936, Standard Specifications for Solid Interlocking Concrete Paving Units.

Concrete pavers produced by Canadian ICPI members typically conform to the standard published by the Canadian Standards Association, CSA-A231.2, Precast Concrete Pavers.

ICPI offers certification of test results to help ensure that the products meet applicable ASTM or CSA standards.

Applications Standards: For pedestrian applications and residential driveways, 2 3/8 in. (60 mm) thick pavers are recommended. Pavements subject to vehicular traffic typically require 3 1/8 in. (80 mm) thick pavers. Some heavy-duty industrial pavements use minimum 4 in. (100 mm) thick units.

Units with an overall length to thickness (aspect) ratio greater than 4 should not be used in vehicular applications. Those with aspect ratios between 3 and 4 may be used in areas with limited automobile use such as residential driveways. Units with aspect ratios of 3 or less are suitable for all vehicular applications.

Interlocking concrete pavements are typically constructed as flexible pavements on a compacted soil subgrade and compacted aggregate base. Concrete pavers are then placed on a thin layer of bedding sand (1 to 1 1/2 in. or 25 to 40 mm), compacted, sand swept into the joints, and the units compacted again. When compacted, the pavers interlock, transferring vertical loads from vehicles to surrounding pavers by shear forces through the joint sand. The sand in the

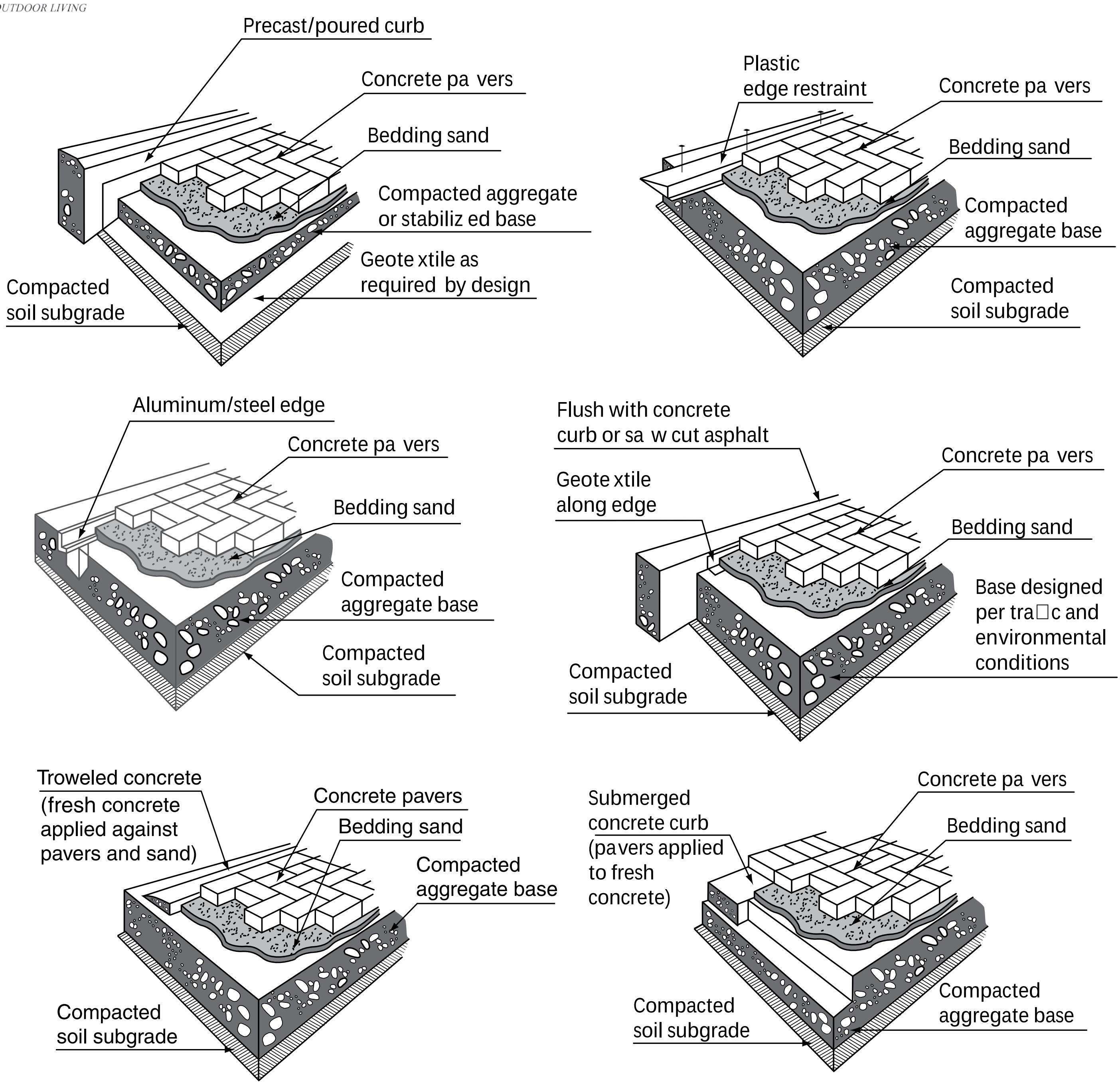

Figure 2. Edge Restraints. Note: Troweled concrete and submerged concrete curbs are recommended in non-freeze thaw areas only.

joints enables applied loads to be spread in a manner similar to asphalt, reducing the stresses on the base and subgrade.

Benefits: As interlocking concrete pavements receive traffic, they stiffen and increase their structural capacity over time. The structural contribution of the interlocking pavers and sand layer can exceed that of an equivalent thickness of asphalt. The interlock contributes to the structural performance of the pavement system. ICPI Tech Spec 4 provides additional information on structural design of the pavers, sand, and base. ICPI takes a conservative approach by not recognizing differences among shapes with respect to structural and functional performance. Certain manufacturers may have materials and data that discuss the potential benefits of shapes that impact functional and structural performance.

Concrete pavers do not require time to cure. They arrive at the site ready to install, ready for traffic immediately after paving. This can reduce construction time and restore access quickly. The joints between each paver eliminate cracking normal to conventional asphalt and concrete pavement.

Unlike concrete or asphalt, concrete pavers do not rely on monolothic continuity of their material for structural integrity. Therefore, utility cuts can be reinstated without damage to the pavement surface. Repair to underground utilities and to local deformations in the base materials can be accessed by removing and later reinstating the same pavers. No pavement materials are wasted or hauled to the landfill. Jackhammers are not required to open interlocking pavements. The modular units enable changes in the layout of the pavement over its life.

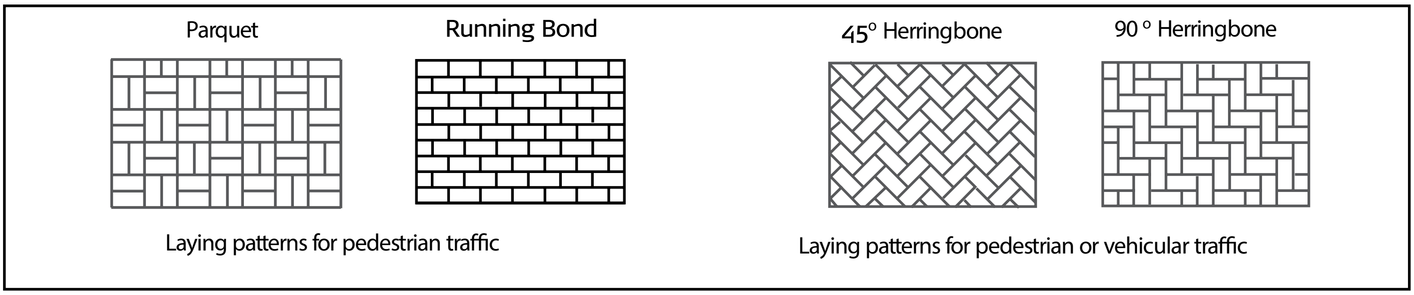

Figure 3. Typical laying patterns.

Colored units can be used for lane and parking delineations, traffic direction markings, utility markings, and artistic super graphic designs. Various colors, shapes, and laying patterns can support control and direction of pedestrian or vehicular traffic, and can be used as detectable warnings on pedestrian ramps at intersections.

The chamfered joints in the pavement surface facilitate removal of surface water. This decreases nighttime glare when wet and enhances skid resistance. Pedestrian slip resistance meets or exceeds guidelines recommended in the Americans with Disabilities Act (ADA). ICPI Tech Spec 13 includes further information on slip and skid resistance of concrete pavers. Snow is removed as with any other pavement. Concrete pavers have greater resistance to deicing salts than conventional paving materials due to high cement content, strength, density, and low absorption.

Sustainable Aspects: Interlocking concrete pavements can be eligible for LEED® credits including those under Sustainable Sites, Materials & Resources. See ICPI Tech Spec 16–Achieving LEED® Credits with Segmental Concrete Pavement. In addition, permeable interlocking concrete pavements can earn Sustainable Site credits for reducing runoff and water pollution. See the ICPI manual, Permeable Interlocking Concrete Pavement for design, specification, construction and maintenance guidelines.

Installation

It is recommended that installation be performed by experienced contractors who hold a current certificate in the ICPI Concrete Paver Installer Certification Program. Contractors holding this certificate have been instructed and tested on knowledge of interlocking concrete pavement construction.

Interlocking concrete pavements typically consist of a soil subgrade, an aggregate base, bedding sand, concrete pavers, edge restraints, and drainage (see Figure 1). Geotextiles are sometimes used under the base, over fine, moist subgrade soils to extend the life of the base and reduce the likelihood of deformation. The installation guidelines below apply to pedestrian and many vehicular applications. For street, industrial, port and airport pavement designs, consult with a qualified civil engineer familiar with local soils, pavement design methods, ICPI resources for these applications, materials, and construction practices. ICPI also has information on design, construction, and maintenance of permeable interlocking concrete pavements for control of runoff and nonpoint storm water pollution.

Soil Subgrade: Once excavation is complete, the soil subgrade should be compacted prior to placing the aggregate base. Compaction should be at least 98% Proctor density (per ASTM D 698) for pedestrian areas and residential driveways, and at least 98% modified Proctor density (per ASTM D 1557) for areas under constant vehicular traffic. Consult compaction equipment manufacturers' recommendations for applying the proper equipment to compact a given soil type. Some soils may not achieve these recommended minimum levels of density. These soils may have a low bearing capacity or be continually wet. If they are under a base that will receive constant vehicular traffic, the soils may need to be stabilized, or have drainage designed to remove excess water.

Aggregate Base: Aggregate base materials should conform to that used under asphalt. If no local, state, or provincial standards exist, then the requirements for aggregate base in ASTM D 2940 are recommended. The base should be compacted in minimum 4 to 6 in. (100 to 150 mm) maximum lifts. The thickness of the base depends on the strength of the soil, drainage, climate, and traffic loads. Base thickness used under asphalt can typically be used under interlocking concrete pavers. Minimum aggregate bases for walks should be 4 to 6 in. (100 to 150 mm), driveways 6 to 8 in. (150 to 200 mm), and streets 8 to 12 in. (200 to 300 mm). Thickness may be adjusted depending on site conditions and traffic.

Compaction of the aggregate base under pedestrian and residential driveway pavements should be at least 98% of standard Proctor density (per ASTM D 698). The aggregate base should be compacted to at least 98% modified Proctor density (per ASTM D 1557) for vehicular areas. Compaction equipment suppliers can provide information on the appropriate machines for compacting base material. These density recommendations for areas next to curbs, utility structures, lamp bases, and other protrusions in the pavement are essential to minimize settlement. Site inspection and testing of the compacted soil and base materials are recommended to ensure that compaction requirements have been met. Compacted base materials stabilized with asphalt or cement may be used in heavy load applications or over weak soil subgrades. The surface of the compacted base should be smooth with a maximum tolerance of ± 3/8 in. (10 mm) over a 10 ft. (3 m) straight-edge.

Bedding Sand: Bedding sand should conform to the grading requirements of ASTM C 33 or CSA-A23.1-FA1. Do not use mason sand. Stone dust or waste screenings should not be used, as they can have an excessive amount of material passing the No. 200 (0.075 mm) sieve. ICPI Tech Spec 17–Bedding Sands for Vehicular Applications provides additional guidance on evaluating beddings sands under vehicular traffic. The sand should be screeded to a nominal 1 in. (25 mm). Do not use the sand to fill depressions in the base. These eventually will be reflected in the surface of the finished pavement. Fill any depressions with base material and compact.

Geotextile may be applied under the bedding sand in certain places. These areas are adjacent to curbs, roof parapets, drains, utility structures, and over asphalt or cement stabilized bases to prevent migration of the bedding sand into joints or cracks. When applied in these locations the fabric should be turned up against vertical surfaces to contain the bedding sand.

Joint Sand: Bedding sand may be used as joint sand, however, extra time and effort may be required in sweeping and forcing the sand between the pavers. For that reason, fine, dry sand may be used that conforms to the grading requirements of ASTM-C144 or CSA-A179. This sand is often called mason sand and is used to make mortar. This sand should not be used for bedding sand.

Concrete Pavers: The shape of the concrete pavers determines the range of laying patterns (Figure 3). 45° to 90° herringbone patterns are recommended in areas subject to continual vehicular traffic. They will give the maximum interlock and structural performance. Some patterns have "edge" pavers specifically designed to fit against the edge restraints. Concrete pavers can be cut with a splitter or masonry saw to fit along the edge of the pavement. For streets and industrial areas exposed to tire traffic pavers should be no smaller than one-third of a unit when exposed to vehicular traffic. Joints between concrete pavers are typically 1/16 to 3/16 in. (2 to 5 mm) wide. They can be slightly wider for units with a stone like finish with rough edges and sides. Bond or joint lines tolerances should be +/- 1/2 in. over a 50 ft (15 m) string line.

Once the pavers are placed in their specified pattern(s), they are compacted into the bedding sand with a plate compactor. The compactor should have a minimum force of 4,000 lbs. (18 kN) and frequency of 75 to 100 hz. After the pavers are compacted, sand is swept and vibrated into the joints until they are full. All pavement within 6 ft (2 m) of unfinished edges should have the joints full and be compacted at the end of each day. Final surface elevations of the pavers should be 1/8 to 1/4 in. (3 to 6 mm) above edges to allow for minor settlement. Final surface elevations around drains should not exceed 1/4 in. (6 mm) in pedestrian areas but may be as much as 3/8 in. (10 mm) in vehicular areas. Lippage should not exceed 1/8 in. (3 mm). See ICPI Tech Spec 2 for further information on construction. ICPI Tech Spec 9 provides a guide specification for installation. Detail drawings and guide specifications are available at the ICPI web site, icpi.org.

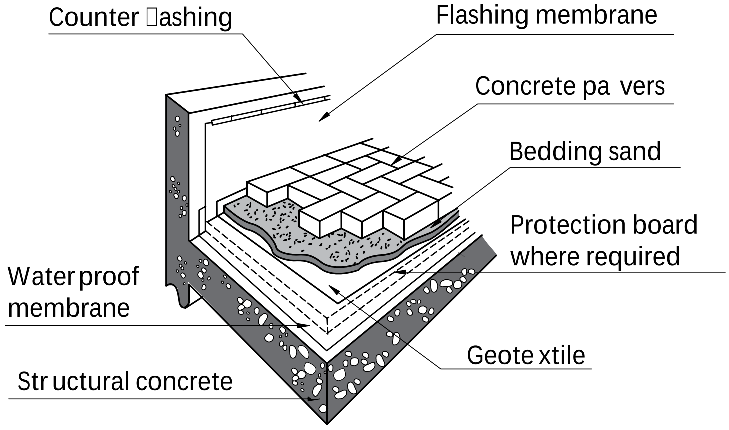

Figure 4. Roof assembly

Edge Restraints: Edge restraints around interlocking concrete pavement are essential to their performance (Figure 2). The pavers and sand are held together by them, enabling the system to remain interlocked. For walks, patios, and driveways, edge restraints can be steel, aluminum, troweled concrete and submerged concrete curb, or plastic edging specifically designed for concrete pavers. Concrete restraints are recommended for crosswalks, parking lots, drives, streets, industrial, port, and airport pavements. Precast concrete and cut stone curbs are suitable for streets, drives, and parking lots. Edge restraints are typically placed before installing the bedding sand and concrete pavers. Some edge restraints such as plastic, steel, and aluminum can be installed after placing the concrete pavers.These edge restraints will require the compacted base to extend past the stakes that secure edging in the base. For residential projects, the distance from the stakes to the base perimeter should be equal, not exceeding 10 in. (250 mm). For commercial applications, the distance should equal the base thickness. See ICPI Tech Spec 3 for further information on edge restraints.

Drainage: Surface and subsurface drainage systems, as well as pavement grades, should conform to that used for any other flexible pavement.

Swimming Pools: High slip-resistance and rapid drainage of water make concrete pavers a desirable surface around commercial or residential swimming pools. The pavers and bedding sand can be placed on a compacted aggregate or concrete base. Concrete will be the typical base as most backfill soils around pool walls will settle because they cannot be adequately compacted. When placed on a concrete base, drain holes are necessary at the lowest elevations to remove excess moisture in the bedding sand. A urethane or neoprene sealant and backer rod should be placed between the course of pavers and the pool coping. Sealing the pavers and joints is recommended.

Roof Plaza/Parking Decks: Interlocking concrete pavements can be placed on parking garage roofs and pedestrian roof plazas. Concrete pavers provide an attractive ballast

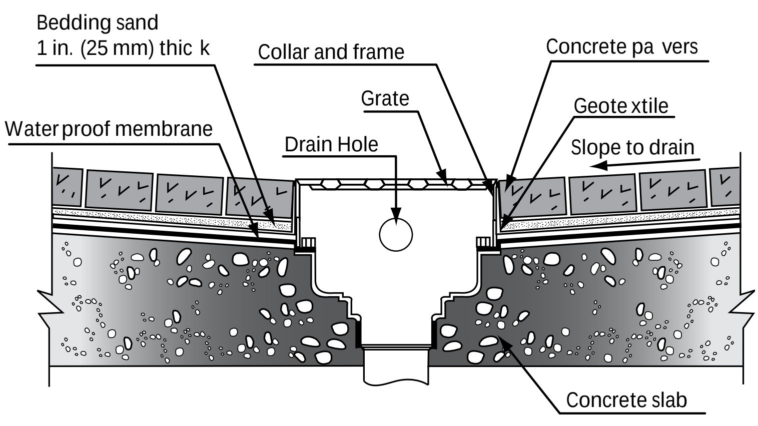

Figure 5. Roof drain holes at bottom of bedding sand layer

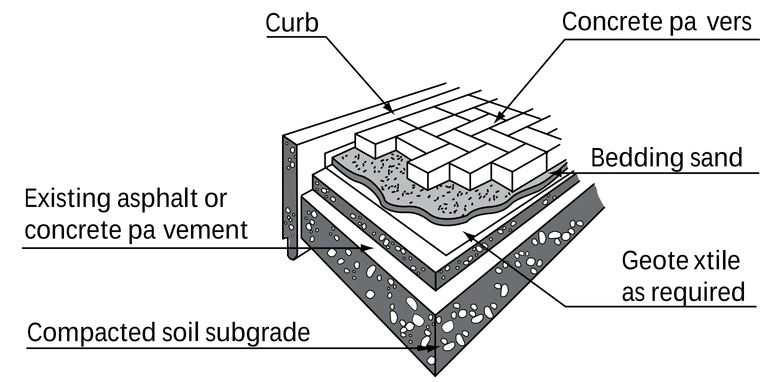

Figure 6. Typical overlay/inlay on existing pavement.

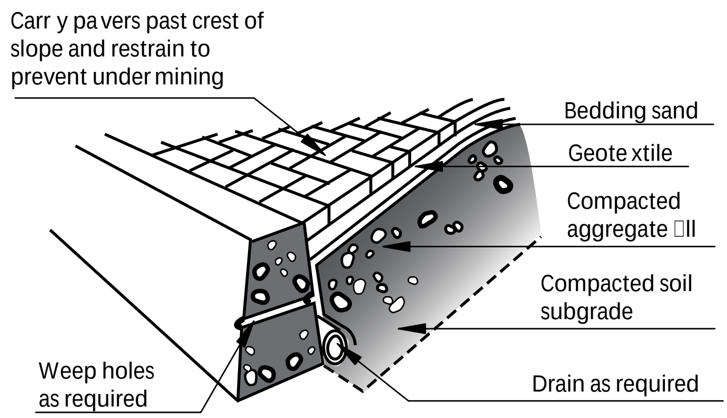

Figure 7. Embankment with concrete pavers

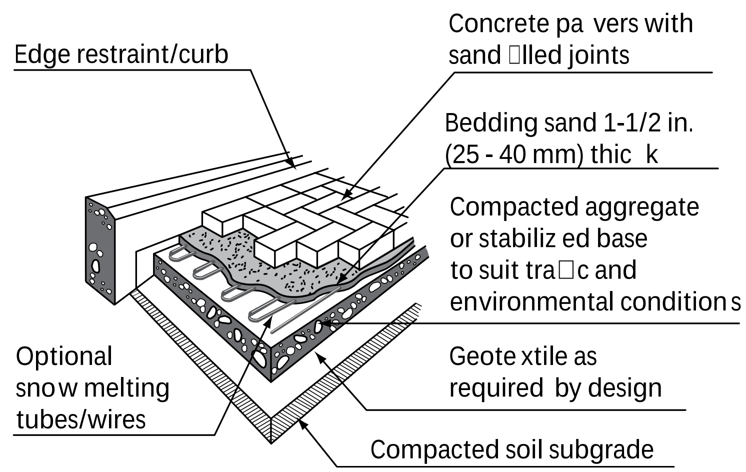

Figure 8. Snow melting system with concrete pavers for pedestrian areas or residential driveways

for the waterproof membrane (Figure 4). As a heat sink, the pavers reduce thermal stress on the membrane. The roof structure should be waterproofed, designed to withstand loads, and be sloped at least 2% to drain. Protection board should be applied according to the recommendations of the waterproof membrane manufacturer. Geotextile is applied around roof drains to prevent the migration of bedding sand. The drains should have holes at the level of the waterproof membrane to allow removal of subsurface water (Figure 5). See Tech Spec 14 for further information on roof plaza deck applications.

Pavement Overlay/Inlay: New or existing asphalt or concrete pavements can be overlaid or inlaid with concrete pavers (Figure 6). The surface of the existing pavement can be ground out and bedding sand and pavers placed in the milled area. Consideration should be given to drainage of excess moisture in the bedding sand during the early life of the pavement overlay/inlay. Drainage can be achieved by drilling/casting vertical holes at the lowest elevations of the pavement, or directing drain holes to catch basins. The drain holes should be covered with geotextile to prevent loss of bedding sand. Geotextile may need to be applied at pavement joints and cracks. Cracks 3/8 in. (10 mm) or larger in width should be patched prior to placing geotextile, bedding sand, and pavers. Thin paving units, 1 1/4 to 1 3/4 in. (30 - 45 mm) thick, have been used in overlays. The units are typically sand set on or adhered to a concrete base for pedestrian applications. They are not recommended for any vehicular application.

Embankments and Vehicular Pavements with High Slopes: Pavers provide a durable surface for control of soil erosion from embankments. A backfill of open-graded aggregate with drains at the bottom of the slope is recommended to relieve hydrostatic pressure (Figure 7). Concrete pavers restrained at the sides and top of the slope should have adjacent areas graded and slope in such a manner that water runs away from the restraints.

Vehicular pavements with slopes over 8% may require concrete header beams. Concrete header beams are recommended at the top and bottom of the sloped area. Intermittently placed beams along the sloped area are not recommended.

Drainage of water in the bedding sand and base is essential along the upslope side of the concrete headers. For concrete pavers and bedding sand over aggregate base, removal of water can be accomplished with minimum 1 in. (25 mm) diameter horizontal weep holes spaced every 10 ft (3 m) and covered with geotextile to prevent loss of base fines or bedding sand. When pavers and bedding are over concrete or asphalt, there should be several vertical, geotextile-covered drain holes in these pavements on the upslope side of the header. The water collected by these drain holes or geocomposite drains should be directed beyond the edge restraints of the pavement.

The overall dimensions of, and the steel reinforcement within the concrete headers will depend upon traffic loads and base design. Minimum recommended dimensions are 6 in. (150 mm) wide and 12 in. (300 mm) deep. The joint sand between the pavers should be stabilized with a sealer to prevent washout. The crossfall of the pavement should be at least 2% from the center.

Snow Melting Systems: Interlocking concrete pavements can accommodate snow melting systems for pedestrian and vehicular applications (Figure 8). The sys-


Figure 9. Mechanical installation equipment places concrete pavers rapidly.

tems consist of hot, liquid-filled tubing or radiant wires placed in the bedding sand, in compacted aggregate concrete, or asphalt base. Snow melt systems turn on automatically when a snowstorm starts, eliminating plowing, ice hazards, and the need for de-icing salts. The result is less potential for injuries from slipping on ice and decreased liability.

An aggregate base can be used to support the tubing or wires for pedestrian areas and residential driveways. Both systems must be secured to the base prior to placing the bedding sand. The systems are installed by specialty contractors (electricians and/or plumbers). The bedding sand may be as much as 2 in. (50 mm) thick to cover and protect the tubing or wires. For other vehicular areas, the tubing or wires should be placed in a concrete or asphalt base. See ICPI Tech Spec 12 for further information on snow melting systems.

Rigid Pavements: Construction of rigid pavements is slower and more expensive compared to sand-set installations. Concrete pavers can be set on a sand-asphalt setting bed with neoprene modified asphalt mastic. The base under the asphalt is typically concrete. Paver joints are filled with sand or stabilized sand. Draining excess water from the concrete base is accomplished with 2 to 3 in. (50 to 75 mm) diameter vertical holes through the concrete. Placed at lowest elevations, the holes are filled with washed pea gravel. Concrete pavers placed on a sand-asphalt bedding course and adhesive with joint sand are usually applied in vehicular areas. This type of assembly is also called bitumen-set pavers or pavers over a bituminous setting bed.

Bitumen-set concrete pavers will increase the cost of the installation when compared to sand set installations. This installation method requires a concrete base and additional costs from handling the asphalt setting bed and mastic. Small areas are installed in the following sequence. A prime coat is placed on a concrete base, the asphalt bed is placed, screeded, and then compacted. Mastic is applied to the bed and the pavers are placed on it. Should the surface of the pavers be stained with mastic, it is very difficult to remove. Reinstatement of bitumen-set pavers is impossible because the asphalt material adheres to the bottom of the pavers when removed. It is less expensive to discard the pavers rather than remove the asphalt from the units and attempt to reinstate them. Bitumen-set concrete pavers are not recommended on asphalt or aggregate bases.

Mortared pavers should only be used in pedestrian areas in non-freeze-thaw areas. Mortared joints have a high risk of deterioration when subjected to vehicular traffic, freeze-thaw cycles and/or de-icing salts. Polymer adhesives specially designed for adhering concrete pavers to concrete enable faster installation without the chance of accidentally staining the surface of the pavers with mortar. These adhesives can be used in areas with freezing climates. Pavers set with adhesives are not recommended for vehicular areas.

Mechanical Installation: Certain laying patterns can be installed mechanically, saving construction time. Specialized installation equipment enables over a square yard (m^2) of concrete pavers to be placed in succession, rather than one paver at a time (Figure 9). Contact a local ICPI supplier for availability of laying patterns and for contractors experienced with mechanical installation equipment. See ICPI Tech Specs 11 and 15 for further information on mechanical installation.

Availability and Price

Availability: Interlocking concrete pavers are available from ICPI members throughout the U.S. and Canada. Check with a local member for available shapes, thicknesses, and colors.

Price: Prices will vary depending on the site location, pattern, thickness, color, area, base requirements, edge restraints, and drainage.

Warranty

ICPI paver suppliers will typically certify that the specified product meets the requirements of ASTM C 936 or CSA A231.2 as applicable. It is recommended that the manufacturer have a current product certification from ICPI. This certifies that concrete pavers submitted by the manufacturer to an independent testing laboratory passed applicable ASTM or CSA tests.

Maintenance

When properly installed, interlocking concrete pavements require practically no maintenance. As with all pavements, they will become soiled over time depending on the amount of use. Contact a local ICPI supplier for information on cleaning concrete pavers. ICPI publishes other technical bulletins on cleaning, sealing, (ICPI Tech Spec 5) and reinstatement of concrete pavers (ICPI Tech Spec 6).

ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®
Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

ICPI INTERLOCKING CONCRETE PAVEMENT INSTITUTE

TECH SPEC

NUMBER 11

Mechanical Installation of Interlocking Concrete Pavements

Mechanical installation originated in Germany and the Netherlands in the late 1970s. The growth of street, port, and airport projects required timely installation with fewer workers. Machines were developed to increase productivity while reducing fatigue and injury (1–4). Today, over 5,000 mechanical installation machines operate in Germany alone with thousands more in use throughout Europe. They are used for projects as small as 10,000 sf (1,000 m^2) (5).

Figure 1. Mechanical installation equipment at Port of Tampa, Florida.

Figure 2. A cube of 90° herringbone pattern rectangular pavers ready for installation.

Mechanical equipment was first introduced in North America in the early 1980s. The first mechanically installed project was placed in 1981, a 1,000,000 sf (93,000 m^2) container terminal in Calgary, Alberta. Since then, hundreds of commercial, municipal, port, and airport jobs have been installed mechanically in most states and provinces across North America. Some examples include city streets in Dayton, Ohio (the first mechanically installed street in the U.S.) (6); Cincinnati, Ohio; Toronto, Ontario; Northbrook, Illinois; Naples, Florida; and Palm Desert, California; container yards in Tampa, New Orleans, Baltimore, and Oakland; and an airfield at St. Augustine, Florida.

Mechanical installation must be viewed as a system of material handling from manufacture to on-site placement of the concrete pavers. This technical bulletin provides guidelines for the manufacturer, designer, and contractor of mechanically installed pavements in order to realize high efficiencies from this system of material handling. Successful mechanical installation relies on four factors that affect efficiency and costs. These include:

1. Equipment specifically designed to efficiently handle
   - (a) transport of packaged concrete pavers onto/around the site,
   - (b) screeding of bedding sand,
   - (c) installation of the concrete pavers.
2. The shape of the paver and configuration of the laying pattern.
3. Careful job planning by the contractor with support from the manufacturer before the job begins.
4. Systematic and efficient execution of the installation on the job site.

Figure 3. Non-motorized equipment used to set a small layer of pavers.
Figure 4. (right) Motorized equipment with a mechanical clamp.

As of 2003, ICPI has released Tech Spec 15 – A Guide for Construction of Mechanically Installed Interlocking Concrete Pavements. The guide is intended for large, mechanically installed projects and is for facility owners, design professionals, contractors, and manufacturers. It provides requirements for quality control of materials and their installation, including bedding sand and pavers. It includes a Quality Control Plan jointly developed and implemented by the paver installation contractor, the paver manufacturer and the general contractor. The specification guide facilitates planning and coordination among these entities, and it supports a systematic approach to manufacture, delivery, installation, and inspection.

1. Equipment for Mechanical Installation

Mechanized equipment includes an operator-activated clamp that lifts one layer or cluster of pavers at a time. Each layer can consist of 20 to 72 paving units. The pavers are manufactured in their prescribed laying pattern within the layer. In rare cases, two smaller layers are manufactured and combined in the factory to make one large layer. Layers are packaged in a "cube," i.e., each layer typically stacked 8 to 10 units high. The cubes arrive at the site with each layer ready to be lifted by the mechanical equipment and placed on the screeded bedding sand. Figure 2 shows a cube of pavers opened and ready for installation by mechanical equipment. When grasped by the clamp, the pavers remain together in the layer. They interlock from lateral pressure provided by the clamp while being lifted.

Each layer or cluster is typically about a square yard (m^2) in area. The exact layer area varies with each paver pattern. The area covered by the layer can be provided by the manufacturer.

Types of Equipment—Mechanized equipment may be either non-motorized or motorized. Non-motorized equipment consists of a wheeled hand cart and clamp that grabs a half layer, or about 15 to 20 pavers. While it is not as efficient as motorized equipment, a hand-held cart can save time and strain on the installation crew (see Figure 3). Non-motorized equipment has not been used extensively in North America. However, it may be useful on jobs where noise from vehicles is not permitted (e.g.,

Figure 5. Motorized equipment with a hydraulic clamp.

Figure 6. The vacuum head over the paver layer.

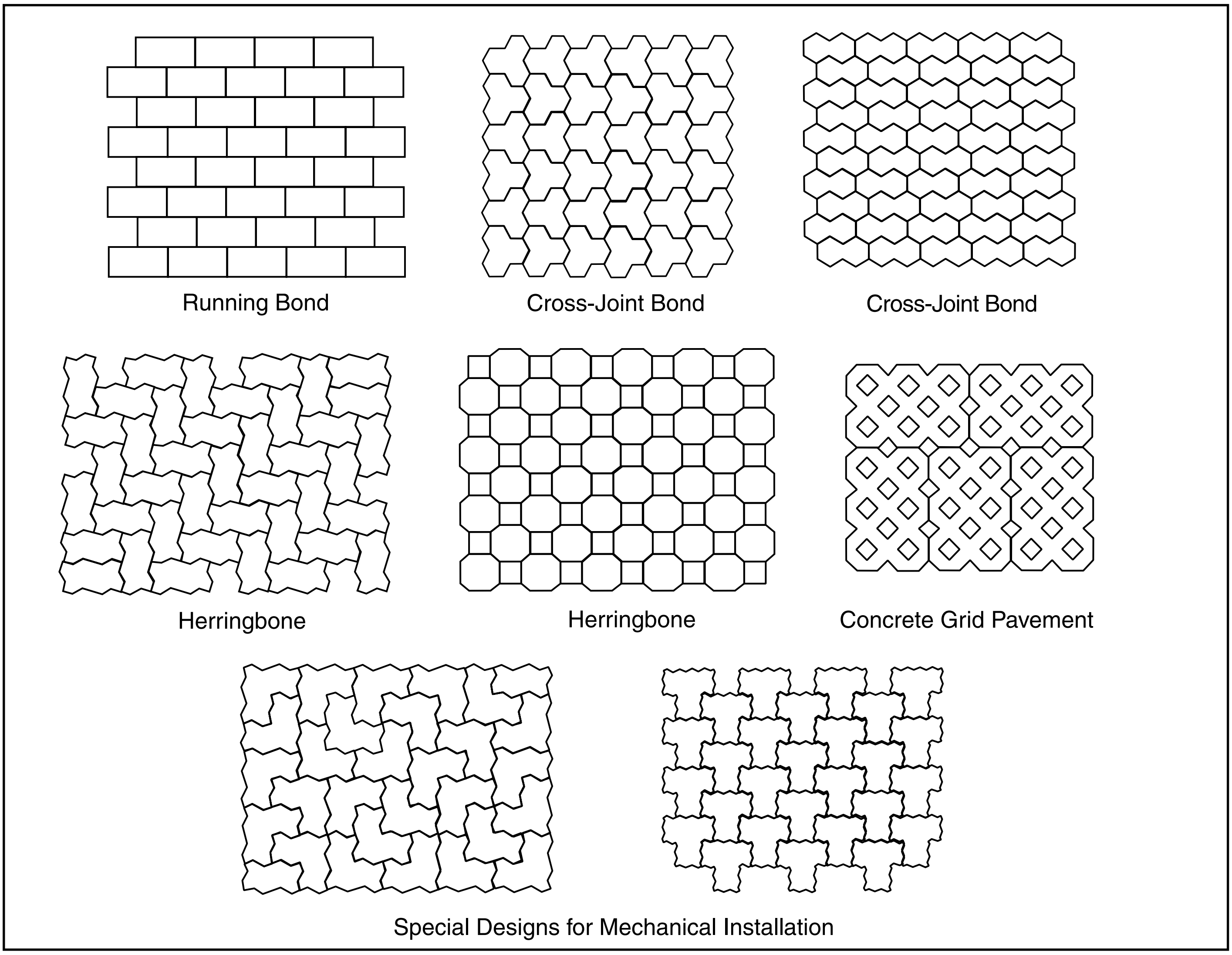

Figure 7. Paver layer categories for mechanical installation. These are representations of many available patterns.

hospitals), or places with weight limitations and very limited working space, such as roofs.

Most motorized equipment prevalent in North America is no heavier than a small automobile and is almost as quiet while operating. This equipment can use three different kinds of clamps for placing concrete pavers. The first type is a mechanical clamp shown in Figure 4 (7). This clamp consists of many levers that are adjusted to conform to the dimensions of the paver layer prior to starting the job. The initial adjustment of the clamp ensures a tight fit against the layer when activated. When the clamp closes and picks up the layer, the movement in the levers compensates for possible slight misalignment of pavers. Misalignment can be from minor dimensional differences among the pavers in the layer, or caused by small bits of dirt that occasionally lodge between them.

When activated by the machine operator, the clamp levers close in unison to pick up a layer. The clamp tightens against its sides while being lifted. The operator then aligns the layer next to the other pavers on the bedding sand. The layer is released from the clamp when almost touching the bedding sand. The layer should not be allowed to gouge the bedding sand as this unevenness will eventually be reflected in the surface of the pavers.

The second type of clamp is hydraulic, i.e., activated by hydraulic pistons that grab the sides of the paver layer as shown in Figure 5. Prior to starting a job, the hydraulic clamps are adjusted to conform to the configuration of the layer to be placed. The pressure of the hydraulic fluid is adjusted as well, so that each clamp tightly fits onto the sides of the layer.

The clamps close on the sides of the layer when triggered by the operator. The clamps have flexible spring steel grippers on them that compensate for minor size differences or debris among the pavers. As with the mechanical clamp, each layer is grabbed, positioned, the clamp opened, and the pavers dropped a short distance onto the bedding sand. The minimum paver thickness that can be laid with hydraulic or mechanical clamps is 2 $^3/_8$ in. (60 mm).

The third kind of clamp consists of a metal head that covers the paver layer and applies a vacuum. The head has many rubber cups arranged in the paver pattern to be placed. Each cup has a hose attached to it. A vacuum is pulled through the hoses to lift and place all pavers simultaneously as shown in Figure 6. The machine operator controls the vacuum in the cups that lifts and releases the pavers. This installation equipment tends to be heavier than the other kinds of motorized installation machines.

Vacuum equipment relies on suction to lift the pavers. No particles should be on the surface of the pavers because they will interfere with the seal between the cups and the paver surfaces. For different laying patterns, the arrangement of the cups on the head must be adjusted or new ones used. Vacuum equipment for installing interlocking concrete pavers is not prevalent in North America. Similar kinds of vacuum equipment are more commonly used to place larger concrete paving slabs ranging in size from 12 x 12 in. (300 x 300 mm) up to 36 x 36 in. (900 x 900 mm).

2. Pavers for Mechanical Installation

There are four general categories of paver patterns used as layers. They are running bond, cross joint bond, herringbone, and special designs for mechanical installation only. Figure 7 illustrates these types of patterns. These will be referenced in the discussion below.

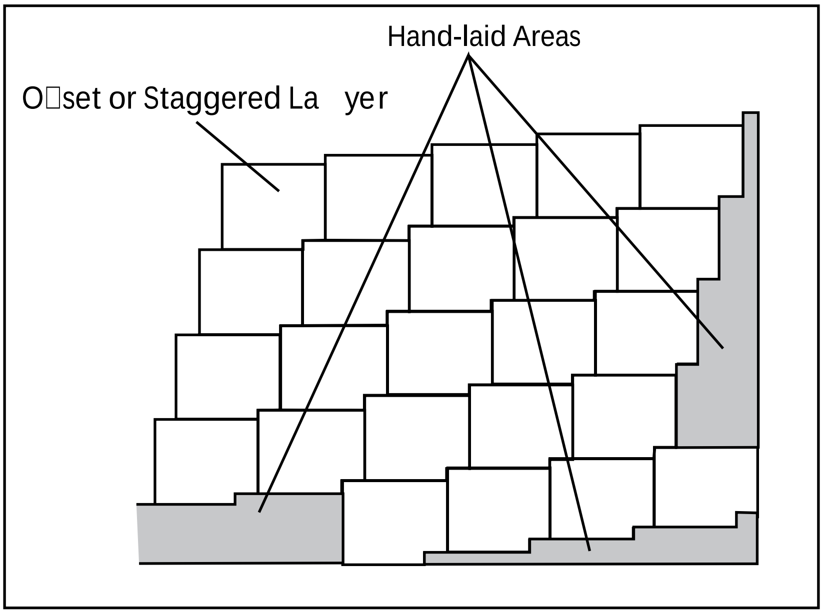

Figure 9. Staggered installation of clusters (8).

Figure 8. Clamps are an efficient method of moving cubes of pavers around the site, and can eliminate the need for wooden pallets.

On some mechanical jobs in a few developing countries, pavers are manufactured and manually arranged in the factory into the laying pattern for installation by machine. While this method may create needed jobs in some regions of the world, high labor costs prohibit this approach in North America. Pavers should be molded in the final laying pattern in order to maximize efficiency and control costs. The following criteria should be used in evaluating mold/layer configurations for efficiency, cost, and performance.

Utilization of the manufacturing pallet—The size of the production machine governs the size of the mold and hence the total number of pavers in each layer. Molds for mechanical installation should be as large as possible and should utilize the available space efficiently to maximize cost-effectiveness. For example, the difference between 35 and 45 pavers in a layer means a 28% increase in the number of pavers placed with the same effort and time.

The contractor can enhance the opportunity for cost-effective installations by reviewing mold layouts with the paver manufacturer for the most efficient use of pavers. The layouts present varying efficiencies in packaging, shipment, and transfer of material on the site, as well as supplemental manual installation, half pavers, bond patterns, interlock, and use of spacer bars.

Packaging and shipment—Pavers are banded as cubes for

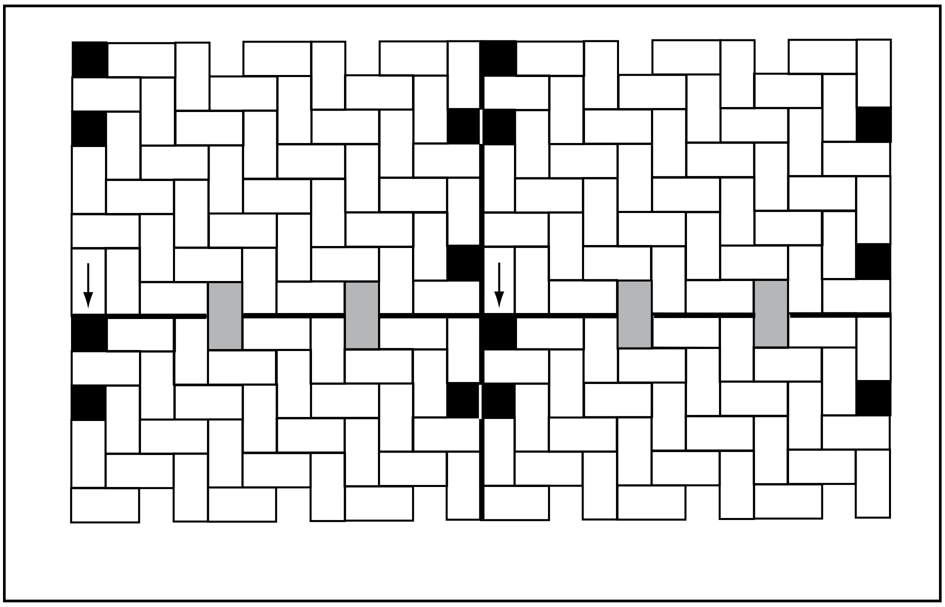

Figure 10. Half pavers to be removed from herringbone layers and filled with whole units. Gray spaces are filled with whole pavers as well.

shipment with steel and/or plastic straps. The layer configuration should enable each cube to be tightly banded with strapping; otherwise the pavers may shift during shipping, especially when the distance from the factory to the site is great. Misaligned pavers on the cube may need to be realigned on the job site prior to placing them. Realignment with installation equipment will waste time on the job site.

Most manufacturers can provide cubes of pavers tightly banded horizontally and vertically to minimize shifting while in transit. Plastic wrap is often applied as shrink wrap or stretch wrap (stretched tightly in many layers). All packaging is removed from the cubes when they are positioned near the laying face (or edge) of the pavement.

Transfer on the site—Most layer configurations enable their transfer (packaged as cubes) around the site with fork lifts or clamps. Cubes of pavers may be moved with or without wooden pallets.

They enable transfer with fork lifts but pallets incur additional costs in handling time and charges. Mechanical clamps specifically made for transferring paver cubes can eliminate the need for pallets on the site, thereby reducing material and labor costs (see Figure 8). If pavers are delivered without pallets and no clamps are available on the site, then the contractor may supply pallets on which to place the cubes for locating them at the laying face of the job with a forklift.

Supplemental manual installation—The amount of supplemental manual installation on a mechanically placed job depends on two factors. First, some areas must be placed only by hand because of the configuration of the site. They can't be reached by a machine, or the layer is too large for the area to be paved. Such areas may include those around light fixtures, utility structures, and drainage inlets.

Second, some patterns may need to be offset by a course or two when placed. In this case, the initial area of the pavers must be placed by hand. The hand-laid areas establish an offset for the coursing and the direction of the subsequent, machine-installed layers. Some herringbone patterns require an offset, and some special designs for mechanical installation may need to be offset to stagger the layers. For example, Figure 9 shows hand-laid areas that start a staggered pattern for the remaining machine-set layers.

Half pavers or half stones—Mechanical placement of some herringbone patterns requires half units. These minimize shifting of layers during transport and facilitate a firm grip by the clamp as it grabs each layer. When placed mechanically, herringbone laying patterns require hand removal of half pavers (nominally 4 x 4 in. or 100 x 100 mm in size) on their perimeter. As work proceeds,

Figure 11. Removal of half pavers and installation of whole units.

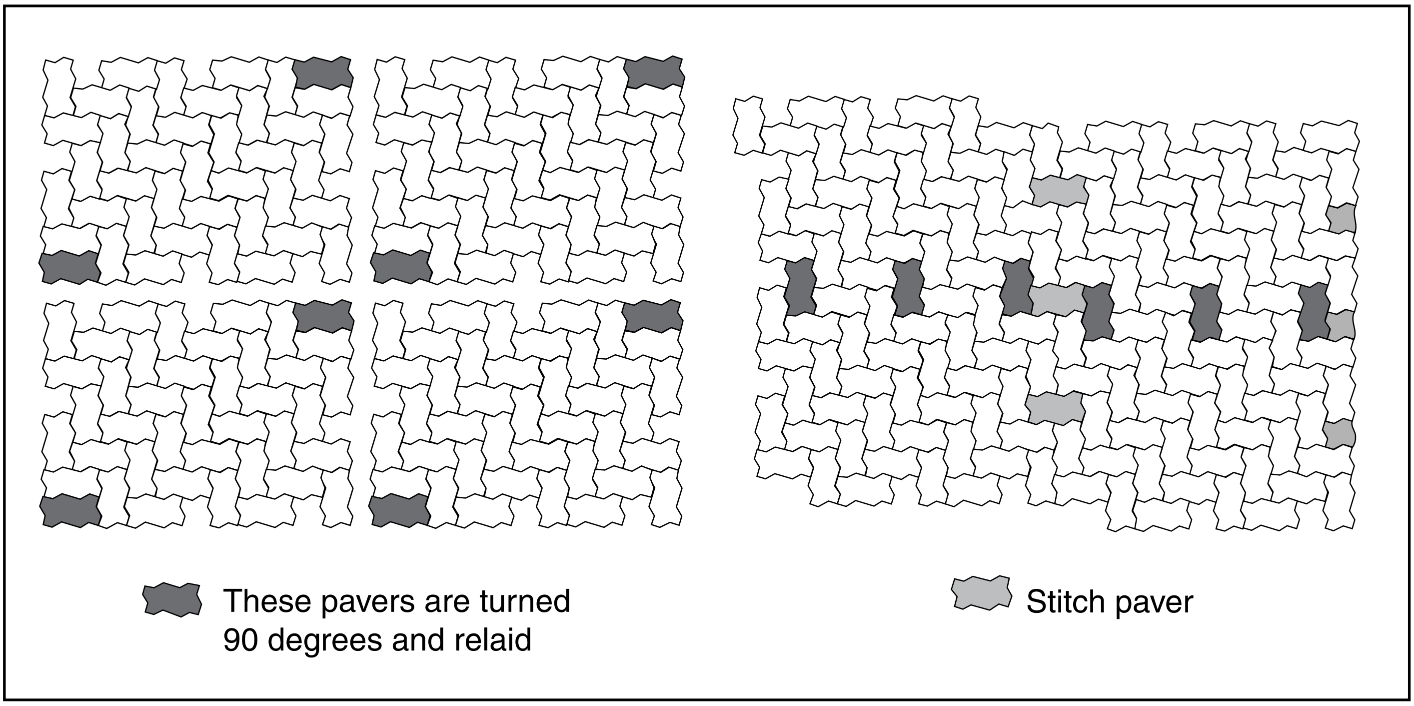

Figure 12. Herringbone pattern with no offset or half pavers.

the removed half pavers are replaced with full-size pavers to create or stitch a pattern that continuously interlocks with no indication of layer or cluster lines. Depending on the layer configuration, two to four half units per layer may need to be removed by hand prior to placing full size units in the openings. (See Figure 10.)

Removal of half pavers is typically done by hand or with a paver extractor. However, they must be removed and replaced with whole units before the pavers are compacted. (See Figure 11.)

Herringbone patterns provide a high degree of interlock. However, a significant cost could be incurred from removing, collecting, and disposing of the half units. Therefore, installation of these patterns can generate waste material and labor costs higher than other laying patterns.

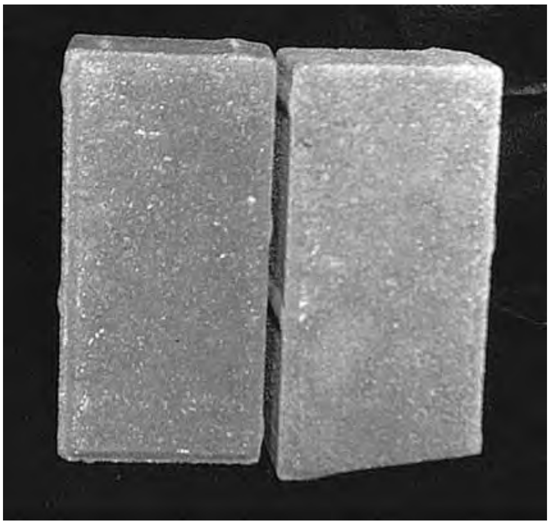

Figure 13. Spacer bars on the sides of concrete pavers are essential for mechanical installation.

One way to reduce the waste material and extra labor required for herringbone patterns is by having them made without half units. When packaged as cubes, the vertical, half paver openings on their sides may be filled with wood or plastic pipe for the layers to remain stable during shipment. The wood or pipes are removed when each cube is opened at the site. When each layer is installed, full-sized pavers still must be placed in the openings between the layers. Figure 12 shows a herringbone pattern with an offset but with no half pavers.

Bond pattern—Likewise, cross bond and running bond patterns generally do not require an offset area laid by hand. If laid end-to-end, the openings created by running bond patterns may require filling the openings with concrete pavers. Rather than trying to mesh or key the layers into each other, a more efficient method is to butt the ends of the running bond pattern and drop in filler pavers by hand.

A running bond pattern with rectangular shaped units can be manufactured in a stack bond (all joints aligned) and the vertical joints shifted one-half unit on the job site. This can be done with mechanical and hydraulic clamps. Some shaped pavers can be made in stack bond patterns and shifted to running bond by some machines. Besides bond patterns, basket weave patterns can be installed mechanically. Concrete grid pavements can be mechanically installed as well. They are typically placed in a stack, running, or modified bond pattern as shown in Figure 7.

Cross joint bond patterns are designed with no half units to be removed by hand, thereby increasing installation efficiency. Proprietary and non-proprietary patterns have been developed for mechanical installation with no half stones. These have a herringbone-like pattern, and may or may not have completely interlocking patterns from one layer to the next. These patterns install quickly.

Interlock among layers—Most layers and patterns provide a continuous interlocking surface of pavers. Horizontal interlock and the pavement structure are further enhanced by patterns that continuously interlock with their neighbors (9). Others are placed in clusters whose patterns do not interlock from one layer to the next. These kinds of patterns can be offset by a half layer to increase interlock.

Spacer bars—Pavers should have spacer bars or nibs on their sides for mechanical installation. The nibs generally protrude no more than 1/16 in. (2 mm) from the sides of the paver. (See Figure 13.) Spacer bars maintain a minimum joint width between the pavers, especially while the units are grabbed by the clamp and placed on the bedding sand. The space allows joint sand to enter and reduces the likelihood of edge spalling should there be local settlement. Some kinds of permeable interlocking concrete pavers have spacer bars between 3/16 to 1/8 (5 and 30 mm) to encourage infiltration of stormwater. Most of these concrete pavers can be installed mechanically.

Spacer bars are recommended that extend the full height of the paver, i.e., from bottom to the top. Installation of 2 3/8 in. (60 mm) thick pavers with mechanical or hydraulic equipment is facilitated when spacer nibs extend the full height of the paver. Others, called “blind” spacers, extend from the bottom to within 3/16 to 1 in. (5 to 25 mm) at the top of the paver so they aren't visible from the surface. They may be tapered at the top as well. These kinds of spacers are not recommended for mechanical installation.

3. Job Planning

Design considerations—Once a laying pattern is selected, coordination between the designer and the contractor when developing the project drawings can save time and costs. One way to save costs is to minimize cutting of pavers along the edges. For some patterns, this is accomplished by using edge pavers to start or close the pattern. Patterns without edge units may begin along an edge that requires little or no cutting of pavers.

Another cost-saving construction detail is surrounding bollards, water valves, gas valves, manholes, light standards, etc., with a concrete collar. The collars should be of sufficient durability and shape to withstand anticipated loads and climate. Square collars are preferred over round ones because they provide a straight surface against which a string course of pavers is placed. A string course around collars will provide additional stability and better appearance when cut pavers are placed against the course. ICPI Tech Spec 3—Edge Restraints for Interlocking Concrete Pavements provides additional information on this construction detail.

If the pavement abuts a high straight curb or a building, two string (running bond) courses or a soldier course of pavers should be placed along the edge (Figure 14). The double course will allow the clamp to operate in the narrow distance between the edge of the layer and the curb or wall. Placement of the laying pattern against this course, rather than directly against a curb or wall presents a clean, sharp appearance at the edges of the pavement.

Paving around a protrusion, such as a manhole, proceeds in a manner similar to manual installation. One side of the manhole is paved, courses counted, and the other side is paved with the number of courses matching the previously laid side. String lines can be pulled longitudinally and laterally across the pattern to check the alignment of joints. String lines should lie on the pavers and no higher. Mechanical installation equipment will likely move strings that are higher.

Manufacturing considerations—As they are manufactured, the fresh layer of concrete pavers exiting the production machine in the factory is either placed on a board and allowed to cure or, generally, stacked 8 to 10 layers high and then cured. When individual layers are placed on separate boards for curing, the process is referred to as single-layer production. The individual layers are allowed to harden for a day and then are stacked and strapped for shipping. If layers are stacked to make a cube while the concrete is fresh, the manufacturing process

Figure 14. A double row of manually placed pavers along a curb or building provides maneuvering space for the mechanical installation clamp.

Figure 15. Spacing of cubes at the laying face is determined by how much area will be covered by each, as well as by the clearance required by the machine clamp. Orientation of the cubes follows the direction of paving.

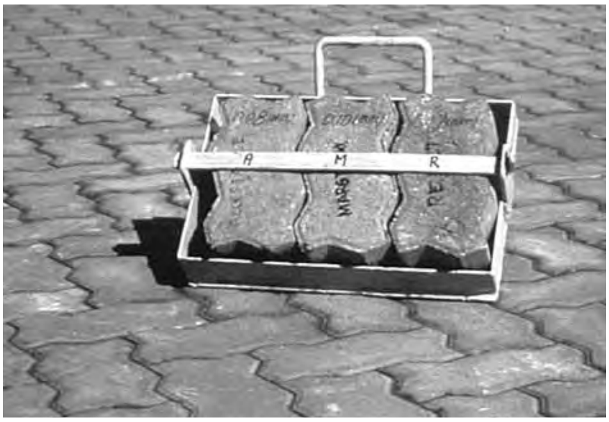

Figure 16. A simple gauge for checking dimensional tolerances on the job site.

is called multi-layer production. The fresh cube of pavers is allowed to harden and then is strapped for shipping.

Pavers made on a multi-layer machine should have a sufficient amount of sand spread on each layer as it is manufactured. This prevents layers from sticking to each other while curing. It will also prevent them from sticking when a mechanical installation clamp lifts a layer on the job site. Sand between the layers will avoid delays from detaching stuck pavers with a mallet and eliminates the risk of dropping the entire layer from the machine clamp.

Manufacturing boards for single-layer production should be smooth so that they don't leave rough edges on the bottom of the concrete pavers. This will avoid minor chipping of their edges during transit and bits of concrete dropping into the cube. The absence of small pieces of concrete will eliminate interference with joint spacing and difficulties with clamping each layer by the installation machine.

Storage and flow of materials on the site — A place to store inbound concrete pavers should be identified as part of planning each project. This location may change as the paving progresses. For example, pavers may be stored on the construction site at the beginning of the job. As more paving is placed, incoming pavers can be stored directly on the paved area. Time savings are maximized when inbound loads of concrete pavers are unloaded once and moved once to the laying face.

The rate of paver delivery to the job site should be coordinated between the contractor and supplier. Too many pavers may crowd the site and slow productivity. Likewise, an insufficient rate of pavers being delivered can keep crews waiting. Time is saved by identifying places for storage on the site before the job develops and by ordering delivery of a specified number of truckloads or cubes of pavers each day. A staging area may be used to receive the delivered pavers and store them until they are ready to be brought to the laying face.

When cubes are moved from a delivery truck and stored in a staging area, they should be placed on level ground. If they are placed on uneven ground, the layers may shift and become uneven. A great amount of shifting will make clamping each layer by the installation machine difficult or impossible in extreme cases.

Cubes are usually moved from the delivery truck to the staging area or directly to the laying face by a clamp truck or a fork lift truck. When located in a staging area cubes should be spaced apart so that the clamps trucks can lift them.

When cubes are delivered near the laying face, they are usually spaced so that the installation machine operator can grab layers from each cube with the least amount of movement. A cube with eight layers will be placed in four to seven minutes, depending on the skill of the operator and the placement of the cubes. As the layers are placed on the bedding sand, a crew member brings more cubes forward to the laying face. The area between the cubes should approximate the area that the cube will cover when placed (Figure 15).

Orientation of the laying pattern—Depending on the pattern, some paver layers can be placed on the bedding sand in only one or two directions. Therefore, the orientation of the cubes on the site with respect to the direction of paving will affect efficiency. Obviously, the cubes should be moved as little as possible once they reach the site. Their location and orientation will need to be determined before starting the job. They should to be communicated to those responsible for moving the cubes on the

Figure 17. Powered screed bucket accelerates spreading of bedding sand. The width of the bucket can be adjusted.

site. This will avoid wasted time from the installation machine making additional motions or from moving the cubes into the proper position. Crew members should be informed on placement and spacing cubes as part of planning the job.

4. Systematic and Efficient Execution

Dimensional tolerances—The dimensional tolerances should be smaller than those stated for length and width in ASTM or CSA standards for concrete pavers, i.e., + 1/16 in. or +1.6 mm. These standards allow for slight growth dimensions as manufacturing of the job progresses (10, 11). This is due to wear on the manufacturing mold from the production process. If not managed, layers will become increasingly difficult to place into the pattern. This will slow crew production as the layers will require adjustment with mallets and pry bars to accept new layers next to them. Experience and computer modelling has shown that pavers will install more rapidly when growth in overall length and width dimensions are kept under 1 mm.

In addition, straight lines and consistent joint widths will be increasingly difficult to maintain. Because pavers are enlarging slightly, joint widths enlarge and joint lines will be impossible to keep straight while attempting to wedge the pavers between layers. Wider joints result in a loss of interlock which may reduce the structural integrity and stability of the pavement surface. Therefore, consistent paver dimensions throughout the job helps the crew work efficiently by maintaining straight lines, uniform joint widths, while contributing to interlock.

Dimensional growth of pavers is managed by periodically changing molds during manufacturing. This will enable pavers to enlarge consistently while staying within specified tolerances. The number of cycles a mold can run prior to changing will depend on its quality and the abrasiveness of the concrete mix. Dimensional growth is also managed by periodically checking the paver dimensions. This distribution can be done with a ruler, template, or a gauge. An example of a gauge is shown in Figure 16.

Dimensional growth is further managed by unloading and installing the largest pavers first. However, loads would need to be marked and distributed on the site in the order of production. This distribution may not be possible on some jobs.

Pavers should have straight, square sides to ensure a secure grip by mechanical or hydraulic clamps. Pavers with bulged or slightly rounded, "bellied" sides can drop while being held by these clamps (12). Furthermore, straight lines and consistent joint widths cannot be maintained and interlock decreases. Bulged sides usually result from excessive water in the concrete mix.

Establishing lines—Job site configuration determines the starting point for mechanical installation. Prior to starting, a string line is pulled or chalk line snapped on the screeded bedding sand. The line is perpendicular to the starting face (which may be a curb if it is square to the line) and several layers are placed on the line to establish straight and square courses of layers. Aligning the layers and joint lines

Figure 18. An asphalt spreading machine is modified to evenly and rapidly spread bedding sand.

at the beginning of the laying process is essential to keeping joints tight and the pattern "in square" as the job proceeds. The lines can guide manual installation of the starting courses (if required) as well as mechanical laying. Parallel string lines are pulled and spaced at intervals equal to several paver layer widths. The distance between string lines should represent the maximum width of the paver layers, i.e., taking into account growth in the layer width from mold wear. The allowable growth, and means of measurement of layers, should be agreed upon between the manufacturer and installer prior to laying the pavers.

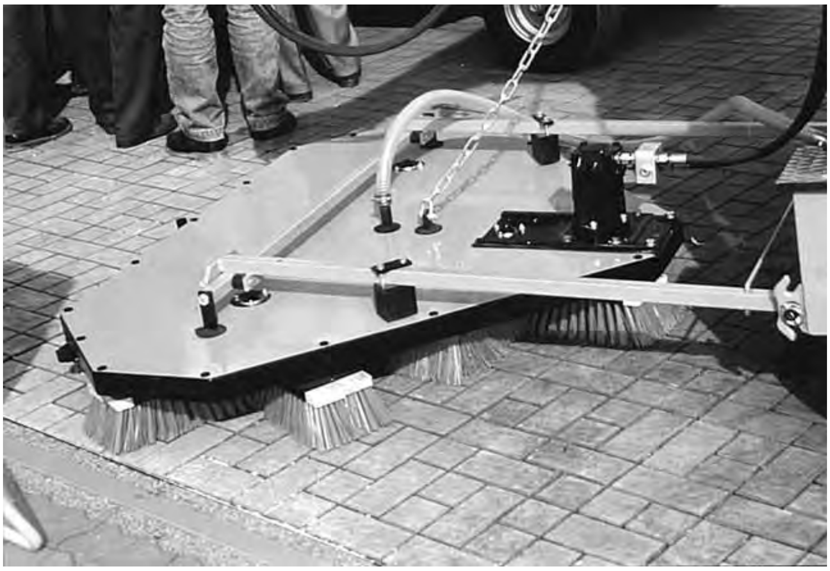

Figure 19. Broom attachments to installation machines accelerate spreading and filling of joint sand.

Bedding sand —Besides a consistent flow of pavers, there must be a sufficient area of bedding sand screeded and ready to receive the pavers. An oversize area will not get filled with pavers by the end of the day. A small area will fill rapidly, and the crew must work quickly to prepare more screeded sand. The optimum area to screed depends on the productivity of the machine operator and the continuous flow of pavers. This area is different for each project.

Spreading of bedding sand can be accomplished with a powered screed bucket as shown in Figure 17 or with an asphalt machine, illustrated in Figure 18. Mechanical installation machines have broom attachments that sweep the joint sand into the joints of pavers (Figure 19). These are much more efficient than using push brooms.

Color blending —Pavers with two or more colors can be blended together in the factory or on site for mechanical installation (13). This will reduce efficiencies normally achieved with mechanical installation. Consistency of the distribution of the pigment in each layer should be verified by inspecting the manufacturer's product at the factory. Sometimes the distribution of pigments among the layers in the cube can create a checkerboard appearance when the layers are placed. However, concrete pavers made with only one color should not create a checkered appearance when installed. This can be minimized by installing from two or three cubes at a time. There may be slight color variations from layer to layer due to the nature of concrete.

Installation crews —Crew sizes and assignments will vary among contractors. A typical crew

Figure 20. Adjusting joint lines with a pry bar prior to compaction.

Figure 21. Once a few layers are removed by hand, then adjacent layers can be separated with a pry bar.

for mechanical installation is two to five persons. It consists of the machine operator and a helper at the clamp. An additional person is needed at the clamp if the pattern requires that whole pavers be placed between layers for a continuous interlocking pattern. Three or four crew members spread and screed sand, bring cubes to the laying face with a lift truck, cut and fill in units along the edges, and compact the pavers.

Clamping, lifting, and placing of pavers are executed as a continuous motion of the machine to maximize productivity. Excess travel of the machine is minimized by placing cubes close to the laying face. The cubes are spaced so that as one cube covers an area, the machine moves easily to the next cube for placing. The machine operator works in a small area supported by a crew that keeps machine travel to a minimum.

The helper at the laying face adjusts the clamp's position before each layer is released onto the bedding sand. The helper removes half pavers and places full-sized pavers as required. He also aligns the pavers with a rubber mallet, making sure that the joints widths are tight and consistent. The alignment of joints and lines is checked by the helper and machine operator using observation by eyesight, string lines, and a transit as the job progresses. Due to the speed at which pavers are mechanically placed, checks should be made with string lines every 20 to 40 ft (6 to 13 m) of paved distance. Joint lines may require adjustment with a pry bar in order to maintain straight lines. See Figure 20.

Project specifications for joint widths should be followed with the contractor straightening uneven jointlines and closing excessively wide joint spaces. While not possible on some jobs, installation of pavers in the order in which they were made enables the contractor to save time and avoid wedging layers of different dimensions between others. Widened joints and uneven joint lines will be reduced as well.

The crew rotates jobs among spreading and screeding the bedding sand ahead of the machine(s), moving cubes into place, removing and neatly storing steel straps and wooden pallets (if used) from the job site, cutting, compacting, spreading joint sand, sweeping, and compacting the pavers behind the installation machine(s). The crew rotates jobs so that no one is fatigued by doing one job continuously.

Any movement of heavy trucks and forklifts should be avoided on a paved area in which units are not yet compacted, joints not filled and compacted again. This will prevent creeping, lipping, breaking or rutting of the surface of the pavement. The pavers should be compacted, joints filled with sand, and recompacted at the end of each day within 6 ft (2 m) of the laying face.

Average productivity per machine and crew including screeding bedding sand, placing, and compacting pavers can be between 3,000 sf (300 m^2) and 6,000 sf (600 m^2) per eight-hour day (1) (3) (4) (14). Keys to high productivity are pre-job planning among the contractor and material suppliers, as well as high quality pavers. They include careful coordination of deliveries, regulated flow of materials onto the site, and crew members who know their tasks. By careful planning, saving even 15 seconds per layer translates into saving many labor hours. For example, a 100,000 sf (10,000 m^2) project may involve placing 10,000 layers. Saving 15 seconds per layer saves 42 labor hours.

Figure 22. After the layers are separated they can be grabbed by the machine clamp.

Mechanical installation may be appropriate for some jobs and not for others. Naturally, the experience of the foreman and crew will influence productivity. Experienced contractors document productivity and labor costs for mechanical and manual installation through a job costing system. Comparisons of previous job costs between the two installation methods will help indicate whether a proposed job should be placed manually or mechanically. In some cases, a close project deadline, rather than job costs, may dictate the use of mechanical installation.

Reinstatement with mechanical equipment—ICPI Tech Spec 6—Reinstatement of Interlocking Concrete Pavements provides guidelines for removing and replacing concrete pavers when making repairs to underground utilities. Prior to extracting layers of pavers with mechanical equipment, an area the size of three layers should first be removed by hand. The removed pavers allow space for separating the remaining layers from each other. The remaining layers are separated in group of layers by a few inches (cm) from each other with a pry bar (Figure 21). This slight distance between layers enables the machine clamp to grab each one (Figure 22). The procedure works best on paving patterns other than herringbone with rectangular units. In most cases extracting individual layers is only possible if they were originally installed without pavers joining one layer to the next.

As with manual removal of pavers, each layer removed by machine can be stacked near the pavement opening. If the pavers must be moved away from the site, the layers can be stacked on pallets for easier removal. The sides and bottoms of each layer should be checked for sand sticking to them prior to reinstatement. The sand will often be removed during handling by the machine.

Conclusion

With manual installation, most crew members move between 7 and 10 tons (6.3 and 9 tonnes) of material per day. Mechanical installation requires less physical exertion, thereby reducing fatigue and job related injuries. There are also time and money saving advantages for the contractor, designer, and project owner. Each project is an exercise in systematic material handling from manufacture to final compaction.

The growth of mechanical installation follows the increased use of concrete pavers in commercial, municipal, port, and airport projects. Owners and designers are encouraged to contact producer and contractor members of the Interlocking Concrete Pavement Institute experienced in the use of mechanical installation in the early stages of a project. Planning will maximize time and money savings. Other ICPI Tech Spec technical bulletins provide additional information on design and construction vital to constructing successful projects with mechanical equipment.

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INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®

Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

ICPI INTERLOCKING CONCRETE PAVEMENT INSTITUTE
TECH SPEC
NUMBER 12

Snow Melting Systems for Interlocking Concrete Pavements

A mobile and ambulatory population requires reduction of pedestrian-related accidents. Snow melting systems for pavements can reduce accidents as well as liability exposure from injuries due to slipping on ice and snow. Moreover, snow melting systems reduce the fatigue and expense related to removing snow. In addition, they can reduce the damaging effects of freeze-thaw cycles, and of de-icing salts experienced by most pavements in cold climates. The inconvenience of spreading de-icing salts is eliminated and interior floor materials are kept cleaner and last longer.

Snow melting systems for interlocking concrete pavements can be used on patios, walkways, residential driveways, building entrances, sidewalks, crosswalks, and streets. A successful project in downtown Holland, Michigan includes a snow melting system in three blocks of concrete paver sidewalks and in the asphalt street (see Figure 1). Holland receives about 75 to 100 inches (190 to 250 cm) of snow each year. By melting the snow, the 167,000 ft^2 (15,500 m^2) heated pavements reduce pedestrian and vehicular accidents. They also reduce wear on the pavements because practically no de-icing salts are needed. Neither the merchants nor the city crews remove snow in this area of the business district, and the floors inside the stores are kept cleaner.

In addition to exterior applications, heating systems under concrete pavers have been used in interior areas such as around swimming pools, hot tubs, and saunas. The heat creates a comfortable, low-slip walking surface for bare feet and it also warms the room.

Types of Systems

Two kinds of systems are used to convey heat to the pavement surface: electric or liquid. Electric systems use wires to radiate heat. Generally, electric systems have a lower initial cost, but a substantial operating cost. They involve a series of control switches, thermostats, and snow-sensing apparatus. One electric system consists of heat tapes (flat wires) that automatically stop heating when sufficient energy is released. When they cool, the wires automatically allow more heat through them.

Liquid systems (also known as hydronic systems) use a mix of hot water and ethylene or propylene glycol mix in flexible pipes. They have a higher initial cost but a lower operating cost. Hot water systems consist of

Figure 1. A snow melting system under concrete pavers in downtown Holland, Michigan has performed well since 1988.

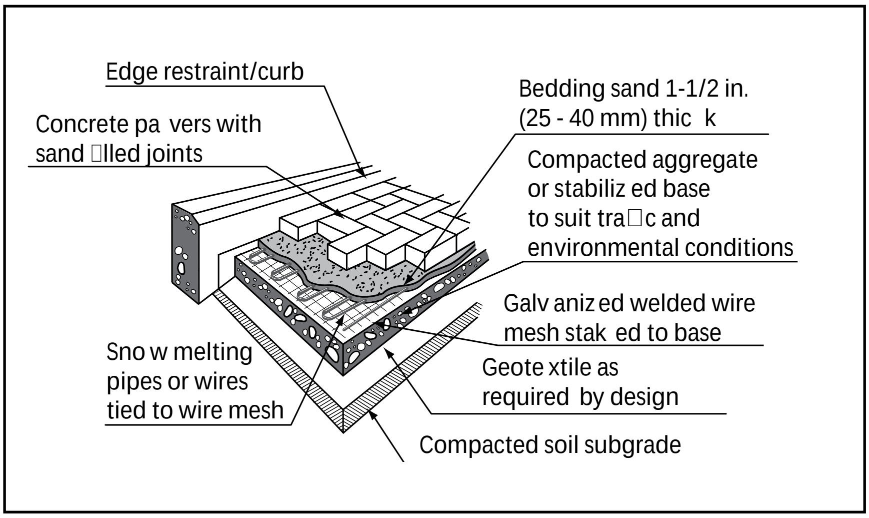


Figure 2. Typical components of a snow melting system for interlocking concrete pavements

flexible pipes, pipe manifolds, pumps, switches, a water heater, thermostats, and snow sensors. They typically rely on a boiler that heats a building. Figure 2 illustrates the typical components of an interlocking concrete pavement with a snow melting system.

Snow melting systems generally do not completely dry the pavement surface. Rather, they melt the snow to water which drains away. Completely evaporating the water on the pavement surface is not economically practical since it requires more energy than for melting snow to water. Occasionally, snowfall or drifting may exceed the heat output of the snow melting system. While some snow remains, it will be easier to remove due to the warm pavement surface.

Snow melting systems can be part of new construction or added later. For driveways, pipes or wires can be placed in the wheel tracks to reduce installation costs. However, the remaining snow may require removal if it blocks the movement of vehicles.

Table 1. Gradation for Crushed Stone Aggregate Base

ASTM D 2490	
Sieve Size	Percent Passing
2 in. (50 mm)	100
1 in. (377.5 mm)	95 to 100
3/4 in. (19.0 mm)	70 to 92
3/8 in. (9.5 mm)	50 to 70
No. 4 (4.75 mm)	35 to 55
No. 30 (0.600 mm)	12 to 25
No. 200 (0.075 mm)	0 to 8

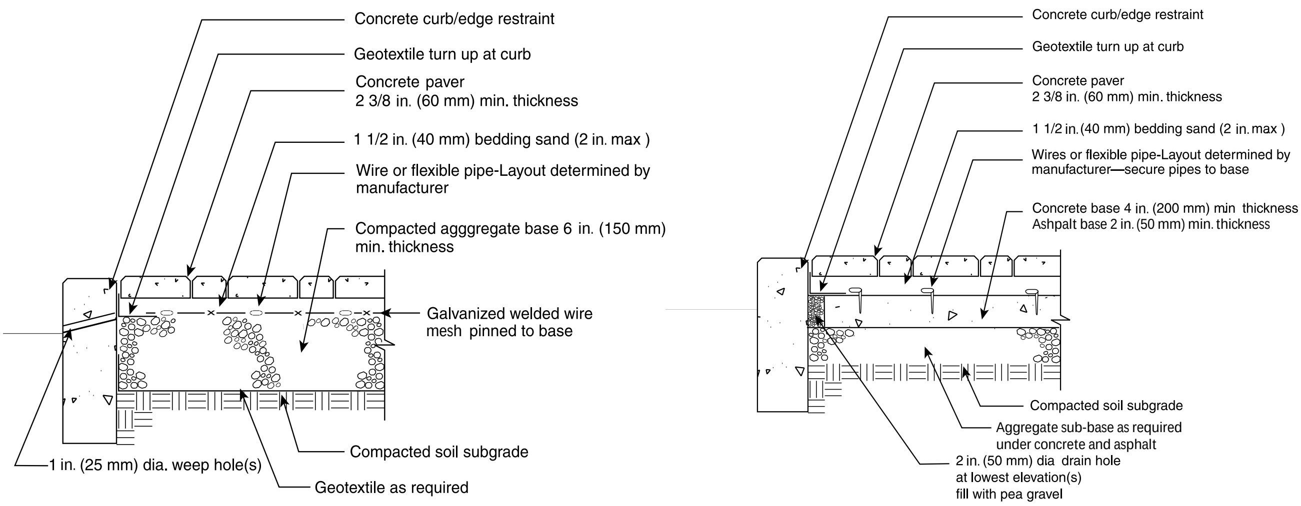
The performance of a snow melting system is measured in inches (cm) of snow melted per hour. Its performance is based on heat output measured in BTUs (British Thermal Units) or watts per square meter (m^2) of pavement. Performance depends on consideration of three overall design factors. First is the rate of snowfall. Second is the temperature of the snow influenced by the air temperature. About 90% of all snow falls between 35° F (2 C°) and 10° F (-12° C). On average, snow falls at about 26° F (-3° C). The lower the air temperature, the less dense the snow. For warmer, wetter, and more dense snow, more energy per area of pavement is required to melt it. Third, wind conditions greatly influence performance of a snow melting system. Strong winds remove heat from a pavement faster than calm air. Location of buildings, walls, landscaping, and fences will influence the amount of wind across a pavement, heat loss, and ultimately the design and performance of snow melting systems.

Rate of snow melting will vary with the application. For example, "Melting 1 in. (25 mm) of snow per hour is usually acceptable for a residence but may be unacceptable for a sidewalk in front of a store. Hospital entrances and parking ramp inclines need to be free of snow and ice at all times"(1). Most manufacturers of liquid and electric snow melting systems also provide design guidelines and/or software to calculate the BTUs per square foot (watts/m2) required to melt a range of snow storms for a given region. The guidelines work through a series of calculations that consider the snow temperature (density), ambient temperature, exposure of the pavement to wind, and unusual site conditions. They provide recommendations on the size and spacing of pipes or wires required, as well as the temperature of the fluid, its rate of flow, or the electricity required. The Radiant Panel Association (radiantpanelassociation.org) provides design guidelines for liquid snow melt systems.

Controls for activating the snow melting system can include a thermostat in the bedding sand to maintain its temperature above freezing. Another kind of control is located near the pavement and activates the heating system when snow or ice falls. Sometimes a low level of heat is maintained in the pipes or wires and is increased by the sensor when snow falls.

Construction Guidelines

Snow melting systems with concrete pavers can be built with three types of bases: concrete, asphalt, or crushed stone aggregate. Concrete and asphalt bases



Heated sidewalk/residential driveway on compacted aggregate base

Heated sidewalk/residential driveway on asphalt or concrete base

Figure 3. Cross sections of a typical heated interlocking concrete pavement for pedestrian and driveway applications

are recommended for roads and crosswalks. While these bases may be used for driveways and pedestrian applications, a crushed stone aggregate base may be more cost-effective.

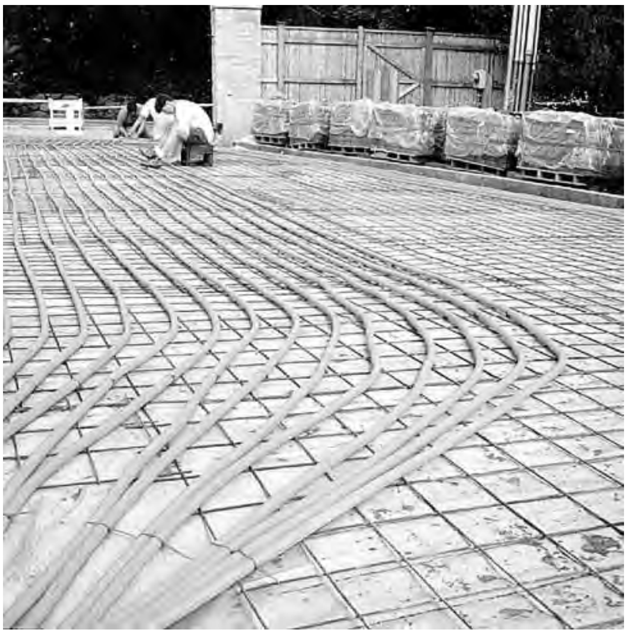
Aggregate Bases for Pedestrian and Driveway Applications

Subgrade Preparation—ICPI Tech Spec 2–Construction of Interlocking Concrete Pavements should be reviewed with this technical bulletin, as it offers guidelines for subgrade preparation, base materials, and installation of bedding sand and concrete pavers. Preparation and monitored compaction of the soil subgrade and the aggregate base are essential to long-term performance. The soil subgrade and base aggregate should be compacted to a minimum of 98% standard Proctor density, per ASTM D 698 (2). Geotextile is recommended over compacted clay soils and silty soils. The geotextile separates the aggregate from the soil, keeping the base consolidated through long-term changes in moisture and temperature, as well as freezing and thawing. Drain pipes may be required in slow draining soils, especially under vehicular applications.

Base materials and preparation—Recommended gradations for aggregate base materials are those typically used under asphalt pavements that meet standards published by the local, state, or provincial departments of transportation. If no standards exist, the gradation shown per ASTM D 2490, Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports in Table 1 is recommended (3).

The minimum thickness of the base should be at least 6 in. (150 mm) for pedestrian areas and 10 in. (250 mm) for driveways. Thicker bases, or those stabilized with cement or asphalt, may be required in areas of weak soils subgrades (California Bearing Ratio < 4), in low-lying areas where the soil drains slowly, or in areas

Figure 4. The heating system is tied to a wire mesh anchored into the compacted aggregate base.



of extreme cold and frost penetration. The minimum surface tolerance of the compacted base should be ± 3/8 in. over a 10 ft (±10 mm over a 3 m) straightedge. Density and surface tolerances should be checked before proceeding with installation of the snow melting wires or pipes.

Prior to placing the wires or pipes, a galvanized wire mesh is placed over the surface of the base. The wire mesh is secured to the base with stakes. The wires or pipes are tied with plastic ties to the wire mesh. Figure 3 illustrates a typical assembly for a pedestrian or driveway application. Figure 4 shows a heating system for a residential driveway tied to the wire mesh.

In some instances, rigid foam insulation may be required over the base. The insulation is placed under the bedding sand with wires or pipes in pedestrian applications only.

Insulation is not recommended in vehicular applications due to a high risk of breaking as well as trapping moisture above it. Insulation may be required on heated pavements over a high water table, when the heating system is operated manually, or when the perimeter of the heated area is large in relation to the total area, as with a long sidewalk. The manufacturer of the heating system should be consulted for specific guidance on insulation thickness, as well as when and where to use it.

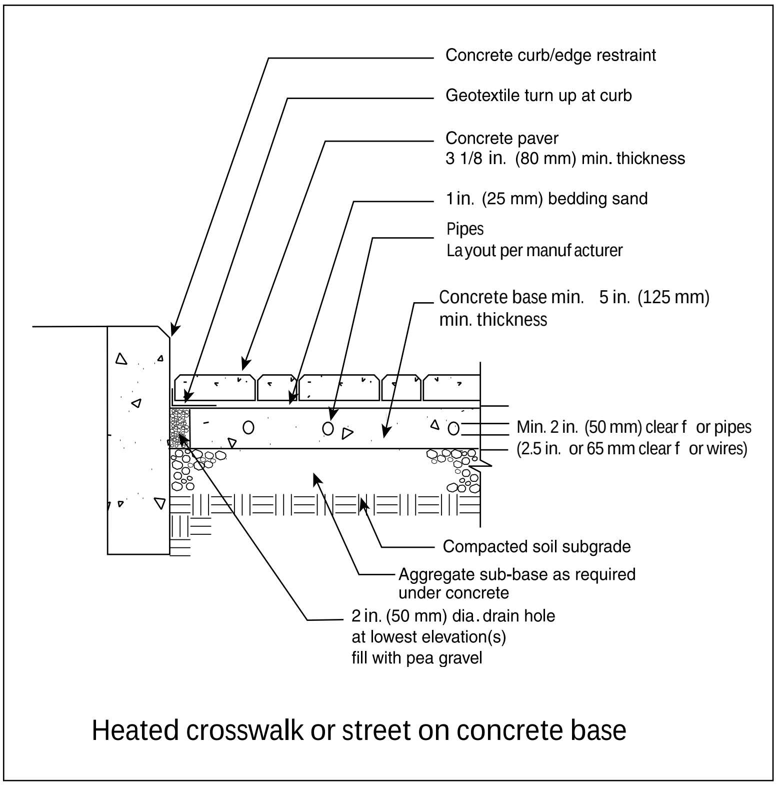


Figure 5. A typical cross section of a heated interlocking concrete pavement for crosswalks and roads subject to vehicluar traffic. For asphalt bases, pipes should be located at least 1 1/2 in. (40 mm) under the asphalt.

Some contractors install the wires or pipe into the top of the base without wire mesh. This is accomplished by installing the pipes or wires in the last inch (25 mm) or so of compacted base surface. Base material is added and compacted to bring the level of the base to its final grade. The pipe or wire is exposed and flush with the compacted surface of the base. The absence of wire mesh will facilitate screeding of the bedding sand.

Asphalt and Concrete Bases for Vehicular Applications

For areas subject to constant vehicular traffic such as crosswalks or roads, wires or pipes should be placed in a concrete slab or in asphalt (rather than on top of these materials). This will protect the pipes or wires from damage due to wheel loads. Bedding sand and pavers are placed over them. Figure 5 illustrates a

Figure 6. Experienced electrical and plumbing contractors should install snow melting systems.

Figure 7. Screeding bedding sand must be done without moving or damaging pipes or wires for melting snow.

Table 2. Grading Requirements for Bedding Sand

ASTM C 33		CSA A23.1-94	
Sieve Size	Percent Passing	Sieve Size	Percent Passing
9.5 mm	100	10 mm	100
4.75 mm	95 to 100	5 mm	95 to 100
2.36 mm	85 to 100	2.5 mm	80 to 100
1.18 mm	50 to 85	1.25 mm	50 to 90
0.600 mm	25 to 60	0.630 mm	25 to 65
0.300 mm	0 to 30	0.315 mm	10 to 35
0.150 mm	2 to 10	0.160 mm	2 to 10
0.75 mm	0 to 1	0.075 mm	0 to 1

typical construction assembly.

Asphalt or concrete pavement materials and thicknesses should be designed to local standards. The manufacturer of the snow melting system can provide additional guidance on the location and detailing of wires or pipes in asphalt or concrete. Generally, they are placed within the concrete slab with a minimum 2 in. (50 mm) clearance from the top and bottom. For asphalt, the pipes are located at least 1 1/2 in. (40 mm) below the bottom of the asphalt layer. Asphalt has a lower heat transfer rate than concrete so asphalt may require more costly, closer spacing of the pipes or wires.

When using an asphalt or concrete base, drainage of excess water in the bedding sand is recommended. Drainage can be achieved by weep holes through the pavement and base at the lowest points. These holes should be 2 in. (50 mm) in diameter and covered with geotextile to prevent loss of bedding sand into them.

Layout of the Heating System

After receiving consultation and design recommendations from the manufacturer, the installation of wiring or pipe should be done by an electrical and/or plumbing contractor experienced with installing these systems (Figure 6). The installed system should be tested for leaks before placing sand or pavers over it. Liquid systems should have their pipes filled and placed under pressure prior to placing asphalt or concrete over them.

The wires are generally no thicker than 3/4 in. (19 mm). Pipes can vary in diameter from 1/2 in. (13 mm) to 1 in. (25 mm) depending on the area to be heated and system flow requirements. Reference 7 provides design and installation guidelines for hydronic pipe and electric wire systems.

Bedding sand—Normally, a consistently thick layer between 1 to 1 1/2 in. (25 to 40 mm) is recommended under concrete pavers. With snow melt systems, up to 2 in. (50 mm) (before compaction) of bedding sand may be required to cover and protect the wires or pipes. The gradation of the bedding sand should conform to ASTM C 33 (3) or CSA A23.1 (5) as shown in Table 2. Limestone screenings or stone dust should not be used as they often have material passing smaller than the No. 200 (0.075 mm) sieve. This fine material slows the drainage of the bedding sand layer. The bedding should be moist when screeded but not saturated. Screed bars (for screeding bedding sand) will need to be carefully placed so as to not disturb or damage the pipe or wires during screeding of the bedding sand. (See Figure 7.)

Figure 8. Spreading joint sand over the installed concrete pavers.

Figure 9. Final compaction of the pavers and settling of the sand into the joints.

All pavers should be compacted, their joints filled with sand and compacted again at the end of each day. If the paver installation takes more than one day, the screeded bedding sand should not extend more than a few feet (1 m) beyond the edge of the open pattern at the end of each day. If there is a chance of rain, this area should be covered with a waterproof covering to prevent the bedding sand from becoming saturated. If the bedding sand is exposed to rain, it will become saturated and will have to be replaced or left to dry for many days. Saturated bedding sand is impossible to compact effectively and often requires removal. This will be very difficult and time-consuming since the pipes or wires will slow bedding sand removal considerably.

Concrete pavers—Concrete pavers should meet the requirements for strength and durability in ASTM C 936 (6) or CSA A231.2 (8). For pedestrian and residential driveway applications, 2 3/8 in. (60 mm) thick pavers are recommended, and 3 1/8 in. (80 mm) thick for vehicular uses. Once the bedding sand is screeded smooth, place the pavers in the prescribed laying pattern. All pavers should be constrained by edge restraints. ICPI Tech Spec 3–Edge Restraints for Interlocking Concrete Pavements offers guidance on the selection and application of edge restraints for all applications.

The concrete pavers should be compacted into the bedding sand with a 75–100 Hz plate compactor having a minimum centrifugal compactive force of 5,000 lbf (22 kN). Bedding sand is then spread across the surface of the pavers. A finer sand may be used to fill the joints that conforms to the grading requirements of ASTM C 144 (9) or CSA A179 (10). In either case, the joint sand should be dry so that it easily enters the joints between the pavers.

The concrete pavers are then compacted again and sand swept into the joints between them until they are completely full. Figures 8 and 9 show spreading the joint sand and the final compaction of the pavers. Excess sand is removed. Check with the manufacturers of snow melting systems to see if cleaners and sealers can be applied with no adverse effects to the pipes or wires. For additional guidance on the selection of cleaners and sealers, see ICPI Tech Spec 5–Cleaning and Sealing Interlocking Concrete Pavements—A Maintenance Guide. The minimum recommended slope of the finished pavement surface should be 2%. Water should not drain onto other pavements where it might collect and freeze.

ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

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TECH SPEC

NUMBER 13

Slip and Skid Resistance of Interlocking Concrete Pavements

Introduction

Slip resistance for pedestrians and skid resistance of tires on the road are important to safety in traversing walks and streets. While many variables influence slip and skid resistance, interlocking concrete pavements offer surface characteristics that provide resistance and added safety when compared to other pavement surfaces. This technical bulletin describes the slip and skid characteristics of concrete pavers and how they can be used to increase safety for pedestrians and drivers.

Slip Resistance for Pedestrians

A slip resistant surface is one that provides friction necessary to keep a shoe heel or crutch tip from slipping under a range of conditions. Many human and surface characteristics influence slip resistance. They encompass the texture of the surface, footwear, wetness, contamination of the surface, the speed and style of walking, running, turning sharply, going up or down a ramp or steps. In addition, the alertness of an individual to surface conditions, physical condition, and walking style, as well as the ability to adjust one's gait to varying surface conditions also influences slip resistance.

Slip resistance under dry conditions is approximated by measuring the static coefficient of friction, i.e., the horizontal force required to initiate sliding at the instant of motion divided by the static weight (gravity force). For example, a coefficient of friction of 0.7 means that seven tenths of the force holding an object in place will be necessary to initiate movement tangential to the surface on which it is resting. Figure 1 illustrates the definition of slip resistance. By comparison, the dynamic coefficient of friction is the ratio of horizontal to vertical forces when movement occurs at a constant velocity.

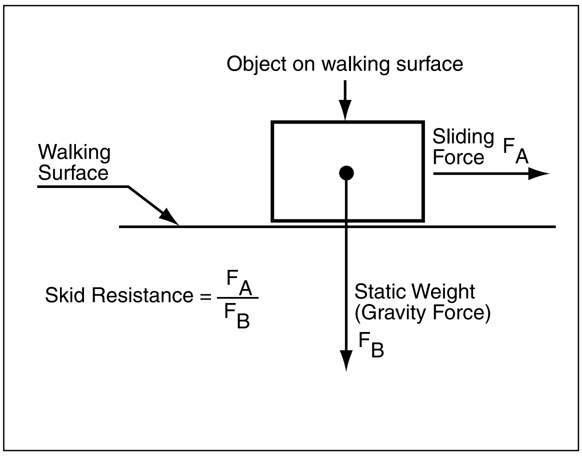

Figure 1. Definition of slip resistance

The static coefficient of friction is ideally measured with no time delay between the application of the sliding force against the gravity force. The sliding force can then be used to measure the slip resistance of wet surfaces. Strictly speaking, the slip resistance of a wet surface cannot be precisely equated to static coefficient of friction. In fact, a false friction force may develop. This is due to the development of adhesion when a measuring device such as a drag meter is placed upon a wet surface (even an instant before it is pulled). The force can often result in the anomalous result where the presence of water can actually improve measured slip resistance.

The Americans with Disabilities Act (ADA) was made U.S. law in 1990 to protect the civil rights of individuals with disabilities. The law provides protection to disabled persons at their place of employment (Title I), from state of local government services (Title II), from public accommodations (Title III), and with telecommunications (Title IV). Title II covers minimum design standards for transportation facilities and Title III covers standards for new construction, as well as alterations to public places and commercial facilities.

The U.S. Departments of Justice and Transportation have issued minimum design standards through the Americans with Disabilities Act Accessibility Guidelines (ADAAG). These guidelines for construction were developed by the U.S. Architectural and Transportation Barriers Compliance Board (ATBCB), also known as the Access Board. The guidelines are subject to periodic revisions and the latest version should be referenced when designing handicapped facilities.

Figure 2. The NIST-Brungraber Mark II tester for slip resistance

Section 302.1 of the 2010 Standards for Accessible Design states, "Floor and ground surfaces shall be stable, firm, and slip resistant and shall comply with 302" (1). This document gives no express value for slip resistance. Typical values are expressed as a minimum coefficient of friction of 0.6 for accessible routes and 0.8 for ramps (dry surfaces) (2). These are advisory recommendations and are not standards. Design and testing standards may be required by the Occupational Safety and Health Administration (OSHA) for workplace safety, by other federal, state, provincial, or local regulations.

Measuring Slip Resistance

There is no single established test method for measuring slip resistance. There are several different methods recommended in publications from the Access Board. These include Horizontal Pull Slipmeter (3) and the PTI Drag Sled Tester (2). The test device recommended as the best currently available for measuring slip resistance, and that recommended by the Interlocking Concrete Pavement Institute (ICPI), is the NIST-Brungraber Tester (2). The test procedure can be conducted by Slip Test, P.O. Box 8, Spring Lake, NJ 07762, tel: 732-449-1789, fax: 732-449-4746. The tester, called the Mark I, can be also be purchased from Slip Test and the test procedure can be mastered in about 30 minutes. The test can be conducted by independent testing laboratories as well.

The Mark I device was developed for testing dry surfaces. Slip Test has developed a more advanced model, the Mark II, for testing both wet and dry surfaces (See Figure 2). The Mark I and II are recognized by the Access Board as the suitable testing machines for slip resistance. Both machines are simple to use and are available from Slip Test.

Slip Characteristics of Concrete Pavers

Concrete pavers can be made with or without surface treatments, and some may be sealed after installation. Treatments include high sand and cement content in the surface, or those with machine-polished surfaces. Others include stone-like textures made by shot-blasting, hammering, washing, or tumbling the surface. Regardless of the presence or absence of surface treatments/sealers, most concrete pavers can meet the ADAAG recommendations for slip resistance. (Pavers with polished surfaces, however, may require testing since their surfaces can be as smooth as marble or other ground surfaces.) The manufactured, textured walking surfaces are typically consistent from paver to paver thus maintaining a high coefficient of friction. Therefore, there is generally not a need to test many paving units.

Should a need for testing arise, designers and purchasers may wish to verify the wet slip resistance of concrete pavers made by ICPI members for specific applications by using the Brungraber Tester. In some cases, the slip resistance of concrete pavers may exceed the ADAAG recommendations. In some applications they can contribute an additional measure of safety. Such areas can be any area that, when wet, can be a potential slipping hazard, especially for walking-impaired people, or those in wheel chairs. Some examples include crosswalks, ramps, or areas traversed by crutch users and those with artificial legs, and places crossed by wheel chairs including curb ramps at intersections.

Most concrete pavers are manufactured with chamfers on the edges of the wearing surface. The chamfers are small, typically 45° bevels, 4 or 6 mm wide, or they can be rounded. Should the units become vertically misaligned in service, the chamfers help provide a smooth transition from unit to unit, thereby reducing the tripping hazard. Like all pavement surfaces, extreme settlement or heaving can create dangerous tripping hazards and such areas should be repaired. Unlike asphalt and cast-in-place concrete, pavers that are verticaly misaligned do not need to be discarded and replaced with a new surface. In most cases, the surface is not destroyed from cracking. Therefore, the concrete pavers can be removed, repairs made to the base, and the same units reinstated without waste or unsightly patches. For further information on reinstatement procedures, see ICPI Tech Spec 7, Reinstatement of Interlocking Concrete Pavement . Other ICPI Tech Specs should be consulted for advice on construction specifications, construction procedures, and on edge restraints.

Skid Resistance for Vehicles

Skid resistance is the resistance to motion between the pavement and vehicle tires. Pavement-tire friction is influenced by the following factors (4):

Pavement characteristics such as texture, roughness, and rutting

Pavement texture consists of microtexture and macrotexture. Macrotexture is defined as 0.2 in. (0.5 mm) or greater deviations in the surface (from a true planar surface) that affect tire-pavement interaction. A pavement with good macrotexture contributes to skid resistance of vehicles traveling over 25 mph (40 kph). Concrete pavers with chamfers offer a unique macrotexture that can benefit skid resistance at these speeds. Specifically, the chamfers form small drainage channels on the pavement surface to help disperse water under moving tires.

Microtexture is defined by smaller deviations in the surface, those less than 0.2 in. (0.5 mm). Microtexture is the primary influence on skid resistance of vehicle tires traveling less than 25 mph (40 kph). Microtexture varies with the hardness of the aggregate in concrete pavers. Harder aggregates are less likely to polish under concentrated braking or accelerating tires thus maintaining a high degree of variation in the texture of the surface.

In many cases, concrete pavers conforming to applicable American (ASTM) or Canadian (CSA) standards do not require special aggregates to maintain skid resistance equal to that of asphalt or PCC pavement surfaces. Like other paving materials, selection of aggregates (hardness, sharpness) and surface texture can be controlled in the mix design and manufacturing process for concrete pavers. Should the need arise for special aggregates with high skid-resistant properties, laboratory research on a range of aggregates has provided some criteria for selecting aggregates with high skid resistance (5)(6) for conventional pavements. These can apply to concrete pavers. The criteria include the following:

- Results of petrographic analysis that show hard minerals combined with some softer minerals.
- Angular and large mineral grains in the individual aggregate particles.
- Aggregates with a high range of hardness as measured by the Mohs' scale.
- Sand-sized and total insoluble residue in carbonate aggregates when subjected to acid-solubility tests.
- Resistance to wear in jar mill abrasion tests, small, laboratory circular test tracks, and relating these results to laboratory skid tests on sample pavements.

Roughness is described as large deviations in pavement surface, most of which affect ride comfort and dynamics of the vehicle. A rough pavement can cause the wheels to bounce and this can reduce friction. Rutting in wheel paths also reduces friction, especially when they fill with water from rainfall.

Tire characteristics including tire type, tire tread, and inflation pressure

Tire design and rubber formulations are often a trade-off between wearing and frictional characteristics. Harder rubber tires wear longer but do not offer the same frictional performance as softer rubber. Deep-treaded tires offer better frictional characteristics because they disperse more water. This is especially important at high speeds where the time for dispersing water from under tires is very short. Excess or low tire inflation pressure also can decrease the skid resistance.

Vehicle operational characteristics such as speed, tire slip, axle load, and the type of vehicle.

Speed of the vehicle is one of the dominant factors in skid resistance. As speed increases, the amount of time to disperse water decreases and water on the pavement has a lubricating effect. When the brakes are applied, the velocity of tires decrease. If a tire's velocity decreases at a rate higher than the vehicle's velocity, the tires will slip on the pavement surface. When the brakes lock, the slipping becomes skidding. Anti-lock brake systems (ABS) are designed to balance the speed of the tires with that of the vehicle during braking, thereby preventing skidding and reducing slipping.

Tire-pavement friction generally decreases as axle load increases and trucks generally have a lower coefficient of friction than passenger cars. This is due to differences in tire compounds and hardness, and the higher temperatures at which truck tires operate.

Environmental factors involving wetness, ice and snow, contamination, and temperature

Engineers and road safety officials are most interested in the skid performance of pavement when it is wet since there is a dramatic difference between wet and dry skid characteristics. A pavement does not have to be completely flooded to realize a decrease in skid resistance. A film of water as thin as 0.002 in. (0.05 mm) can substantially decrease skid resistance. Ice, snow, and contamination (mud, oil, gravel, etc.) are all obvious contributors to the loss of skid resistance. Skid resistance decreases as ambient air and tire temperatures rise.

When considering road safety, pavement skid resistance is one of several factors, all of which may contribute to skid-related accidents, near misses, and ultimately characterize a pavement as safe or unsafe. Others influences on pavement skid resistance include:

- Traffic characteristics such as average daily traffic, posted speed, and the percent of trucks in the traffic mix;
- Curves and slopes in the road; and
- Driving difficulty such as the number of turning lanes, access points, traffic signals, and surrounding land use.

Skid resistance is one of many factors influencing agency decisions on when to resurface or reconstruct a road. The age, traffic, a rough ride due to settlement and rutting, and citizen complaints are some other factors. Each agency has its own decision criteria for pavement maintenance and rehabilitation.

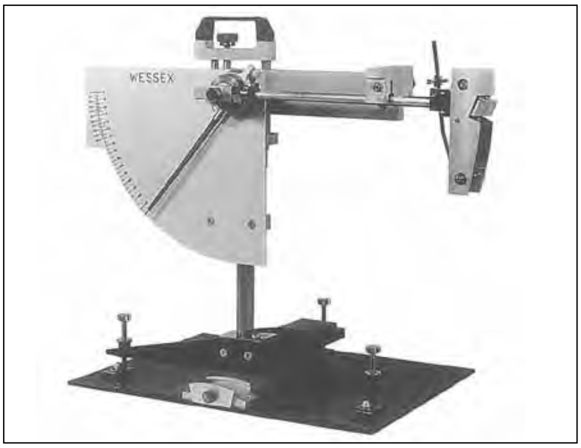

Figure 3. A British Pendulum Tester

Measuring Pavement Skid Resistance

There are two approaches to measuring skid resistance; static and dynamic. Static measuring devices measure resistance while moving across a small portion of the pavement. They do not involve the use of a tire. Dynamic devices make measurements with a tire while moving at a constant velocity across the pavement surface. A common device used for static measurement is the portable British Pendulum Tester. See Figure 3. This test method is described in ASTM E 303, Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester (7). This device is used for laboratory or on-site testing of skid resistance on surfaces. It consists of a small rubber shoe at the end of spring-loaded pendulum. The tester measures frictional resistance between the rubber shoe and the point of contact with the pavement. The contact area of the shoe against the test surface is about 3 in.^{2} (19 cm^2), so measurements are influenced only by microtexture of the surface.

To perform a test, the test surface is wetted, the pendulum is pulled back, and the shoe rubs across the surface. Friction resistance is read on a scale on the machine as the British Pendulum Number or BPN. A BPN rating between 45 and 55 indicates a satisfactory surface in only favorable weather and vehicle conditions. A rating of 55 or greater indicates a generally acceptable skid resistance in all but the most severe weather conditions. A 65 and above rating indicates a good to excellent skid resistance in all conditions.

The BPN correlates with the performance of a vehicle braking with locked wheels on a wet pavement stopping from 30 mph (50 kph). The tester is not designed to give ratings above 30 mph (50 kph) and results do not readily correlate to results from full-scale dynamic tests using a tire and trailer. The BPN test generally gives higher skid resistance ratings than dynamic tire and trailer tests.

Most dynamic skid resistance measurement methods assess the interaction between a pavement and a locked, non-rotating tire. These test methods employ a standard-sized tire towed in a wheeled device behind a vehicle. A standard amount of water is applied ahead of the tire while moving, the tire is locked while the vehicle maintains a constant speed and the resistance between the tire and the wet pavement is measured. Some dynamic skid testing devices include the Stradograph, the Sideways Force Coefficient Routine Investigation Machine (SCRIM)(8), and the Mu Meter (9).

In the North America, 40 state and provincial agencies use the test procedure described in ASTM E 274, Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire (10). Figure 4 illustrates the equipment. This test uses a standard test tire towed in a device behind a vehicle. A standard amount of water is applied ahead of the tire while moving, the tire is locked while the vehicle maintains a constant speed, usually 40 mph (65 kph), and the resistance between the tire and the wet pavement is measured. The force required to slide the tire is divided by the wheel load and multiplied by 100. The results are expressed as a skid number (SN) or friction number (FN).

Skid resistance measurements on asphalt pavements will vary with the time of year and weather. Since much skid data has been collected over the years for asphalt pavement, normalization procedures are used to eliminate influences of the season and weather. Weather and seasonal influences on portland cement concrete (PCC) pavements produce less predictable results in skid testing. Therefore, no normalization procedures yet exist for PCC pavements.

Skid Resistance Values for Interlocking Concrete Pavements

A review of the literature on skid resistance of concrete pavers shows their skid resistance to be equal or better than asphalt. Most indicate that, subject to the proper mix design and manufacturing controls, concrete pavers can maintain good skid resistance values throughout the life of the pavement. Studies of static skid resistance by different researchers in various countries used the British Pendulum Tester to assess new and trafficked concrete pavers. A summary of test results follows:

- Shackel (11) measured a bus route in Durban, South Africa after 17 years of traffic. BPN values averaged 61 with a standard deviation of 4.3.
- Clifford (12) conducted numerous tests at various locations in South Africa for the National Institute of

Figure 4. ASTM E 274 Test Equipment consists of a truck and trailer assembly. A tire within the trailer is towed at a given speed, locked, and skidded across water dispensed on the pavement in front of it.

Road Research. These tests included the locations and results listed in Table 1.

- Mavin (13)(14) measured BPNs in Melbourne, Australia, at 3 parking lots and on a quarry access road that received high truck traffic. BPNs on the new parking lots averaged 81 and declined to 53 with over three years of use. While BPNs for new concrete pavers dropped after use in the parking lots, the values did not fall below accepted standards. The 80kN Equivalent Single Axle (ESA) loads on the quarry road ranged from 0 to 150,000 over three years and BPNs increased from 45 initially to 62-65 at 75,000 to 150,000 ESAs.
- Muira et al. (15) compared the performance of concrete pavers to asphalt put into service at the same time in a lightly trafficked street in Japan. After 12 months of service, BPNs for both the concrete pavers and the asphalt were 56-59.
- Sharp and Armstrong (16) showed that concrete pavers at a full-scale test track in Australia had an initial BPN of 70 and progressively decreased after installation and reached a minimum value of 57 after 460 ESAs.
- Garrett and Walsh (17) tested an experimental access road leading to a industrial park and freight facility near Maidstone, England. After one year of testing pavers made by eight different manufacturers, results showed BPNs between 44 and 56. These values were considered above those for county roads with similar traffic and risk levels.
- Lesko (18) performed tests on 7 different areas of concrete pavers in a climbing lane with a 5% slope on a highway in Denmark. Initial BPNs ranged between 65 and 70 with values measured two years later between 49 and 60.
- Domenichini et al. (19) recorded BPNs on an 11-year old, 830 ft (253 m) long street with a 8% to 10% slope in the center of Recoara Terme, a small town in northern Italy. The average daily traffic was 1,230 vehicles in both directions with approximately 4% commercial trucks and buses. Test results indicated BPNs of 49 on concrete pavers located in the wheel tracks and 69 outside the trafficked areas. The study noted that European standards for interlocking concrete pavers recommends a minimum surface BPN of 45.

The first dynamic testing on concrete pavers was by Lesko (18) at 20, 60, and 80 kph using a Stradograph, a towed, treadless tire pitched at an oblique angle and locked while riding on wet pavement. Test results on 7 different (wet) concrete paver road sections over two years at these speeds showed values did not fall below 0.40 which is considered a satisfactory value for skid resistance.

Table 1—BPN Results by Clifford (12)

Location	BPN Range
1-year old city vehicle maintenance yard	48-61
8-year old residential pavement	54-59
20-year old residential pavements	41-55
5-year old access road to wind tunnel test facility	48-72
3-year old loading and servicing area next to government buildings	52-57
3 to 8-year old main and secondary roads at botanical gardens	45-85

Table 2—SCRIM Tests by Clifford (12)

Location	Average*	Range
1-year old city vehicle maintenance yard	63-71	25-85
5-year old Access road to wind tunnel test facility	62-77	45-85
3 to 8-year old main and secondary roads at botanical gardens	68-72	35-85

*Averages of measurements taken at several locations within the site

The SCRIM device was used by Clifford (12) on concrete pavers at three of the sites as part of the aforementioned study that involved a British Pendulum Tester. SCRIM tests are typically at 50 kph or 80 kph using a treadless tire mounted on a vehicle at 20° to the line of travel. The vehicle applies water in front of the loaded test wheel and the side force friction on the tire is measured.

Tests by Clifford with the SCRIM device were conducted at 50 kph. In South Africa, the SCRIM target value for collector roads is 0.45; for arterial roads, 0.50; and for thoroughfares, 0.55. Results in Table 2 show a range from 0.25 to 0.85 with averages between 0.71 and 0.35.

The Interlocking Concrete Pavement Institute (ICPI) engaged The Pennsylvania Transportation Institute (PTI) to conduct skid measurements on two sections of new interlocking concrete pavement (20). Each section was 2 ft (0.6 m) wide by 150 ft (45 m) long and laid in a 90° herringbone pattern. See Figures 5 and 6.

Five skid resistance measurements were performed at three speeds; 25, 40 and 50 mph (40, 65, and 80 kph) using the test method described in ASTM E 274. The test used a standard grooved test tire described in ASTM E 501, Standard Specification for Standard Tire for Pavement Skid Resistance Tests (21). Tests were conducted in October 1997. The average results from the two sections are shown in Table 3. These are expressed as Skid Numbers (SN).

Skid Resistance Requirements

Some states and provinces have minimum skid resistance requirements in construction specifications for new pavements. These help ensure that the new pavement meets certain texture requirements before opening them to traffic. These requirements will vary based on the type of highway pavement, available materials and construc-

Figure 5. The test track section and concrete paver surface at The Pennsylvania Transportation Institute test facility.

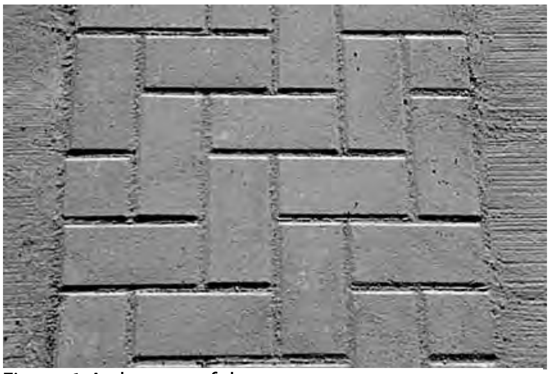

Figure 6. A close-up of the concrete paver surface at the PTI test track.

to interlocking concrete pavements.

One study for roads in Virginia (22) suggested a minimum SN_{40} of 30 for interstate and other divided highways, and a minimum SN_{40} of 40 for two-lane highways. Another study by the National Cooperative Highway Research Project (NCHRP) in 1967 (23) recommended minimum skid numbers for main rural highways. Table 4 shows the minimum skid numbers at various traffic speeds, and those measured at 40 mph (65 kph) on roads with various traffic speeds.

tion methods.

For testing in-service pavements, some consistency exists among highway agencies on test methods. Many use the ASTM E 274 test method; other states and provinces use the Mu Meter, or have developed their own tire and trailer equipment to derive a skid coefficient or 'f' value. In most cases, the results from these test methods can be correlated to results using the ASTM E 274 test method.

Since test methods and traffic speeds vary over a wide range of conditions, no universal, minimum standard for skid resistance has been established. Typically, pavement engineers utilize the skid number measured using test method ASTM E 274 at 40 mph (65 kph) (i.e., SN_{40}) as a reference value. Some researchers have attempted to define minimum skid requirements at certain speeds, on types of roads, and in particular regions. These can be used as overall guidelines rather than strict requirements when comparing skid resistance of conventional surfaces

The test results on new interlocking concrete pavement test at PTI indicate skid values well above those regarded by engineers as the minimum, and by the studies in references 22 and 23.

Reducing Traffic Accidents with Concrete Pavers

An important study in Japan demonstrates the ability of interlocking concrete pavements to reduce accidents and increase safety at intersections (24). Accidents were monitored over 12 months and vehicle braking distances were measured with a high-speed video camera at an asphalt-paved intersection in Ichihara City. Daily traffic volumes on each street from 7:00 a.m. to 7:00 p.m. ranged between 3,479 and 7,119 vehicles.

After 6 months of monitoring traffic volume and accidents, the asphalt within and on the approaches to the intersection was removed and replaced with concrete pavers. The change in pavement surface reduced the number of accidents by nine from December to May compared accidents counted in the previous June to November period.

The concrete pavers also reduced braking distances. A light-duty van was tested with three drivers on wet and dry conditions stopping from 20, 40, and 60 kph. Stopping distances were shorter on the concrete pavers and the greatest improvement was a reduction of 5 m (16 ft.) at 60 kph as shown in Table 5. The contribution of the chamfers in the surface of the concrete pavers towards dispersing water may explain the reduction in stopping distances at this speed.

Table 3—Average SN Values for Interlocking Concrete Pavement Sections (15)

Test Section	Speed mph (kph)	SN	Standard Deviation
A	25 (40)	51.9	0.5
A	40 (65)	46.5	1.1
A	50 (80)	40.0	1.5
B	25 (40)	57.2	1.1
B	40 (65)	49.6	3.0
B	50 (80)	43.1	0.5

Table 4—Recommended Minimum Skid Number for Main Rural Highways (23)

Traffic Speed mph (kph)	SN Measured at traffic spead	SN measured at 40 mph (65 kph)
30 (50)	36	31
40 (65)	33	33
50 (80)	32	37
60 (95)	31	41
70 (110)	31	46

Skid Resistance of Aircraft Pavements

Since 1983, over 12 million ft² (1.2 million m²) of interlocking concrete pavements have been used in airfield applications. Tests conducted by airports and the U.S. National Aeronautics and Space Administration (NASA) demonstrate the skid resistant properties of concrete pavers. A NASA study (25) tested concrete pavers at 5 knots and 100 knots/

hour speed at the Aircraft Landing Dynamics Facility in Langley, Virginia. The tests utilized a tire and 123 kN loads and 1.7 MPa pressure typical to a Boeing 737 or DC-9 aircraft. Figure 7 illustrates the test equipment and Figure 8 illustrates the test surfaces.

The test results demonstrated substantially higher side force friction values for concrete pavers under wet conditions than plain portland cement concrete surfaces. The report indicated "that for aircraft ground steering maneuvers under wet conditions, the paver blocks would provide better friction than the conventional smooth concrete surface (25)."

Other skid resistance tests include that by Dallas/Fort Worth International Airport where a Saab skid tester was used to evaluate new interlocking concrete pavements in 1990. The values derived from the test were 0.63 to 0.69 with 0.65 being the average value, all considered very good for a new airfield pavement (26).

Harmonization of Skid Testing

ASTM E 1960, *Standard Practice for Calculating International Friction Index of a Pavement Surface*, (27) has harmonized skid resistance measurements through the calculation of the International Friction Index (IFI) based on measurement of pavement macrotexture and wet pavement friction. The IFI was developed by the PIARC (World Road Association) to compare and harmonize pavement texture and skid resistance measurements. The IFI allows for the harmonizing of friction measurements with different equipment to a common calibrated index. This practice provides for harmonization of friction reporting for devices that use a smooth tread test tire.

Table 5—Stopping distance in meters on asphalt and concrete pavers (24)

	20 kph (12.5 mph)		40 kph (25 mph)		60 kph (37 mph)	
	Dry	Wet	Dry	Wet	Dry	Wet
Asphalt	1.70	3.20	5.85	9.60	14.2	26.7
Concrete pavers	1.68	2.50	5.23	8.15	13.6	21.3

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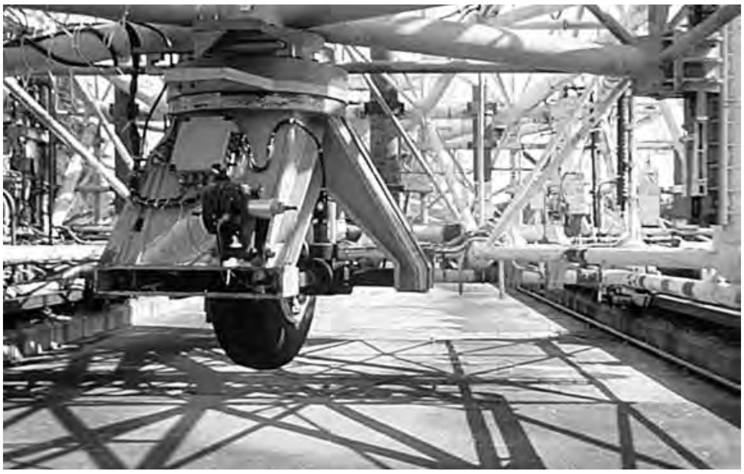

Figure 7. Test equipment for evaluation of the friction properties of concrete pavers at NASA's Aircraft Dynamics Landing Facility (ADLF) in Langley, Virginia

Figure 8. Test surface at the NASA ADLF facility

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ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®
Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org
Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171
In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

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TECH SPEC

NUMBER 14

Concrete Paving Units for Roof Decks

Introduction

An increasing amount of new and rehabilitated roof decks use segmental concrete paving units to support pedestrian and vehicular applications. The units provide an attractive, durable walking surface for pedestrian plaza decks. They can be used to create outdoor space, usable exterior living environments at commercial and residential buildings e.g. next to offices, hotels, hospitals, universities, observation areas on commercial buildings and at cultural centers. See Figure 1. Parking structures and the roof decks of underground buildings use concrete pavers to support vehicular traffic as shown in Figure 2.

Segmental concrete paving units protect roofing materials from damage due to foot traffic, equipment, hail and vehicles. Concrete provides a heat sink that reduces the thermal stress and deterioration of waterproofing materials. The units flex with the movement of the structure as well as with vehicular and seismic loads. Additionally, the units provide a slip-resistant surface and are especially attractive when viewed from adjacent buildings. They can exhibit high durability under freeze-thaw and deicing salt conditions.

A primary role of segmental concrete units is ballast for roofing materials to prevent uplift from high winds. When caught by high winds, gravel ballast on roofs can shift and distribute unevenly. This leaves roof materials exposed to winds, thereby increasing the risk of their uplift. In some cases the gravel can be blown from roofs creating a hazard for glass, pedestrians and vehicles. Concrete units are preferred over gravel ballast because they provide a consistent, evenly distributed weight for protection from wind uplift and damage. Furthermore, concrete unit paving is required by many building codes as roof ballast for high-rise buildings.

This Tech Spec provides guidance on the design and construction of roof assemblies using precast concrete pavers or concrete paving slabs using with various setting methods for pedestrian and vehicular applications. There are many kinds of roof assemblies placed under these types of paving units. The compatibility of paving units and setting methods with the components of roofing assemblies such as waterproof membrane, protection board and insulation should always be verified with the manufacturers of such components.

Vegetated, low-slope roof surfaces or "green roofs" are receiving increased attention from designers and clients interested in reducing building energy costs and the urban heat island. This trend is changing the aerial view of our cities. Furthermore, sustainable building rating systems such as LEED® recognize green roof technology as well as highly reflective roof surfaces. Concrete unit paving offers designers a reflective surface that can be easily integrated into green roof projects while earning LEED® credits. ICPI Tech Spec 16-Acheiving LEED® Credits with Segmental Concrete Pavement provides additional information on how to integrate green roofs with concrete unit paving.

Figure 1. Concrete pavers provide a durable and attractive roof plaza deck surface. At left is the observation deck on the 86th floor of Empire State Building in New York City. At center is a hotel plaza deck constructed with concrete paving slabs.

Figure 2. Concrete pavers serve vehicular traffic and parking over a concrete parking structure next to a residential development.

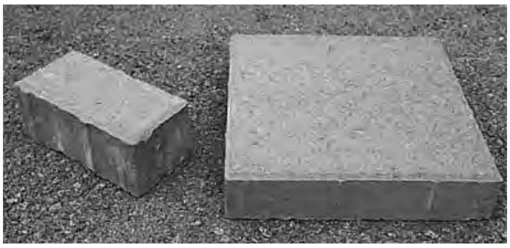

Figure 3. Concrete paver (left) and a concrete paving slab (right): similar paving products with varying applications for roof decks.

Figure 4. Some ballast-type slabs for roof decks are made with lightweight concrete materials. They can be joined with tongue-and-grooves and/or with connectors to resist wind uplift. This is one of several designs available.

Plaza Deck Components

Concrete pavers and slabs—There are two categories of segmental concrete deck materials for roofs, concrete pavers and slabs. See Figure 3. Concrete pavers are units that are a minimum thickness of 2 3/8 in. (60 mm) and whose length to thickness (aspect ratio) does not exceed 4 to 1. They conform to the requirements of ASTM C 936 (1) in the U.S. or CSA A231.2 (2) in Canada. These units can be used in pedestrian and vehicular applications. Concrete pavers 2 3/8 in. (60 mm) thick are commonly used in pedestrian plaza or terrace applications. When the capacity of the structure is limited to additional weight, units as thin as 1 1/2 in. (40 mm) have been used in pedestrian applications. For vehicular uses, the recommended minimum thickness of units is 3 1/8 in. (80 mm).

Precast concrete paving slabs range in nominal size from 10 x 10 in. (250 x 250 mm) to 36 x 36 in. (910 x 910 mm). Like pavers, concrete paving slabs can be manufactured with a variety of colors, special aggregates and architectural finishes to enhance their appearance. Surface finishes include shot-blasted, hammered and ground or polished. They differ from pavers in that slabs typically require at least two hands to lift and place them, and the length to thickness (aspect ratio) is 4 to 1 or greater. Paving slabs generally range in thickness from 1 1/2 in. to 2 in. (40 to 50 mm) and thicker units are also applied to roofs. Slabs are only for pedestrian plaza applications and are not recommended for vehicular use. Slabs risk tipping, cracking from bending forces, and shifting under repeated forces from turning and braking tires.

Concrete paving slabs made in Canada should conform to CSA A231.1 (3). This standard applies to paving slabs used on roofs as well as at-grade construction. The standard requires a minimum average flexural (bending) strength of 650 psi (4.5 MPa), freeze-thaw durability when exposed to deicing salts and conformance to dimensional tolerances. Flexural (rather than compressive strength) is used to assess unit strength since the larger slabs are exposed to bending and cracking. Compressive strength is excluded from the standard because it is not a true measure of the performance of the concrete. It can increase as the thickness of the tested unit decreases. Therefore, a high compressive strength test result required from a thin slab gives a false indication of a slab's resistance to bending since thinner slabs will break in bending more readily than thicker ones.

Unit dimensions are measured on samples and compared to the dimensions of the manufacturer's product drawings. Allowable tolerances for length and width in CSA A231.1 are –1.0 to +2.0 mm from the manufacturer's product drawings. Height should not vary ±3.0 mm. Units should not warp more than 2 mm on those up to 450 mm in length and/or width. For units over 450 mm, warping should not exceed 3 mm. There is no standard for precast concrete paving slabs in the U.S.

There are some lightweight, low-flexural strength ballast slabs (mistakenly named roof pavers) manufactured with a tongue-and-groove or bevels along their sides to increase their interlock. Other designs include plastic fasteners to connect one unit to the next. These methods of joining the sides to one another provide greater resistance to uplift from wind. Figure 4 illustrates one type of unit with tongue and grooved sides (not visible) and connecting tabs between each unit. Some of these types of units are made with lightweight concrete, or are thinner in order to reduce the dead load on the roof structure. Some designs have grooves on their bottom surface. When installed, these follow the roof slope to help remove water. These types of units offer limited architectural enhancement from patterns, colors, or surface finishes.

ASTM has issued C 1491, Standard Specifi-cation for Concrete Roof Pavers (5). This product specification is appropriate for ballast-only type paving units (pavers or slabs) used only in direct contact with roof materials and only for limited pedes-

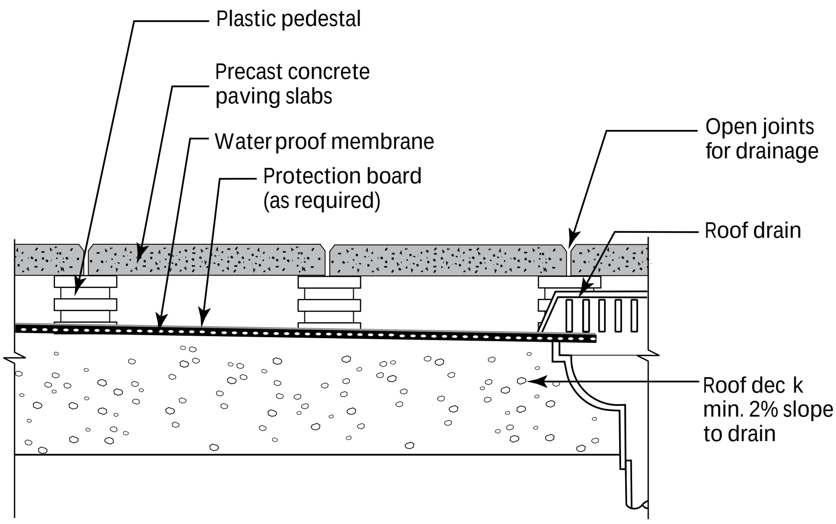

Figure 5. Paving slabs on pedestals

trian use such as walkways for maintenance personnel. Products that meet this standard should not be subject to constant pedestrian use, not placed on pedestals and never be subject to vehicles. Specifiers and contractors are advised to use roof paving products for vehicular and pedestrian applications that meet the previously mentioned ICPI guidelines or CSA standards. ICPI takes a conservative approach by not recognizing differences among shapes with respect to structural and functional performance. Certain manufacturers may have materials and data that discuss the potential benefits of shapes that impact functional and structural performance.

Setting materials

Pedestals —Paving slabs for plaza decks are often placed on plastic or fiberglass pedestals. The result is a level deck, concealment of slope and drains and water storage space under the units during very heavy rainfalls. Pedestal-set paving units install quickly and enable fast removal for repair of waterproofing materials and for maintenance of deck drains. The units can be reinstated after repair with no visible evidence of movement. Damaged paving units can also be easily removed and replaced. Figure 5 shows a diagram of a pedestal system with paving slabs.

In most pedestal-set applications, units are 18 x 18 in. (450 x 450 mm) or larger. The corners of paving units rest on a plastic pedestal. These units usually require shimming after placement. Shims are inserted under the corners of a nonaligned paving unit until its surface is even with adjacent units. Some plastic pedestals have a built-in leveling device to reduce the amount of labor involved with shimming. Some are telescoping cylinders whose length can be changed by rotating an adjustable sleeve within another. Other designs have a base that tilts slightly to compensate for the slope of the roof.

Vertical spacers are often molded in the plastic pedestals to ensure uniform joint widths among the paving units. The open joints allow runoff to pass through them onto the waterproof membrane and into roof drains. The joint created by the spacer should not exceed 3/16 in. (5 mm) and this will minimize the likelihood of tripping.

Another type of pedestal system consists of 8 in. (200 mm) square extruded polystyrene blocks (typically 2 in. or 50 mm thick) glued together, spaced on a grid across the deck and adhered to a polystyrene insulation board that rests on the waterproof membrane. Many contractors use 60 psi (0.4 MPa) polystyrene blocks to support the paving units. The bottom block of foam may have grooves in contact with roofing materials to facilitate drainage. The grooves should point toward drains.

A patented leveling system trims the tops of the polystyrene blocks to the required height. Shimming is not necessary except for the occasional paving unit that might be slightly out of dimension. Spacing is typically maintained with neoprene rubber spacer tabs adhered to the corners of the paving units, although plastic pedestals can be used. This pedestal system supports units up to 36 x 36 in. (910 x 910 mm). The foam pedestals can extend as high as 2 ft (0.6 m). Figure 6 shows the foam pedestals in place and receiving the paving slabs (6).

Figure 6. Foam pedestal system

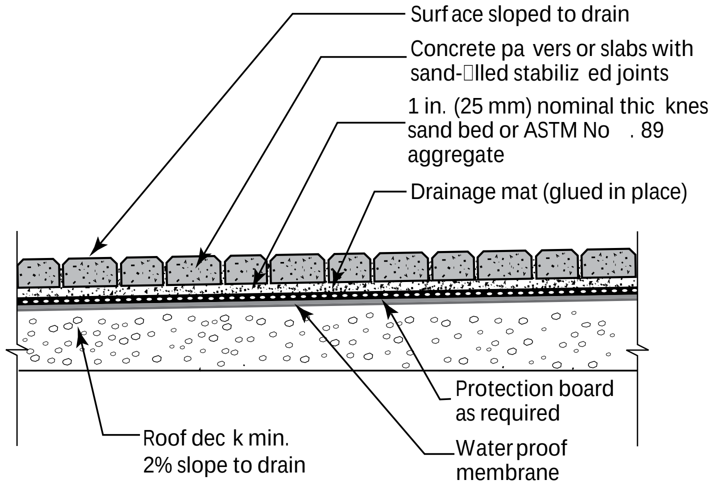

Figure 7. Sand-set concrete pavers or slabs for a pedestrian roof plaza deck. Units no larger than 12 x 12 in. (300 x 300 mm) length and width are recommended for sand-set applications to avoid tipping.

Bedding and Joint Sand for Pedestrian Applications — Sand-set pavers and slabs (up to 12 x 12 in. or 300 x 300 mm) are common options for pedestrian applications. The typical sand thickness is nominal one inch (25 mm). Figure 7 illustrates a sand-set application for pedestrians.

A key design consideration is not allowing the bedding sand to become saturated. Continually saturated sand and joints can support moss or vegetation that eventually clogs roof drains. Saturated sand can increase the potential for efflorescence that might exist in some concrete paving units. While not attractive, efflorescence will eventually disappear and it is not detrimental to structural performance.

The risk of saturated bedding sand is reduced by adequate slope of the roof structure and correct sand gradation. Sand requires at least a minimum deck slope of 2% to drain. Gradation of the bedding sand for pedestrian applications should conform to ASTM C 33 (7) or CSA A23.1 "FA 1" (8). It is important that no material (fines) pass the No. 200 (0.075 mm) sieve as the presence of this size of material will greatly slow the movement of water through the bedding sand.

Gradation for Bedding Sand			
ASTM C33		CSA A23.1 FA1	
Sieve Size	Percent Passing	Sieve Size	Percent Passing
3/8 in.(9.5 mm)	100	10.0 mm	100
No. 4 (4.75 mm)	95 to 100	5.0 mm	95 to 100
No. 8 (2.36 mm)	80 to 100	2.5 mm	80 to 100
No. 16 (1.18 mm)	50 to 85	1.25 mm	50 to 90
No. 30 (0.6 mm)	25 to 60	630 µm	25 to 65
No. 50 (0.3 mm)	5 to 30	315 µm	10 to 35
No. 100 (0.15 mm)	0 to 10	160 µm	2 to 10
No. 200 (0.075 mm)	0 to 1	80 µm	0 to 1

Note: Bedding sands should conform to ASTM C33 or CSA A23.1 FA1 gradations for concrete sand. For ASTM C33, ICPI recommends the additional limitations on the No. 200 (0.075 mm) sieve as shown. For CSA A23.1 FA1, ICPI recommends reducing the maximum passing the 80 µm sieve from 3% to 1%.

Gradation for Joint Sand			
ASTM C144		CSA A179	
Sieve Size	Percent Passing	Sieve Size	Percent Passing
No. 4 (4.75 mm)	100	5.0 mm	100
No. 8 (2.36 mm)	95 to 100	2.5 mm	90 to 100
No. 16 (1.18 mm)	70 to 100	1.25 mm	85 to 100
No. 30 (0.6 mm)	40 to75	630 µm	65 to 95
No. 50 (0.3 mm)	10 to 35	315 µm	15 to 80
No. 100 (0.15 mm)	2 to 15	160 µm	0 to 35
No. 200 (0.075 mm)	0 to 5	80 µm	0 to 10

Table 1. Bedding and Joint Sand Gradation for Concrete Pavers and Paving Slabs for Roof Decks

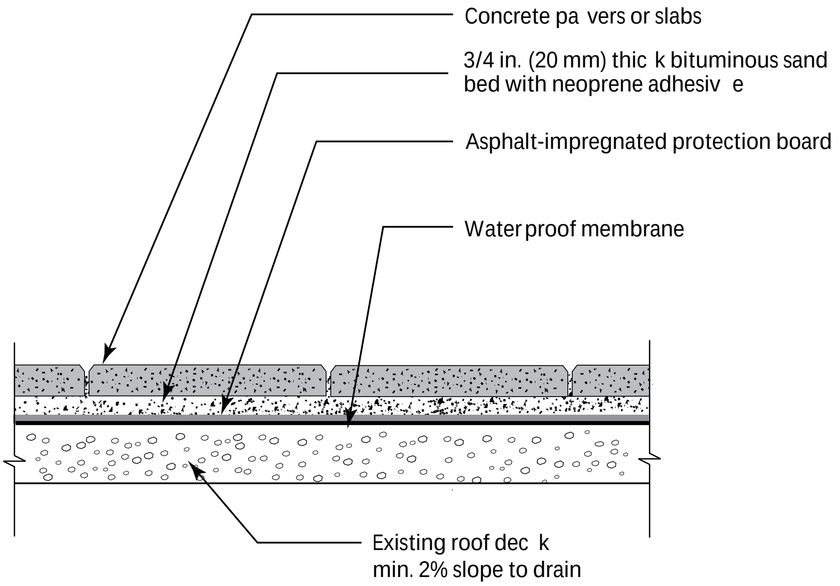

Figure 8. Neoprene adhesive on an asphalt-stabilized sand setting bed

With any segmental paving system, the final, installed result should provide a smooth, stable, and even surface. For pedestrian plaza deck applications, lipping tolerances among adjacent paving units should be no greater than 1/8 in. (3 mm). Surface tolerances of the finished elevations should be no greater than ± 1/8 in. (±3 mm).

Recommended gradations for pedestrian applications are provided in Table 1. Limestone screenings or stone dust should not be used since they typically have fines passing the No. 200 (0.075 mm) sieve. It is accepted construction practice to use bedding sand for joint sand. Additional effort in sweeping and compacting joint sand may be required to work the larger particles down the joints. The sand should be dry when applied so that it flows freely into the joints.

Bedding and Joint Materials for Vehicular Applications —As with pedestrian plaza or terrace applications, bedding materials for vehicular applications need to freely drain water so that they do not become saturated. Again, an essential roof structure requirement is a 2% minimum slope. Parking decks with saturated bedding sand subjected to constant wheel loads will pump sand laterally or upward and out of the paving assembly. Joint sand is carried out as well, and loss of interlock follows. An unstable surface results where loose pavers receive damage (chipping and cracking) from continued wheel loads. Loss and lateral movement of bedding sand can result in damage to and leaks in the waterproof membrane from loose paving units.

In a few older, vehicular roof deck applications, there have been instances of bedding sand becoming clogged with fines

Grading Requirements for ASTM No. 9 and ASTM No. 89 Bedding Materials		
Sieve Size	ASTM No. 9 Percent Passing	ASTM No. 89 Percent Passing
1/2 in. (12.5 mm)	–	100
3/8 in. (9.5 mm)	100	90 to 100
No. 4 (4.75 mm	85 to 100	20 to 55
No. 8 (2.36 mm)	10 to 40	5 to 30
No. 16 (1.18 mm)	0 to 10	0 to10
No. 50 (0.300 mm)	0 to 5	0 to 5

Table 2. ASTM No. 9 or 89 materials for the bedding material may be an advantageous alternative to some sands for vehicular and pedestrian applications

over several years. The source of fines is likely from a combination of a lack of adequate slope, dirt deposited from vehicles and sometimes from degradation and wearing of the sand into finer material under constant traffic. The fines eventually accumulate in the bedding sand and slow drainage.

To help prevent the bedding layer from becoming saturated or becoming clogged, bedding material with a coarser gradation than that shown in Table 1 may be advantageous for vehicular or pedestrian applications. An example is material conforming to the gradation of ASTM No. 9 or No. 89 aggregate (9). See Table 2. The void space in this aggregate can allow for movement and removal of fines.

Joint sand should have sufficient coarseness such that it does not vacate the joints by working its way down and into the bedding material. The bedding material gradation should overlap with that of ASTM C 33 or CSA A23.1 joint sand to help prevent it from working into the bedding sand.

Joint Sand Stabilization—Joint stabilization materials are recommended in sand-set roof applications for pedestrian and vehicular use. They are applied as a liquid or mixed dry with the joint sand and activated by moistening the joints with water. These materials reduce infiltration of water and ingress of fines brought to the surface by vehicles, and they achieve early stabilization of joint sand. Stabilization can help prevent the joint sand from being washed out by rainfall or blown out by winds. ICPI Tech Spec 5– Cleaning, Sealing and Joint Sand Stabilization of Interlocking Concrete Pavements offers further guidance on the types of joint stabilizers and their applications.

Neoprene adhesive with bitumen-sand bed—This setting method typically involves applying an asphalt primer to the substrate and then placing a 3/4 in. (20 mm) (1 in. or 25 mm maximum) thick asphalt-stabilized sand layer over it, followed by a neoprene adhesive. The sand asphalt mix is applied hot and compacted. The units are set into the adhesive after a dry skin forms and the joints are then filled with sand. Figure 8 provides a schematic cross-section. The waterproof membrane manufacturer should confirm compatibility of the primer, asphalt setting bed and adhesive with the membrane. Joint sand stabilizer can provide early stabilization of the joint sand. Cement mixed with sand to stabilize it in joints is not recommended since the cement can stain the surface of the paving units.

Drainage should be provided at roof drains as with sand-set assemblies. This includes holes in the sides of roof drains to remove water that collects below the paving units. Details on drains are discussed later.

Mortar—While it is not a common setting material, a mortar bed (approximately 3:1 sand to cement) may be used to level and secure pavers or slabs. This setting method is not used over drainage mats. See Figure 9. Like a bitumen setting bed, mortar is costly to remove and replace should there be a need for roof maintenance. In addition, mortar deteriorates in freeze-thaw

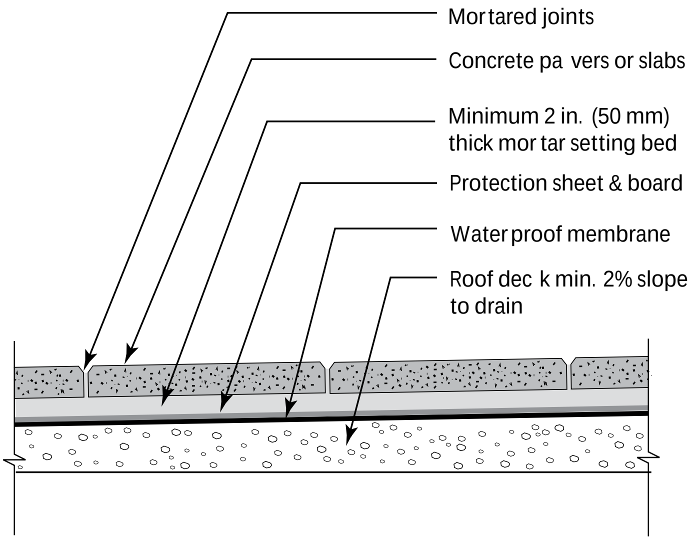

Figure 9. Mortar bed under paving units

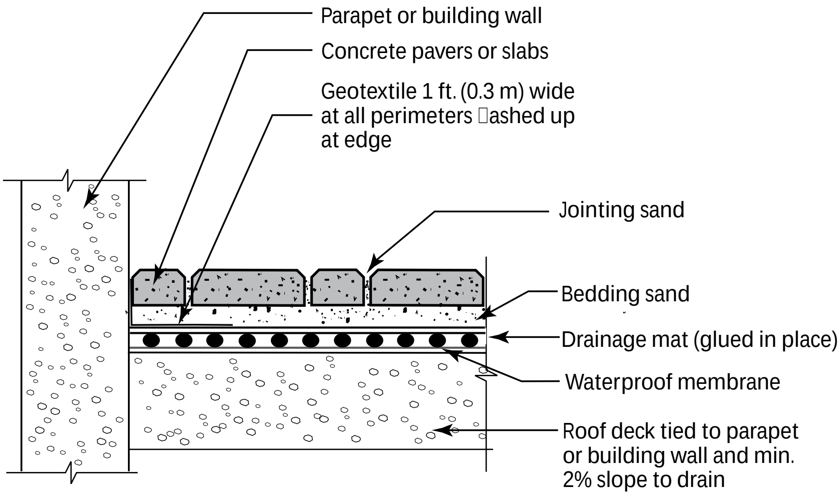

Figure 10. Detail showing geotextile at all edges of sand and aggregate bedding courses for a pedestrian application.

climates, and especially when exposed to deicing salts. In ASTM C 270, Standard Specification for Mortar for Unit Masonry, the Appendices include a table on the Guide for the Selection of Masonry Mortars. While Type S is recommended, the guide states caution in selecting mortar for horizontal applications. While they are not foolproof, latex or epoxy modified mortars can reduce the onset of deterioration from freeze-thaw and salts making them acceptable for some pedestrian applications. However, loading and environmental factors preclude the use of mortar-set paving units for vehicular applications, and this setting method is better suited for non-freezing areas.

Geotextiles, Protection Board, Insulation and Drainage Mats

Geotextiles —With sand or aggregate bedding materials, geotextile will be needed to contain them and keep them from migrating into deck drains or through wall drains such as scuppers. In addition, sand or aggregate requires geotextile under it to prevent loss into the protection board and insulation (if used). Geotextile manufacturers should be consulted on geotextile selection. The fabric should be turned up against drains, vents and other protrusions in the roof and along parapets and walls.

To contain sand and aggregate bedding materials, the geotextile should extend up the side. Figure 10 shows this detail which will help prevent loss of bedding materials from a deluge of rainfall that causes temporary ponding around the drains. A separate piece of geotextile is wrapped around the roof drain to prevent loss of bedding sand or aggregate.

Protection board —Most waterproofing systems require a protection board over them to prevent damage to the waterproofing from paving units and to reduce thermal stresses from temperature changes. This can be an asphaltic protection board or other materials. The manufacturers of waterproofing systems can provide guidance on the use of protection layers and they can recommend specific materials when this option is required. Protection board is generally not used in vehicular applications.

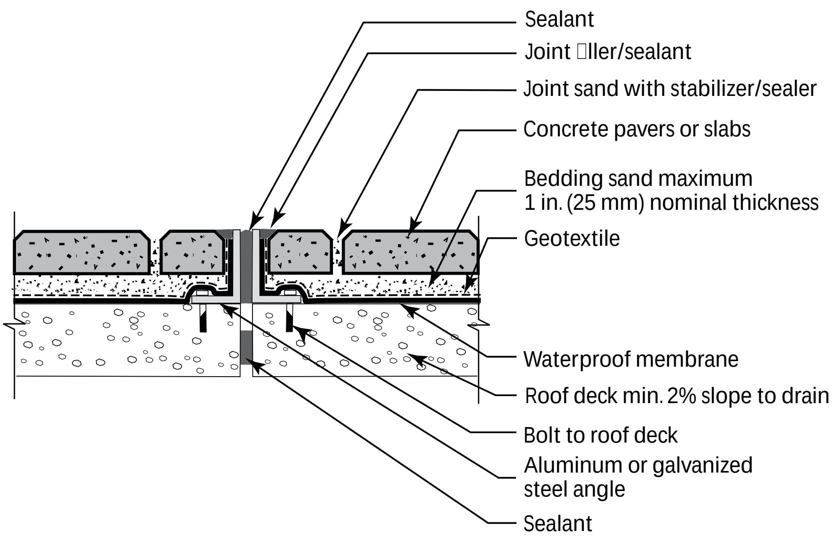

Figure 11. Edge restraint detail at a roof construction joint for pedestrian roof applications (14)

Insulation —If a pedestrian plaza deck covers an inhabited space, insulation may be required. Insulation typically consists of foam or fiber boards placed over the waterproofing. Sometimes they are adhered directly to the waterproofing. Insulation may be tapered to roof drains to facilitate movement of water into the drains. Insulation board in contact with the waterproof membrane should have drainage channels to facilitate drainage of water under it. Insulation under pavers in vehicular applications requires careful design and execution. As with other engineered pavements, consult an experienced designer familiar with these applications. A secure location for insulation is sandwiched in place inside the concrete deck.

Drainage mats —Drainage mats are generally placed under bedding sand and over waterproof membranes to accelerate drainage of water from the sand. Drainage mats are typically 1/4 to 3/8 in. (6 to 10 mm) thick. They consist of a plastic structure covered by geotextile. The structure and geotextile support and contain the bedding sand under the paving units while allowing water to move into it and laterally to roof drains. They are recommended in pedestrian applications under a sand setting bed. They should be placed at a minimum of 2% slope.

Installation of drainage mats for pedestrian applications should start at the lowest slope on the roof with the work proceeding upslope. Flaps on each should go under the next (in a manner similar to placing roof shingles) so that the water drains from one section to the next. This helps prevent water from leaking under the mats. While mats reduce the amount of water reaching the waterproof membrane, they are not a substitute for deck waterproofing. The paving installation contractor should install mats.

Drainage mats are typically supplied in rolls making them difficult to flatten, and they often don't remain flat during installation. An adhesive between the mat and waterproof membrane will likely be required to maintain flat drainage mats during their installation.

Drainage mats can be used under foam or plastic pedestal systems. While drainage mats may be tested according to the compressive strength test method in ASTM D 1621 (10), they may require additional testing by pre-loading to ensure that they will not crush under loads from the pedestals.

Drainage mats should not be used under vehicles. Mats deflect under wheel loads, eventually fatiguing, compressing and deforming. Repeated deflection tends to shift the pavers, bedding and joint sand, making interlock difficult to maintain. The deflection causes the joint sand to work its way into the bedding and the bedding sand shifts under loads, especially when saturated. The loss of joint and bedding sand, with possible eventual crushing of the mat, retains water and this can saturate the bedding sand.

Waterproof Membranes

The choice of waterproofing is influenced by the application, the project budget, the deck materials under it and the type of structure supporting the roof. There are three broad types of waterproofing materials used under concrete paving units. They are single-ply, liquid membranes, built-up or modified bitumen roofing. A brief description of these materials follows with their compatibility to segmental paving (11,12).

Single-ply roofing is strictly for pedestrian applications and it is the most widely used waterproofing. It is typically made from vulcanized (cured) elastomers such as ethylene propylene diene monomer (EPDM), neoprene, or butyl. These flexible sheets have excellent weathering properties, high elongation and puncture resistance. When assembled on a roof, the sheets are spliced together at the job site with an adhesive. The entire assembly of sheets can be loose-laid and ballast provided by paving units. They also can be partially or fully adhered, or mechanically fastened to the roof deck.

Another type of single-ply membranes includes non-vulcanized elastomers such as polyisobutylene (PIB), chlorinated polyethylene (CPE), chlorosulfanated polyethylene (CSPE). These materials are usually reinforced with a polyester mat laminated between two plies. Thermoplastics such as polyvinyl chloride (PVC) sheets are heat welded in the field. Like the elastomers, PVC is loose-laid with ballast paving units, partially or fully adhered, or mechanically fastened to the deck material.

Rubberized asphalt membranes and polyethylene laminates have been used extensively to waterproof pedestrian plaza decks. Prefabricated sheets are made in small sheets and are spliced together in field. They generally are fully adhered to the concrete deck, so their longevity is highly dependent on the quality of the workmanship in splicing and on the smoothness and quality of the concrete.

Manufacturers of single-ply membranes should be contacted about the extent of warranties on the field splices under paving units. Additional measures may be necessary to protect the splices from the paving. This can include installation of a second, sacrificial membrane layer directly under the paving units.

Liquid applied membranes are installed either hot or cold depending on the materials. Rubberized asphalt membranes are hot applied to the concrete deck to form a continuous coating with no seams. These are for pedestrian plaza decks only. Cold-applied liquid resins and elastomers such as polyurethane are generally suitable as waterproofing on concrete decks subject to vehicular use. Sprayed-in-place polyurethane foam acts as an insulator and as waterproofing. The material is soft and is not recommended for use with concrete paving units.

Built-up roofing is made from paper, woven fabric or glass fiber mats, polyester mats or fabrics adhered together in alternating layers with bitumen or coal tar. The exterior surface of the layers is covered with bitumen or coal tar. Built-up roofs use concrete pavers or slabs as a walking surface to prevent wear and puncture of the membrane, especially around mechanical equipment. The use of pedestal systems should be avoided in built-up roofing due to the likelihood of indentations in the layered waterproofing materials.

Modified bitumen consists of plastic or rubber additives pressed into asphalt sheets. They are installed by heating the sheets with a torch and applying them to the deck substrate, or by mopping bitumen and securing them to the substrate with it. Some systems use cold cement or mastics to adhere the sheets to the substrate. Some modified bitumen waterproofings create overlap "bumps" every yard (meter) or so. There can be an additional construction cost to avoid these when using a pedestal system. These systems do not require segmental paving ballast unless insulation needs to be secured in place. While these systems are generally compatible with concrete paving units in pedestrian applications, manufacturers should be contacted for verification of use with paving units under vehicular traffic.

Each of these waterproofing systems has advantages and disadvantages on speed of installation, costs, durability and manufacturer warranties. Many waterproof membrane manufacturers require the use of roofing contractors that have been certified to install a particular manufacturer's roofing system. The subject of roof waterproofing is large and outside the scope of this publication. There are many references on roofing and waterproofing systems. An overview is provided in *Roofing—Design Criteria, Options, Selection* (12). Other resources are publications by the National Roofing Contractors Association at http://www.nrca.net and the Roof Consultants Institute at http://www.rci-online.org.

Deck Structure Systems

Concrete—There are four types of concrete deck structural systems (11). They are reinforced concrete slabs, post-tensioned slabs, pre-stressed precast elements such as "T" beams with a concrete topping, and concrete poured onto and formed by steel decks. Each type responds to waterproofing differently. For example, volumetric changes in reinforced concrete slabs can cause reflective cracking in liquid-applied membranes and some fully adhered bituminous systems. Post-tensioned slabs are generally suited for liquid applied membranes because the slabs have a low amount of deflection and cracking. Loose-laid waterproofing systems are suited for over precast elements because they can accommodate the many joints in the deck, whereas liquid-applied and fully adhered membranes are prone to reflective cracking and splitting at joints.

In lighter, less expensive roofs, the concrete deck is poured onto and formed by a corrugated steel deck. In some cases the concrete is lightweight, i.e., weighing less per cubic foot or cubic meter than ordinary ready-mixed concrete. The weight of

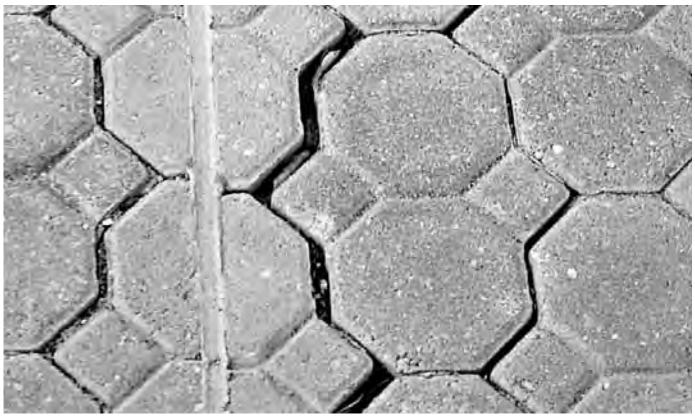

Figure 12. An absence of edge restraints and use of a sealant in this construction joint caused the pavers to shift and open their joints on both sides of the sealant.

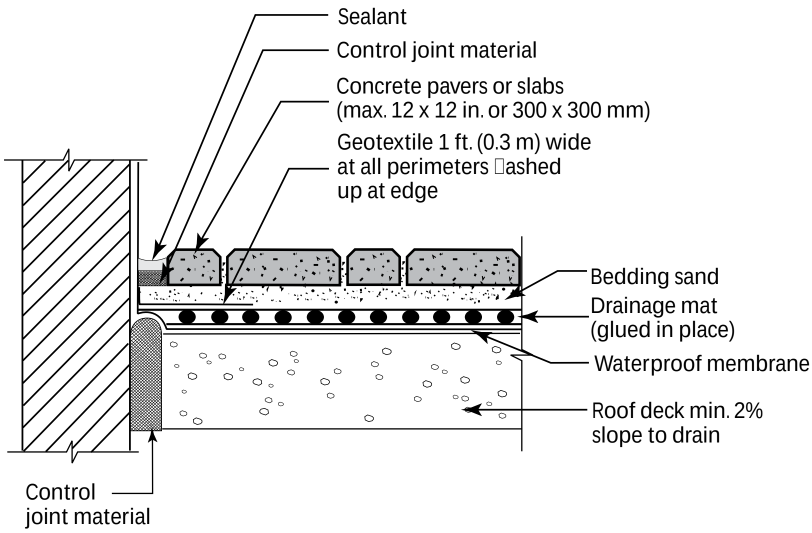

Figure 13. Detail at building wall not joined to decking using paving units and bedding sand with a drainage mat for pedestrian applications only

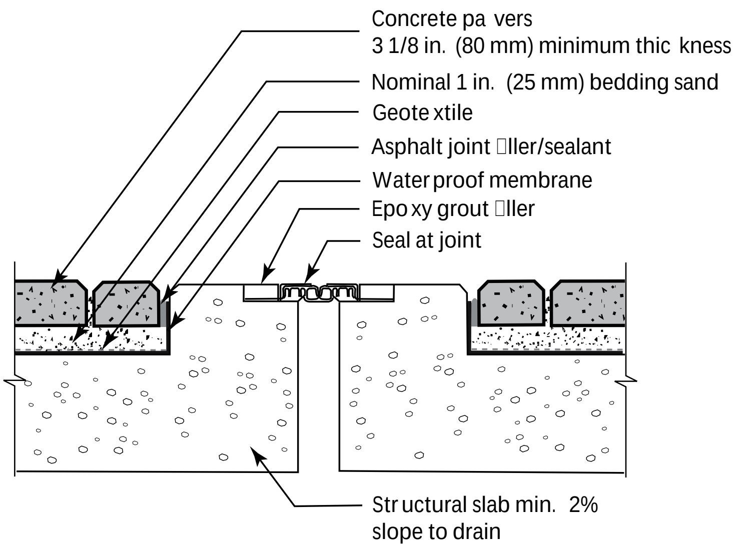

Figure 14. Edge restraint detail at a roof expansion joint for vehicular applications

lightweight concrete is reduced by using lighter aggregates and by air-entraining the concrete mix. Lightweight concrete reduces loads on the columns and beams, thereby reducing their size and expense. (See Reference 13 for further information on light-weight concrete.) Steel decks topped with concrete should be vented so that moisture can escape if waterproofed with liquid-applied or fully adhered materials. Some waterproofing manufacturers do not recommend use of their materials over lightweight concrete.

Steel —Corrugated steel decks are generally covered with insulation and loose-laid single-ply membranes. This inexpensive assembly often uses ballast made with lightweight concrete paving units. These assemblies typically do not use heavier precast concrete pavers or paving slabs.

Design Considerations

Detailing for movement for pedestrian applications —Roof joints should be located when there is a change in roof direction, dimension, height, material, or when there are extreme differences in humidity or temperature within a building. Most roof structures have joints that allow each part of the structure to move independently due to settlement, seismic activity and thermal expansion/contraction. There is usually a flexible sealant in the joint to prevent water from entering and leaking into the space below. The sealant can be a compression seal squeezed into the joint, or a more expensive and durable strip seal. A strip seal is a length of flexible material fastened to metal clips secured to the concrete deck. The strip seal flexes with the movement of the adjacent structures.

Figure 11 illustrates a joint in a concrete structure and with sand-set paving units over it. Expansion joints should be treated as pavement edges. As with all segmental pavement construction, an edge restraint is required to hold the units together. Figure 11 shows steel angle restraint on both sides of the joint and secured to the concrete deck. There should be a compression seal at the top against the steel edge restraints, as well as one between the concrete decks. This detail is recommended at roof expansion joints for pedestrian applications.

This detail shows the paving pattern stopping at a joint in the deck and resuming on the opposite side. The sealant is joined to the edge restraint and not to the sides of the paving units. The use of a sailor or soldier course of pavers on both sides of the joint will present a clean visual break in the pattern. Figure 12 shows the consequences of not stopping the pattern with an edge restraint at an expansion joint. The pavers separated and exposed the bedding sand and waterproof membrane.

Parapets or building walls can typically serve as edge restraints. For sand-set paving assemblies, expansion material should be placed between the outside edge of the pavers and

Figure 15. An absence of holes in the sides of this roof drain led to ponding.

vertical walls of buildings when functioning as separate structures from the deck on which the paving units rest. Figure 13 shows this detail with expansion material. It should not adhere to the paving units or the wall, but should independently expand and contract with their movement. Expansion materials at the perimeter of the pavers are not necessary to place against walls or parapets when the pavers are resting on the same structure as the walls. Figure 10 illustrates this condition.

Detailing for movement for vehicular applications—Figure 14 details an expansion joint in a roof application subject to vehicles such as a parking structure. Although compression seals can be used, this assembly uses a strip seal for bridging the joint. The ends of the concrete deck are formed as edge restraints to hold the concrete pavers in place.

2 3/8 in. (60 mm) vs. 3 1/8 in. (80 mm) thick pavers for vehicular applications—Most vehicular applications with pavers are supported by a concrete structure. The support from such a structure is often used as rationale for using pavers that are less than 3 1/2 in. (80 mm) thick. Thicker units render greater vertical and rotational interlock. Using concrete pavers less than 3 1/2 in. (80 mm) thick in vehicular of applications increases the risk of reduced surface stability by reducing horizontal and rotational interlock under turning and braking vehicles.

Weight—Concrete pavers, slabs and bedding materials exert substantial weight on roof structures. The structure supporting these materials should withstand dead and live loads. The advice of a structural engineer should be sought to assess the capacity of the roof and tolerable deflections from paving-related loads especially when units are added to an existing roof deck structure. The weight of paving units can be obtained from manufacturers for the purposes of calculating loads. Bedding sand (1 in. or 25 mm thick) weighs approximately 10 lbs. per sf (49 kg/m^2).

Resistance to wind uplift—The designer should consult *Loss Prevention Data for Roofing Contractors* Data Sheets published by Factory Mutual (FM) Engineering Corporation (15). Data Sheets 1-28 and 1-29 provide design data including the minimum pounds per square foot (or kg/m^2) of paving unit weight required for resistance to wind uplift. The FM charts consider wind velocity pressure on roofs at various heights in different geographic locations. Design pressures are then compared to the type of roof construction, parapet height and the whether the paving units have tongue-and-groove, beveled joints, or are strapped together. Some high wind regions may have local building codes with additional weight requirements for paving units, especially on high-rise buildings.

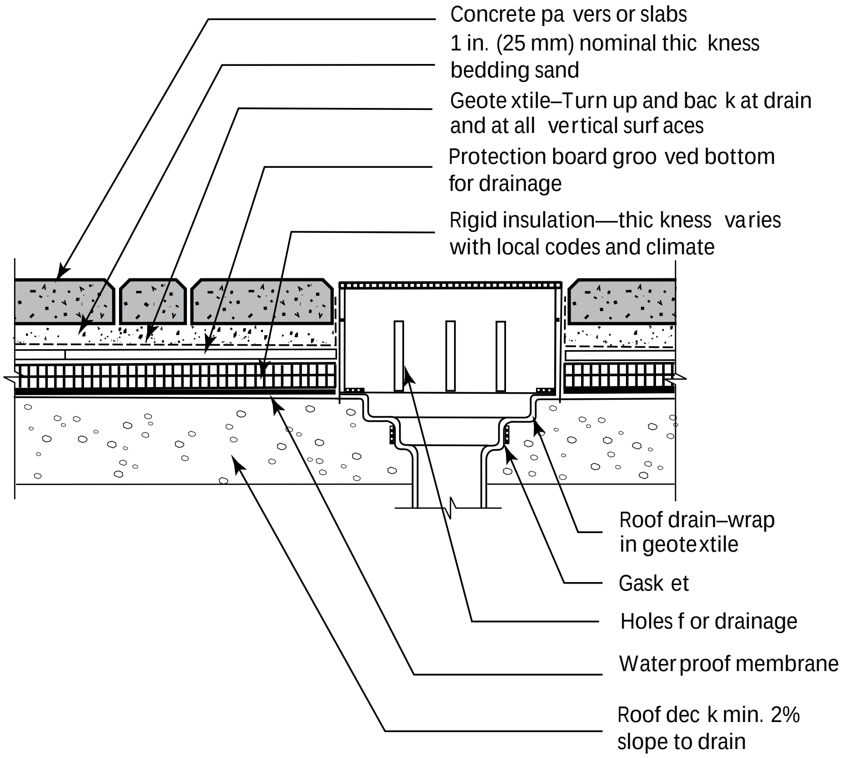

Figure 16. A drain detail for a pedestrian plaza deck over habitable space.

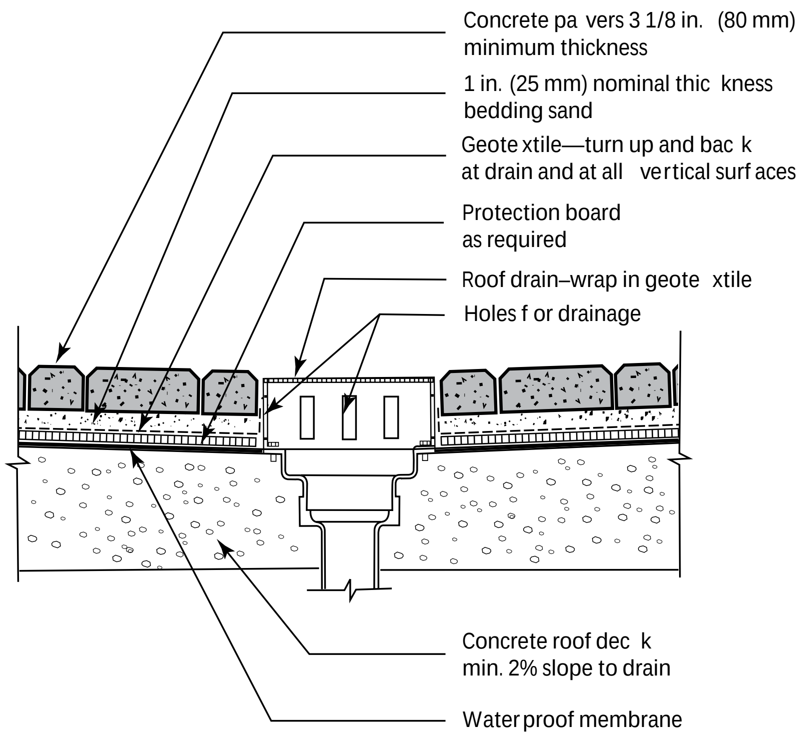

Figure 17. A drain detail on a vehicular roof application.

Slope for drainage—A flat or "dead level" roof, i.e., one with no pitch, should never be designed. A dead level roof does not drain, creating a high risk of leaks in the waterproofing, as well a potential saturation of bedding sand (when used). The membrane will be exposed to continual standing water and ice that accelerates its deterioration and increases the potential for leaks. Likewise, paving units and bedding materials in constantly standing water subject to many freeze and thaw cycles will experience a decrease in their useful life.

Regardless of the deck substrate, it should be built with a minimum 2% slope to drain. This may be difficult to achieve with certain decks sloping toward area drains and some decks are built flat and then a topping applied to achieve slopes. The designers should take every opportunity to use deck systems that enable construction of a minimum 2% slope as some toppings are not waterproof and flat roofs will eventually leak.

Slopes for pedestrians and vehicles—The maximum slope is constrained by the need for a comfortable walking surface and the maximum percentage is typically 8% (4.5°). For driving surfaces, the maximum recommended slope should not exceed 20% (11°) and ideally should not exceed 8% as such surfaces will often see pedestrian use. For slopes exceeding 4% with exposure to vehicles, consideration should be given to using bituminous-set rather than sand set systems.

Roof drains—Depending on the design, roofs are drained at their edges and/or from the interior with roof drains. When roofs decks are loaded with dead and live loads, they will deflect. Continual deflection over time results in deformation of the roof. This movement can make drain inlets or scuppers adjacent to columns or on frame lines at the perimeter of the highest points of the roof. Therefore, sufficient pitch to the roof that accounts for such deflections is essential to continual drainage. In addition, the surface of the paving should be a minimum of 3/16 in. (5 mm) above the inlet of roof drains.

When sand or aggregate is used for bedding or fill, it is essential that holes be in the sides of drains to allow water to escape the bedding sand. The bottom of the holes should be at the same elevation as the top of the waterproof membrane. As previously noted, drains should be wrapped in geotextile to prevent loss of bedding material through the drain holes.

Figure 15 illustrates ponding around a parking deck roof drain that didn't have drain holes in its sides to drain subsurface water. Figures 16 and 17 illustrate a possible drain solution with holes for a pedestrian roof and parking deck. For paving slabs with pedestals, the slabs generally are located over roof drains, or are cut to fit around drains (see Figure 5). Bitumen-set assemblies require holes in the sides of the drains to remove water that may collect below the paving units. Bitumen and neoprene must not be allowed to clog roof drains or holes on their sides during installation.

Raising elevations—New and rehabilitated roofs may require fill material for raising the paved surface so it conforms to adjacent elevations. The deck surface receiving the fill material should slope a minimum of 2%. Fill materials are typically concrete, asphalt, or open-graded base. The structure should be evaluated first by a structural engineer for its capability in taking the additional load. Lightweight concrete may be considered if there are load limitations. These fill materials are often placed over a water-proof membrane. Consideration should be given to using insulation and protection board over the waterproof membrane. Attention in detailing and during construction should be given to how the fill materials will meet vents, skylights and other protrusions in the roof without damage to them, their flashing, or to their waterproofing. Open-graded bases will require geotextile under them to contain them. The fabric should cover all sides of the base.

Dense-graded aggregate base fill materials are not recommended since water can collect at the bottom of the base and soften it. Over time, this condition can increase the potential for deformation of the base under repeated vehicular wheel loads. In addition, aggregate base materials can shed fine particles that, over time, can clog geotextiles and drains. Concrete, asphalt, or open-graded bases are preferred as fill materials since they do not deform when continually exposed to water. In addition, they seldom shed particles into the roof drains so they present a much lower risk of clogged geotextile and drains.

Due to its high temperature at application, asphalt may not be compatible with some waterproof membranes, insulation, or protection board. All fill materials should be reviewed with the manufacturer for compatability with these components. Other important considerations are the minimum thickness to which the fill materials can be applied without cracking and deterioration from freeze-thaw cycles and salts. The design and selection of fill materials should address movement from temperature changes, vibration (if exposed to vehicles) and seismic activity.

Figure 18. A mechanical screed used to level bedding sand on a roof parking deck project.

Figure 19. Mechanical equipment used to install concrete pavers on a roof deck.

Construction Considerations

Low slope roofs and waterproofing systems are generally installed by a specialty roofing subcontractor. A second subcontractor specializing in the installation of segmental paving supplies and installs bedding materials, pedestals, pavers or slabs after the waterproofing is placed by the roofing contractor. Installation of protection board and/or drainage mat may be by the paving contractor or roofing contractor depending

Figure 20. Vacuum assisted mechanical equipment for installing paving slabs.

on the project specifications. Testing of the waterproofing for leaks and any repairs should be completed prior to starting the paving.

Job Planning —Roof jobs are typically built in a very limited space. There will be an additional expense of moving the paving units from the ground to the roof. Most roofs may not have space to store cubes of pavers and stockpiled sand, and if they did, they most likely do not have the structural capacity to withstand their concentrated weight. The advice of a structural engineer should be should be sought on assessing the maximum load capacity of the roof to safely support the weight, packaging and distribution of all materials delivered to the roof, or a crane used to lift them from the exterior.

Forecasting delivery time for moving pavers to the roof, as well as sand, pedestals, saw(s), tools, geotextile and crew to the roof is critical to accurately estimating roof projects. Labor functions and costs must be tracked on each project for use in future bids. For example, additional time and expense may arise from the need for the paving contractor to place temporary protection on the waterproof membrane to prevent damage during construction. A one-story parking garage may allow all materials to be driven onto and delivered quickly to the roof. A multi-story parking garage with pavers on the top floor may have a 6 ft - 6 in. (2 m) ceiling height that will not allow delivery of pavers and sand in large trucks. Trucks with a low clearance will be needed to move materials through the structure and to the roof, or craned to the roof.

The packaging of most concrete pavers and slabs allows their transport to the roof via elevator or crane during construction. Roof access, construction scheduling, the capacity of the roof to withstand loads from packaged materials, and reduction of labor costs will dictate the economics of using a crane to transport materials to the roof. The roofing contractor often handles this.

In some cases, an elevator may be the only means of transport. An example of using only an elevator to move crews, tools and materials was to the observation deck on the 86th floor of the Empire State Building in New York City (Figure 1) where the deck was rehabilitated with concrete pavers.

The layout of paving slabs can be more demanding than the

Figure 21. The plaza area around Scope Center in Norfolk, Virginia, (left) and one side of the Alamo Dome (right) in San Antonio, Texas, include roof plaza decks surfaced with concrete pavers.

layout of interlocking concrete pavers. Some designers prefer joint lines to be located in particular places such as centered at columns or staircases. Careful planning of the layout will spare wasted cuts and adjusting the pattern on site to conform to the drawings and design intent.

Sometimes railing posts along the perimeter of a roof may require coring holes in paving slabs to fit around them. In addition, paving units may need to be cut to fit against moldings and other protrusions from parapets. The location of the pattern and cutting should be anticipated in advance of the construction.

Installation of bedding sand—After placing the geotextile, the bedding sand is screeded using screed bars and a strike board to 1 in. (25 mm) thickness. Mechanical screeders may be used on large deck jobs as shown in Figure 18. This shows 40,000 sf (3,715 m^2) of pavers on a concrete parking deck next to a condominium housing project. Once the bedding sand is screeded, the pavers are compacted into the bedding sand. Sand is spread, swept and vibrated into the joints with at least two passes of a plate compactor. Excess sand is removed upon completion of compacting.

For larger than 12 in. x 12 in. (300 mm x 300 mm) slabs, bitumen or pedestals are recommended as the preferred setting methods rather than a sand bed. If placed on bedding sand, larger slabs tend to tip and tilt when loads are placed on their corners. Pedestals and bitumen are more stable assemblies for pedestrian applications. When compacting paving slabs with a plate compactor, using "add-on" rollers on this equipment should be considered to help eliminate risk of damage.

Some jobs may require slabs to completely cover the roof right up to the parapets and protruding vents. If full slabs do not fit next to vents and parapets, the slabs are saw cut and placed on pedestals next to them.

Mechanical installation—Roof decks can be built by mechanically placing the paving units. Figure 19 shows a parking deck being installed with mechanical equipment. Slabs can be installed with vacuum equipment that relies on suction to grab and place each unit. See Figure 20. For most jobs, these kinds of equipment can not run directly on the waterproofing. They must run over installed concrete pavers. Therefore, a starting area of pavers may need to be placed by hand and the equipment placed on it to continue the paving. Further information on mechanical installation is found in ICPI Tech Spec 11—Mechanical Installation of Interlocking Concrete Pavements. Regardless of the installation method, all federal, provincial, state and local worker safety rules should be followed for fall protection of crews working on roofs.

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ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®

Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

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A Guide for The Construction of Mechanically Installed Interlocking Concrete Pavements

Introduction

This guide is intended to assist design professionals in developing a construction specification for the mechanical installation of interlocking concrete pavement. The core is the Quality Control Plan that requires a high level of planning and detail for executing large-scale projects. When refined into a project specification, it should be a tool to obtain a commitment to its requirements by the General Contractor (GC), paver installation subcontractor, manufacturer, and facilitate coordination among them. The ultimate outcome is increased assurance for owners of large paved facilities.

The set of contractual relationships among the owner, engineer, GC, subcontractors, and manufacturers (suppliers) will vary with each project. This guide assumes that an engineer works for the owner who hires a GC to build the project. The GC subcontracts to a company specializing in interlocking concrete paving. The GC or subcontractor purchases pavers from a paver manufacturer. The engineer or other employees working for the owner inspect and accept the paving.

This Tech Spec does not include material or installation guidelines for permeable interlocking concrete pavement (PICP) installations. See the ICPI manual Permeable Interlocking Concrete Pavements, available at ICPI.org.

Construction specifications in North America follow various formats. A common one is set forth by the Construction Specifications Institute (CSI) called MasterFormat (2004) and this guide is written to fit this format. Specifications using the CSI format sections have three parts; General, Products, and Execution. This guide is divided into these three parts to assist in writing each.

1.0 PART 1—GENERAL

This specification guide includes the installation of interlocking concrete pavers with mechanical equipment, bedding and joint sand and optional joint sand stabilization materials. ICPI Tech Spec 11–Mechanical Installation of Interlocking Concrete Pavements (ICPI 2004) should be

Figure 1. Mechanical installation of interlocking concrete pavements (left) and permeable units (right) is seeing increased use in industrial, port, and commercial paving projects to increase efficiency and safety.

Figure 2. Bundles of ready-to-install pavers for setting by mechanical equipment. Bundles are often called cubes of pavers.

consulted for additional information on design and construction with this paving method. Other references will include American Society for Testing and Materials and the Canadian Standards Association for the concrete pavers, sands, and joint stabilization materials, if specified. Other subcontractors or the GC provides the base, drainage, and earthwork.

1.1 Definitions

This guide sets forth definitions so all project participants use the same terms within the specification:

Base: Layer(s) of material under the wearing course and bedding course.

Bedding course: A screeded sand layer on which the pavers are bedded.

Bundle: Paver clusters stacked vertically, bound with plastic wrap and/or strapping, and tagged for shipment to and installation at the site. Bundles of pavers are also called cubes of pavers. Concrete paver bundles supplied without pallets are strapped together for shipment then delivered and transported around the site with clamps attached to various wheeled equipment. The subcontractor may provide some wooden pallets at the site to facilitate movement of bundles. See Figure 2.

Chamfer: A 45° beveled edge around the top of a paver unit nominally 2 to 6 mm wide.

Cluster: A group of pavers forming a single layer that is grabbed, held and placed by a paver-laying machine on a screeded sand bedding course.

Interlock: Frictional forces between pavers which prevent them from rotating, or moving horizontally or vertically in relation to each other.

Joint: The space between concrete pavers typically filled with sand.

Joint sand: Sand used to fill spaces between concrete pavers.

Joint sand stabilizer: Liquid applied materials penetrate the in-place joint sand or an additive is mixed dry with sand prior to filling the joints. Joint sand stabilization materials are optional and may be of value in certain applications.

Laying face: Working edge of the pavement where the laying of pavers occurs.

Wearing course: Surfacing consisting of interlocking concrete pavers and joint sand on a sand bedding layer.

Wearing surface: The top surface that contacts traffic whose edges are typically chamfered.

1.2 Submittals

The following is submitted by the GC to the engineer for review and approval:

1. 14 pavers with the date of manufacture marked on each. These can be made available for testing.
2. Manufacturer's catalog cut sheets and production mold drawings.
3. The pattern for joining clusters when the pavers are placed on the bedding sand.
4. 6 lbs. (3 kg) bedding sand.
5. 6 lbs. (3 kg) joint filling sand.
6. Manufacturer's catalog cut sheets of joint stabilization material (if specified).
7. 1 quart (liter) joint sand stabilizer or joint sand additive (if specified), or 2 lbs. (1 kg) joint sand stabilizer additive.
8. Quality Control Plan.

1.3 Quality Control Plan

The GC provides the engineer, paver installation subcontractor, and manufacturer with a Quality Control Plan describing methods and procedures that assure all materials and completed construction submitted for acceptance conform to contract requirements. The Plan applies to specified materials procured by the GC, or procured from subcontractors or manufacturers. The GC meets the requirements in the Plan with personnel, equipment, supplies and facilities necessary to obtain samples, perform and document tests, and to construct the pavement.

Development and implementation of the Quality Control Plan is a joint effort by the project engineer, the GC, the paver installation subcontractor, material suppliers and testing laboratories.

The GC performs quality control sampling, testing, and inspection during all phases of the work, or delegates same, at a rate sufficient to ensure that the work conforms to the GC requirements. The Plan is implemented wholly or in part by the GC, a subcontractor, manufacturer, or by an independent organization approved by the engineer. Regardless of implementation of parts of Plan by others, its administration, including compliance and modification, remains the responsibility of the GC.

The Plan should be submitted to the engineer at least 30 days prior to the start of paving. The GC, paving subcontractor, and manufacturer then meet with the engineer prior to start of paving to decide quality control responsibilities for items in the Plan. The Plan includes:

1. Quality Control organization chart with the names, qualifications, and contact information of responsible personnel, and each individual's area of responsibility and authority.
2. A listing of outside testing laboratories employed by the GC and a description of the services provided.
3. Preparation and maintenance of a testing schedule containing a listing of all tests to be performed, who will do them and the frequency of testing.
4. Procedures for ensuring that tests are conducted according with the Quality Control Plan including documentation and steps for taking corrective actions if materials do not meet criteria for meeting the standards.
5. The paver installation subcontractor's method statement.

1.3.1 Quality Control Plan Elements

Testing—Independent testing laboratories typically are involved in testing sand and concrete pavers. They should have in-house facilities for testing bedding and joint sands. The laboratory should provide a letter certifying calibration of the testing equipment to be used for the specified tests. Upon approval of the engineer, the laboratory performs testing of sand and paver samples prior to commencement of paving to demonstrate their ability to meet the specified requirements.

Paver Manufacturer—The paver manufacturer provides evidence of capability to manufacture interlocking concrete pavers. Information may include a history of supplying projects of similar application and size, with project references and contact information in writing for verification. Personnel and qualifications may be part of the submission. The project history and references should demonstrate ability to manufacture interlocking concrete pavers and related work indicated in the plans and specifications to the satisfaction of the engineer.

The submission should include a description of the manufacturer's ability to make, cure, package, store and deliver the concrete pavers in sufficient quantities and rates without delay to the project. Evidence can include diagrams and photos showing the number and stacked height of pavers on pallets, or in bundles without pallets, banding of the pavers, use and placement of plastic wrap, pallet dimensions and construction, and overall loaded pallet or bundle dimensions.

Transportation planning for timely delivery of materials is a key element of large interlocking concrete pavement projects. Therefore, the manufacturer should include a

Figure 3. A cluster of pavers (or layer) is grabbed for placement by mechanical installation equipment. The pavers within the cluster are arranged in the final laying pattern as shown under the equipment.

storage and retrieval plan at the factory and designate transportation routes to the site. In addition, there is a description of the transportation method(s) of pavers to the site that incurs no shifting or damage in transit that may result interference with and delay of their installation. The manufacturer's portion of the quality control plan includes typical daily production and delivery rates to the site for determining on-site testing frequencies.

A key component in the plan is a method statement by the manufacturer that demonstrates control of paver dimensional tolerances. This includes a plan for managing dimensional tolerances of the pavers and clusters so as to not interfere with their placement by paving machine(s) during mechanical installation. The contents of this plan include, but are not limited to the following:

1. Drawings of the manufacturer's mold assembly including overall dimensions, pattern, dimensions of all cavities including radii, spacer bars, and the top portion of the mold known as a head or shoe.
2. If a job is large enough to require more than one mold, the actual, measured dimensions of all mold cavities need to be recorded prior to manufacture of concrete pavers for this project. This is needed because the new or used production molds may vary in overall cluster size. Mixing pavers from a larger mold with a smaller mold may cause installation problems.
3. Molds will wear during manufacture of pavers. Production mold wear is a function of the concrete mix, mold steel, and production machine settings. A manufacturer can control by rotating the molds through the production machine(s) on an appropriate schedule so that all molds experience approximately the same amount of wear on the inside of the mold cavities. The manufacturer can also hold a larger mold out of the rotation until the smaller

(newer) molds wear sufficiently to match its size. An initial, baseline measurement of all mold cavities provides starting point for documenting and planning for mold cavity growth.

4. The manufacturer should state the number of molds and a mold rotation plan with a statement of how often mold cavities will be measured during production, as well as the method of recording and reporting, and the criteria for mold rotation. While mold cavity wear will vary depending on a number of factors, approximately 0.1 mm wear of the mold cavities can typically be expected for every 10,000 cycles. Production records for each bundle should show the date of manufacture, a mix design designation, mold number, mold cycles and sequential bundle numbers.

A large variation in cluster size can reduce mechanized paving productivity, thereby increasing costs and lengthening production schedules. Extreme variations in cluster size can make mechanical installation impossible. Following certain procedures during manufacture will reduce the risk of areas of cluster sizes that will not fit easily against already placed clusters. Such procedures include (1) consistent monitoring of mold cavity dimensions and mold rotation during manufacture, (2) consistent filling of the mold cavities, (3) using a water/cement ratio that does not cause the units to slump or produce "bellies" on their sides after the pavers are released from the mold, and (4) moderating the speed of production equipment such that pavers are not contorted or damaged. All of these factors are monitored by regular measurement of the cluster sizes by the manufacturer and the subcontractor.

It is essential that at least two identical jigs be used to check cluster dimensions, one in the paver production plant and the second on the job site. The manufacturer should provide these two jigs. The jigs should check the overall length and width of assembled, ready-to-place clusters. The sampling frequency should provide at least a 95% confidence level and the frequency should be agreed upon in writing by the owner, GC, subcontractor and manufacturer.

In no case should the "stack test" be used as a means for determining dimensional consistency. This test consists of stacking 8 to 10 pavers on their sides to indicate square sides from a stable column of pavers, or leaning and instability due to bulging sides or "bellies." It is a test for checking for bellied pavers, thereby providing a quick field determination of the possibility of pavers that may not be capable of being installed with mechanical equipment. It is an early warning test to indicate the possibility of installation problems from bellied pavers (Probst 1998). The stack test is not reliable and should not be substituted for actually measuring the pavers to see if they meet specified tolerances.

The mold pattern, the mold rotation plan and the anticipated mold wear information should be reviewed and submitted by both the manufacturer and the paver installation subcontractor. This is necessary to insure that they have a common understanding and expectations.

The subcontractor's quality control procedures include, but are not limited to the following:

1. Demonstrate past use of mechanical installation by key staff on single projects having a similar application and loads.
2. Provide mechanical installation project history including references in writing with contact information for verification. The history and references should demonstrate ability to perform the paver installation and related work indicated in the plans and specifications to the satisfaction of the engineer.
3. List the experience and certification of field personnel and management who will execute the work.
4. Provide personnel operating mechanical installation and screeding equipment on job site with prior experience on a job of similar size.
5. Report methods for checking slope and surface tolerances for smoothness and elevations.
6. Show a means for recording actual daily paving production, including identifying the site location and recording the number of bundles installed each day.
7. Show diagrams of proposed areas for storing bundles on the site, on-site staging of storage and use, and the starting point(s) of paving the proposed direction of installation progress for each week of paving. These should be made in consultation with the GC as site conditions that effect the flow of materials can change throughout the project.
8. Provide the number of paver installation machines to be present on the site, and anticipated average daily installation rate in square feet (m^2).
9. Provide a diagram, including dimensions, of the typical cluster or layer to be used.
10. Provide a diagram of the laying pattern used to join clusters including a statement about or illustration of the disposition of half-pavers, if any.
12. The subcontractor and manufacturer are encouraged to hold memberships in the Interlocking Concrete Pavement Institute.

1.4 Mock-Up

A requirement for a test area or mock-up may or may not be included in the project specification documents. If required in the specifications, the mock-up shall serve as an example of compliance with the construction documents. The mock-up may be constructed prior to the start of construction or may be part of the first days work.

The mock-up:

1. Install a minimum of 10 ft x 10 ft (3 x 3 m) paver area.
2. Use this area to determine the surcharge of the bedding sand layer, joint sizes, lines, laying pattern(s), color(s) and texture of the job.
3. Evaluate the need for protective pads when compacting paving units with architectural finishes.
4. This area will be used as the standard by which the work will be judged.
5. Subject to acceptance by owner, mock-up may be retained as part of finished work.

6. If mock-up is not retained, remove and properly dispose of mock-up.

Although a mock-up can be a valuable tool, it does not guarantee workmanship or quality. A collaborative effort between the contractor, specifier and owner is the best way to assure a successful project. A site visit and inspection of the installation during the first day of paving is often a much better solution to a mock-up from financial and expediency perspectives. In either case, the owner's representative shall provide the contractor with a written statement of approval.

1.5 Delivery, Storage And Handling

All required testing for products or materials should be completed and the results submitted in writing for approval by the engineer prior to delivery of that product or material to the site. Materials should arrive at the site with no damage from hauling or unloading, and be placed on the site according the Quality Control Plan. Each bundle of pavers should be marked with a weatherproof tag that includes the manufacturer, the date of manufacture, the mold number, the project (or project phase), for which the pavers were manufactured, and the sequential bundle number. The sequential number should be applied to the bundle based on the manufacturing run for the job, not on the order of delivery. Any breaks in numbering should be reported immediately by the manufacturer to the subcontractor, GC and engineer in writing.

Bedding and joint sand delivered to the site should be covered and protected from wind and rain. Saturated bedding cannot be installed because it will not compact. Environmental conditions precluding installation are heavy rain or snowfall, frozen granular base, frozen sand, installation of pavers on frozen sand, and conditions where joint sand may become damp so as to not readily flow into the joints.

2.0 PART 2—PRODUCTS

2.1 Concrete Pavers

In North America, concrete pavers should meet ASTM C 936 (ASTM 2008.) in the United States or CSA A231.2 (CSA 2006) in Canada. Besides supplier information, the color(s), plus the exact length, width, and height dimensions of the units should be stated. Spacer bars are required for mechanical installation and are not included in the overall dimensions. Spacer bars should protrude from the side of the paver a distance equal to the minimum allowable joint width. See Figure 4.

Nominal Thickness	Multiply Tested Compressive Strength by
3 1/8 in. (80 mm)	1.18
4 in. (100 mm)	1.24
4 3/4 in. (120 mm)	1.33

Table 1. Aspect Ratio Factors

ASTM C 936 includes the following requirements:

1. Absorption: 5% average with no individual unit greater than 7% per ASTM C 140 (ASTM 2001).
2. Abrasion resistance: No greater volume loss than 0.92 in.^{3} (15 cm^3) per 7.75 in.^{2} (50 cm^2) and average thickness loss shall not exceed 0.118 in. (3 mm) when tested in accordance with Test Method ASTM C 418 (ASTM 2005).
3. Compressive strength: Average 8,000 psi (55 MPa), with no individual unit below 7,200 psi (50MPa) when tested according to ASTM C 140. If whole pavers are tested, an aspect ratio factor should be multiplied by the tested compressive strength per Table 1 to compensate for the height of the unit (BS 6717 1993):
4. Freeze-thaw deicing salt durability: average weight loss not exceeding 225 g/m^2 of surface area after 28 cycles or 500 g/m^2 after 49 cycles per ASTM C 1645 (2009). Freeze-thaw testing can be conducted in tap water for projects not subject to deicing salts. Furthermore, freeze-thaw testing can be omitted altogether for pavers in projects not subject to freezing.

If cut, cube-shaped coupons are tested, use the 55 MPa and 50 MPa values regardless of the initial dimensions of the paver from which the coupon was cut.

CSA A231.2 includes the following requirements:

1. Compressive strength: Average 7,200 psi (50 MPa) at 28 days with no individual unit less than 6,500 psi (45 MPa) . The CSA test method for compressive strength tests a cube-shaped specimen. This method eliminates differences in compressive strength resulting from various thicknesses of pavers.
2. Freeze-thaw deicing salt durability: average weight loss not exceeding 225 g/m^2 of surface area after 28 cycles or 500 g/m^2 after 49 cycles. Testing in a saline solution can be omitted for projects not subject to deicing salts. The CSA test uses a lower freezing temperature than the ASTM C 1645 test method.

The ASTM and CSA freeze-thaw deicing salt tests for freeze-thaw durability requires several months to conduct. Often the time between manufacture and time of delivery to the site is a matter of weeks or even days. In such cases, the engineer may consider reviewing freeze-thaw deicing salt test results from pavers made for other projects with

Figure 4. Spacer bars are small nibs on the sides of the pavers that provide a minimum joint spacing into which joint sand can enter.

the same mix design. These test results can be used to demonstrate that the manufacturer can meet the freeze-thaw durability requirements in ASTM C 936 and CSA A231.2. Once this requirement is met, the engineer should consider obtaining freeze-thaw deicing salt durability test results on a less frequent basis than stated here.

Sometimes the project schedule requires that pavers be delivered to a job site prior to 28 days. If that is the case, the manufacturer can develop strength-age curves to demonstrate the relationship of compressive strength at 3, 7, or 14 days with respect to what the strength will be at 28 days. This should be submitted to the engineer before the start of the project. Under no conditions should the pavers be opened to container handling equipment prior to achieving their 28-day compressive strength.

A key aspect of this guide specification is dimensional tolerances of concrete pavers. For length and width tolerances, ASTM C 936 allows ±1/16 in. (±1.6 mm) and CSA A231.2 allows ±2 mm. These are intended for manual installation and should be reduced to ±1.0 mm (i.e., ±0.5 mm for each side of the paver) for mechanically installed projects, excluding spacer bars. Height should not exceed ±1/8 in. (±3 mm) from specified dimensions. Dimensions should be checked with calipers.

2.1.1 Quality Assurance Testing

An independent testing laboratory typically conducts tests on the pavers and sands. The General Conditions of the Contract (typically found in Division 01 of the project manual) may specify who pays for testing. It is recommended that the GC be responsible for all testing. All test results should be provided to the engineer, GC, subcontractor, and manufacturer, and within one working day of completion of the tests. All should be notified immediately if any test results do not meet those specified. The independent testing is intended for project quality assurance. It does not replace any testing required for quality control during production.

For the initial testing frequency, randomly select 14 full-size pavers from initial lots of 25,000 sf (2,500 m^2) manufactured for the project, or when any change occurs in the manufacturing process, mix design, cement, aggregate or other materials. 25,000 sf (2,500 m^2) approximates an 8-hour day's production by one paver manufacturing machine. This can vary with the machine and production facilities. This quantity and the sample size should be adjusted according to the daily production or delivery from the paver supplier. Consult the paver supplier for a more precise estimate of daily production output. Initial sampling and testing of pavers should be from each day's

ASTM C33		CSA A23.1 FA1	
Sieve Size	Percent Passing	Sieve Size	Percent Passing
3/8 in.(9.5 mm)	100	10.0 mm	100
No. 4 (4.75 mm)	95 to 100	5.0 mm	95 to 100
No. 8 (2.36 mm)	80 to 100	2.5 mm	80 to 100
No. 16 (1.18 mm)	50 to 85	1.25 mm	50 to 90
No. 30 (0.6 mm)	25 to 60	630 μm	25 to 65
No. 50 (0.3 mm)	5 to 30	315 μm	10 to 35
No. 100 (0.15 mm)	0 to 10	160 μm	2 to 10
No. 200 (0.075 mm)	0 to 1	80 μm	0 to 1

Note: Bedding sands should conform to ASTM C33 or CSA A23.1 FA1 gradations for concrete sand. For ASTM C33, ICPI recommends the additional limitations on the No. 200 (0.075 mm) sieve as shown. For CSA A23.1 FA1, ICPI recommends reducing the maximum passing the 80 μm sieve from 3% to 1%.

Table 2. Gradation for Bedding Sand

ASTM C144		CSA A179	
Sieve Size	Percent Passing	Sieve Size	Percent Passing
No. 4 (4.75 mm)	100	5.0 mm	100
No. 8 (2.36 mm)	95 to 100	2.5 mm	90 to 100
No. 16 (1.18 mm)	70 to 100	1.25 mm	85 to 100
No. 30 (0.6 mm)	40 to 75	630 μm	65 to 95
No. 50 (0.3 mm)	10 to 35	315 μm	15 to 80
No. 100 (0.15 mm)	2 to 15	160 μm	0 to 35
No. 200 (0.075 mm)	0 to 5	80 μm	0 to 10

Note: The allowable maximum percent passing the No. 200 (0.075 mm) sieve may need to be decreased to allow for penetration of surface applied liquid joint sand stabilizer. Test penetration depths on the site mock-up area of paving.

Table 3. Gradation for Joint Sand

production at the outset of the project to demonstrate consistency among aggregates and concrete mixes.

Testing includes five pavers for dimensional variations, three pavers for density and absorption and three pavers for compressive strength (and three pavers for freeze-thaw durability if required). If all tested pavers pass all requirements for a sequence of 125,000 sf (12,500 m^2) of pavers, then reduce the testing frequency for each test to three full-sized pavers from each 25,000 sf (2,500 m^2) manufactured. If any pavers fail any of these tests, then revert to the initial testing frequency.

125,000 sf (12,500 m^2) approximates five days of production by one paver manufacturing machine. This can vary with the machine and production facilities. This quantity and the sample size should be adjusted according to the daily production or delivery from the paver supplier. Consult the manufacturer for a more accurate estimate of the five-day production output.

The entire bundle of pavers from which the tested paver(s) were sampled should be rejected when any of the individual test results fails to meet the specified requirements. Additional testing from bundles manufactured both before and after the rejected test sample should be performed to determine, to the satisfaction of the engineer, the sequence of the paver production run that should be rejected. Any additional testing should be performed at no cost to the owner. The extent of nonconforming test results may necessitate rejection of entire bundles of pavers or larger quantities. The engineer may need to exercise additional sampling and testing to determine the extent of non-conforming clusters and/or bundles of pavers, and base rejection of clusters of entire bundles on those findings.

2.2 Bedding Sand

Bedding sand gradation should conform to ASTM C 33 (ASTM 2001) or CSA A23.1 (CSA 2006) as appropriate with modifications as noted in Table 2. Supply washed, natural or manufactured, angular sand.

At the start of the project, conduct gradation tests per ASTM C 136 (ASTM 2001) or CSA A23.2A (CSA 2000) for every 25,000 sf (2,500 m^2) of wearing course or part thereof. Testing intervals may be increased upon written approval by the engineer when sand supplier demonstrates delivery of consistently graded materials.

The Micro-Deval test is recommended as the test method for evaluating durability of aggregates in North America. Defined by CSA A23.2-23A, The Resistance of Fine Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus (CSA 2004), the test method involves subjecting aggregates to abrasive action from steel balls in a laboratory rolling jar mill. In the CSA test method a 1.1 lb (500 g) representative sample is obtained after washing to remove the No. 200 (0.080 mm) material. The sample is saturated for 24 hours and placed in the Micro-Deval stainless steel jar with 2.75 lb (1250 g) of steel balls and 750 mL of tap water (See Figure 1). The jar is rotated at 100 rotations per minute for 15 minutes. The sand is separated from the steel balls over a sieve and the sample of sand is then washed over an 80 micron (No. 200) sieve. The material retained on the 80 micron sieve is oven dried. The Micro-Deval loss is then calculated as the total loss of original sample mass expressed as a percentage. ASTM D 7428 (2008) is a similar test where the test apparatus uses the same size drum and rotates at the same rpm.

Table 4 lists the primary and secondary material properties that should be considered when selecting bedding sands for vehicular applications. Other material properties listed such as soundness, petrography and angularity testing are at the discretion of the specifier and may offer additional insight into bedding sand performance.

Repeat the Micro-Deval test for every 250,000 sf

Material Properties	Test Method	Recommended Maximum or Minimum
Primary Properties		
Gradation	See Table 1 and Table 2	Maximum 1 % passing No. 200 (0.075 or 0.080 mm) sieve
Micro-Deval Degradation	CSA A23.2-23A ASTM D 7428	Maximum 8%
Constant Head Permeability	ASTM D 2434	Minimum 2 x 10^{-3} cm/second (2.83 in/hr)
Secondary Properties		
Soundness – Sodium Sulfate or Magnesium Sulfate	ASTM C 88	Maximum 7%
Silica (Quartz and Quartzite)/ Carbonate Ratio	MTO LS-616 ASTM C 295	Minimum 80/20 ratio
Angularity and Particle Shape	ASTM D 2488	Minimum 60% combined sub- angular and sub- rounded

Note 1: See “Recommended Material Properties” on page 5 of ICPI Tech Spec 17

Note 2: Bedding sand may also be selected based on field performance. Field performance is selected when the specifier or contractor assumes responsibility for the selection and performance of bedding sand not conforming to the properties in Table 4. Field performance as a selection criteria is suggested when the available local materials do not meet the primary material properties suggested in Table 4, but the specifier or contractor can demonstrate to the satisfaction of the owner (or owner’s representative), successful historical field performance. In this case the owner should specify the class of vehicular traffic, and the contractor should verify past field performance of the bedding sand under similar vehicular traffic.

Table 4. Recommended Laboratory Material Properties for Bedding and Joint Sands in Vehicular Applications 1,2

(25,000 m^2) of bedding sand or when there is a change in sand source. Test intervals for other material properties should be at every 200,000 sf (25,000 m^2) of bedding sand or higher as determined by the engineer. ICPI Tech Spec 17—Bedding Sand Selection for Interlocking Concrete Pavements in Vehicular Applications provides additional background to these test methods and criteria.

2.3 Joint Sand

Joint sand gradation should conform to ASTM C 144 (ASTM 2002) or CSA A179 (CSA 2000) with modifications as noted in Table 3. Supply washed, manufactured, angular sand.

At the start of the project, conduct gradation test for every 25,000 sf (2,500 m^2) of concrete paver wearing course. Testing intervals may be increased upon written approval by the engineer when the sand supplier demonstrates delivery of consistently graded materials.

2.4 Joint Sand Stabilizer

Stabilization materials for joint filling sand are optional and there are two categories of materials. These are liquid penetrating and dry mix formulas including materials mixed with joint sand and activated with water. Both categories of materials achieve early stabilization of joint sand. Liquid penetrating materials should have 24-hour cure time and be capable of penetrating the joint sand to a minimum depth of 1 in. (25 mm) prior to curing. Dry mix organic or polymer additives combine with joint sand prior to placing it in the joints. These materials typically cure in a few hours after activation with water. If the need for joint sand stabilization is determined, the application rate and method should be established on the mock-up area of paving.

3.0 PART 3 – EXECUTION

3.1 Examination

The elevations and surface tolerance of the base determine the final surface elevations of concrete pavers. The paver installation subcontractor cannot correct deficiencies in the base surface with additional bedding sand or by other means. Therefore, the surface elevations of the base should be checked and accepted by the GC or designated party, with written certification to the paving subcontractor, prior to placing bedding sand and concrete pavers.

The GC should inspect, accept and certify in writing to the subcontractor that site conditions meet specifications for the following items prior to installation of interlocking concrete pavers:

1. Subgrade preparation, compacted density and elevations conform to specified requirements.
2. Geotextiles or geogrids, if applicable, placed according to drawings and specifications.
3. Aggregate, cement-treated, asphalt-treated, concrete, or asphalt base materials, thicknesses, compacted density, plus surface tolerances and elevations that conform to specified finished surface requirements.

Heavy-duty paving will often have high strength base material such as cement stabilized base, concrete slabs or asphalt. Even though these materials are used as a base layer, the construction specification must require installation of the top layer of these materials to typical surface finish tolerances. Asphalt crews, for example, may use different elevation control methods for base lifts than they do for top lifts. The base lift methods often are not as tightly controlled for grade as variations can be made up by the top lift of asphalt. If a base lift is directly under the bedding sand, a top lift may not be present, nor close surface tolerances normally expected from a top lift. Compensation for variations in base lift elevations must not be from adding more bedding sand. Special care should also be taken at edge contacts to ensure that asphalt, or other materials are installed deeply enough to allow a complete paver and sand section above.

Edge restraints should be in place before pavers are installed. Some projects can have completed edge restraints with paving activity near them while the construction schedule dictates that the opposite side of the area may see ongoing construction of edge restraints. In such cases, the GC should propose an edge restraint installation schedule in writing for approval by the engineer. All bollards, lamp posts, utility covers, fire hydrants and like obstructions in the paved area should have a square or rectangular concrete collar. The location, type, and elevations of edge restraints, and any collars around utility structures, and drainage inlets should be verified with the drawings.

Likewise, verification of a clean surface of the base surface is required, including no standing water or obstructions prior to placing the bedding sand and concrete pavers. There will be a need to provide drainage during installation of the wearing course and joint sand by means of weep holes or other effective method per the drawings, temporary drains into slot drains, dikes, ditches, etc. to prevent standing water on the base and in the bedding sand. These may be indicated on the drawings. If not, they should be a bid item provided by the GC from the paver installation subcontractor. All locations of paver contact with other elements of the work should be inspected, including weep holes, drain inlets, edge restraints, concrete collars, utility boxes, manholes and foundations. Verify that all contact surfaces with concrete pavers are vertical.

Areas where clearances are not in compliance, or where the design or contact faces at adjacent pavements, edges, or structures are not vertical should be brought to the attention of the GC and engineer in writing with location information. The GC should propose remediation method(s) for approval by the engineer. All such areas shall be repaired prior to commencing paver installation. Alternately, the GC may propose a repair schedule in writing for approval by the engineer.

3.2 Installation

There are a variety of ways to install interlocking concrete pavements. The following methods are recommended by ICPI as best practices. Other methods vary mainly in the techniques used for compaction of the pavers and joint sand installation. ICPI recommends using a vibrating plate compactor on concrete pavers for consolidation of bedding and joint sands. Other methods that have been used under specific project conditions including vibrating steel rollers and applying water to move sand into the joints.

The bedding sand installation begins by screeding a uniform layer to a maximum 1 in. (25 mm) thickness. Maintain a uniform thickness within a tolerance of ±1/4 in. (±6 mm). Allow for consolidation due to compaction of the pavers, typically 3/16 in. (5 mm), and an additional 3/16 in. (5 mm) for paver surfaces above curbs and utility structures. For example, if the pavers are 3 1/8 in. (80 mm) thick, the elevations of the base surface should be 3 3/4 in. (95 ± 5 mm) below the finish elevation of the pavement. The exact amount of consolidation will vary depending on local sands and this is determined in the mock-up. Do not fill depressions in the surface of the base with bedding sand, as they may reflect to the paver surface in a few months.

Variations in the surface of the base must be repaired prior to installation of the bedding sand. The screeded bedding course should not be exposed to foot or vehicular traffic. Fill voids created by removal of screed rails or other equipment with sand as the bedding proceeds. The screeded bedding sand course should not be damaged prior to installation of the pavers. Types of damage can include saturation, displacement, segregation or consolidation. The sand may require replacement should these types of damage occur.

Installation of the concrete pavers starts with securing string lines, laser lines or snapping chalk lines on the bedding course. These or other methods are acceptable to maintain dimensional control in the direction of paving. These lines are typically set at 50 ft. (15 m) intervals for establishing and maintaining joint lines at maximum allowable width of clusters. The installation subcontractor will determine exact intervals for lines.

A starting area may need to be placed by hand against an existing curb. This will establish coursing, squareness of the pattern, and offset of the mechanical installed layers. Interlocking patterns such as herringbone patterns are recommended for port pavements. The orientation of the pattern is typically governed by the site operational layout and orientation should be included in the drawings. An angular laying face (or faces) should be maintained with the laid clusters creating a saw tooth pattern. This will facilitate rapid installation and adjustment of clusters as laying proceeds. Figure 7 illustrates this pattern for the laying face.

Bundles of pavers are positioned by the laying face and machines pick from them as laying proceeds. Straight joint lines are maintained by adjusting clusters and pavers with rubber hammers and alignment bars. If the cluster pattern is shipped to the site with half-sized paver units, adjust their locations, or remove them and fill openings with full-sized pavers so that each cluster is stitched and interlocked with adjacent clusters into the designated laying pattern. There may be paver layers that do not require the removal of half pavers if the layers are installed in a staggered fashion. The resulting final pattern should be illustrated in the method statement in the Quality Control Plan. As paving proceeds, hand install a string course of pavers around all obstructions such as concrete collars, catch basins/drains, utility boxes, foundations and slabs.

Pavers are typically cut with powered saws. Cutting pavers with mechanical (non-powered) splitters for industrial pavement is an acceptable method as long as the resulting paver meets project tolerances for squareness and surface variations, as well as specified joint widths. Do not allow concrete materials emitted from cutting operations to collect or drain on the bedding sand, joint sand or in unfinished joints. Figure 8 shows a cutting with a dust collection system to prevent contamination of surfaces. If such contact occurs, remove and replace the affected materials.

Whenever possible cut pavers exposed to tire traffic should be no smaller than one-third of a full paver and all cut pavers should be placed in the laying pattern to provide a full and complete paver placement prior to initial compaction. Coursing can be modified along the edges to accommodate cut pavers. Joint lines are straightened and

Figure 7. Maintaining an angular laying face that resembles a saw-tooth pattern facilitates installation of paver clusters.

Figure 8. Edge pavers are saw cut to fit against a drainage inlet.

Figure 9. Initial compaction sets the concrete pavers into the bedding sand.

Figure 10. During initial compaction, cracked pavers are removed and immediately replaced with whole units.

brought into conformance with this specification as laying proceeds and prior to initial compaction. Sometimes the pattern may need to be changed to ensure that this can be achieved. However, specifiers should note that some patterns cannot be changed because of the paver shape and some paver cuts will need to be less than one-third.

Remove debris from surface prior to initial compaction and then compact the pavers using a vibrating plate compactor with a plate area not less than 2 sf (0.2 m^2) that transmits a force of not less than 15 psi (0.1 MPa) at 75 to 100 Hz (see Figure 9). After initial compaction, remove cracked or broken pavers, and replace with whole units. Figure 10 shows removal of a paver with an extraction tool. Initial compaction should occur within 6 ft. (2 m) of all unrestrained edges at the end of each day.

After initial compaction of the pavers, sweep and vibrate dry joint sand into the joints until all are completely filled with consolidated joint sand (see Figures 11 and 12). The number of passes and effort required to produce completely filled joints will vary based on many factors. Some of these include sand moisture, gradation and angularity, weather, plus the size, condition and adjustment of the vibrating plate, the thickness of the pavers, the configuration of the pavers and the skill of the vibrating plate operator.

Joint sand should be spread on the surface of the pavers in a dry state. If it is damp, it can be allowed to dry before sweeping and vibration so it can enter the joints readily. Vibration and filling joints with sand to within 6 ft. (2 m) of any unconfined edge at the end of each day.

The various activities of the crews should be scheduled so that the paver surface is completed each day. This is the best practice. The surface should be placed to specified tolerances with all cut pavers in place before initial compaction, and the joints completely filled after the final compaction. This provides the maximum protection from weather and vehicles. Moreover, once an area is completed, inspected and accepted, it can be put to immediate use by the owner.

Coordination and Inspection—Large areas of paving are placed each day and often require inspection by the engineer or other owner's representative prior to initial

Figure 11. Sweeping jointing sand across the pavers is done after the initial compaction of the concrete pavers.

Figure 12. Final compaction should consolidate the sand in the joints of the concrete pavers.

and final compaction. Inspection should keep up with the paving so as to not delay its progress. There may be the occasional case where there inspection is not administered on a timely basis. In such unlikely cases, the engineer should decide the total allowable uncompacted area. It should be based on the daily production of the subcon- tractor, inspection schedules, and weather. Therefore, the engineer may establish a maximum distance from the lay- ing face for uncompacted pavers that relates to the timing of inspection. For work in rainy weather, the 6 ft. (2 m) distance should be maintained, regardless of the timing of inspection. Rainfall will saturate the bedding sand under uncompacted pavers with no sand in the joints. This con- dition makes the bedding course impossible to compact.

3.2.1 Joint Sand Consolidation

After the final compaction of the joints in the sand, filling and consolidation of the joint sand should be checked by visually inspecting them. Consolidation is important to achieving interlock among the units. Consolidation also reduces infiltration of water into the sand and base. This can be done by dividing the project into areas of about 5,000 sf to 10,000 sf (500 to 1,000 m^2). Visually and physically inspect each area by taking at least 30 mea- surements of joint sand depth and consolidation. Take measurements by inserting a thin, rigid putty knife into the joint and pressing down. See Figure 13. It should not penetrate more than 1/4 in. (6 mm) when pressed firmly into the joint.

If areas are found deficient in consolidation and/or joint sand, make additional passes of a plate compactor. It should have a minimum compaction of 6,000 lbf (26 kN). Higher force compactors will be required on pavers thicker than 3 1/8 in. (80 mm). Inspect the joints again after refilling and compaction. Fill and compact until the joint sand has consolidated so that a putty knife moves less than 1/4 in. (6 mm) into the joint.

Figure 13. A simple test with a putty knife checks consolidation of the joint sand.

3.3 Tolerances on Completion

The minimum joint width is determined by the size of the spacer bar used for the project. This is typically 1/16 in. (2 mm). The maximum joint width depends on the paver shape and thickness. Generally, thicker pavers with more than four sides (dentated) will require slightly larger joints, often as much as 1/4 in. (6 mm).

Recommended tolerances are as follows:

1. Joint widths: This depends on the paver thickness. For 3 1/8 and 4 in. (80 and 100 mm) thick pavers, 1/16 to 3/16 in. (2 to 5 mm) is acceptable. No more than 10% of the joints should exceed 5 mm for the purposes of maintaining straight joint lines. For 4 3/4 in. (120 mm) thick dentated pavers, the maximum joint spacing can be increased to 1/4 in. (6 mm) with no more than 10% of the joints exceeding 6 mm for the purposes of maintaining straight joint lines.
2. Bond or joint lines: ±1/2 in. (±15 mm) from a 50 ft. (15 m) string line.
3. Surface tolerances: ±3/8 in. over a 10 ft. (±10 mm over a 3 m) straightedge. This may need to be smaller if the longitudinal and cross slopes of the pavement are 1%. Surface elevations should conform to drawings. The top surface of the pavers may be 1/8 to 1/4 in. (3 to 6 mm) above the final elevations after the second compaction. This helps compensate for pos- sible minor settling normal to pavements. The surface elevation of pavers should be 1/8 to 1/4 in. (3 to 6 mm) above adjacent drainage inlets, concrete collars or channels. Surface tolerances on flat slopes should be measured with a rigid straightedge. Tolerances on complex contoured slopes should be measured with a flexible straightedge capable of conforming to the complex curves in the pavement.

3.4 Protection and Clean Up

The GC should insure that no vehicles other than those from the subcontractor's work are permitted on any pav- ers until completion of paving. This requires close coordi- nation of vehicular traffic with other contractors working in the area. After the paver installation subcontractor moves to another area of a large site, or completes the job and leaves, he has no control over protection of the pavement. Therefore the GC should assume responsibility for protecting the completed work from damage, fuel or chemical spills. If there is damage, it should be repaired to its original condition, or as directed by the engineer. When the job is completed, all equipment, debris and other materials are removed from the pavement.

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ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE ®

Tel: (703) 657-6900
Fax: (703) 657-6901
E-mail: ICPI@icpi.org
Web: www.icpi.org

Interlocking Concrete Pavement Institute
13921 Park Center Road, Suite 270
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

ICPI
INTERLOCKING CONCRETE PAVEMENT INSTITUTE

TECH SPEC

NUMBER 16

Achieving LEED® Credits with Segmental Concrete Pavement

Background

Rapidly rising energy and material costs have accelerated energy and natural resource conservation in design and construction. Sustainable development has evolved as a response and ethos to encourage conservation. It is also a framework for creating environments that enhance human existence and natural processes.

Broadly defined, sustainable development meets the needs of the present without compromising the ability of future generations to meet their needs. Within the North American design and construction community, a means for addressing sustainability or 'green building' is through LEED® or Leadership in Energy and Environmental Design. Developed by the U.S. Green Building Council (USGBC) in 1998, LEED® provides voluntary guidelines for reducing energy and wasted resources from building and site design. The Canadian Green Building Council (CaGBC) formed in 2003 published similar LEED® guidelines tailored to Canadian climates. U.S. and Canadian guidelines were developed by a range of representatives from the building industry and environmental science.

LEED® establishes a consensus-based means for measuring building and site performance. It promotes designs that integrate energy and resource conservation. LEED® is being applied to many publicly funded projects and a growing number of private ones. A primary objective of LEED® is to help facility owners reduce maintenance and life-cycle costs. This is accomplished by including all players in an integrated development process during the design stages of a project.

Figure 1. Sustainability for buildings extends to the site with sustainable paving that promotes infiltration and reflects radiant heat from sunlight.

Contents

Purpose

LEED® rating systems have been developed or are under development for:

- New Commercial Construction and Major Renovation projects (NC)
- Commercial and Retail Interiors
- Core and Shell
- Homes
- Neighborhood Development
- Schools, Healthcare and Retail
- Existing Building Operations and Maintenance

This publication provides guidance on applying the rating system for New Commercial Construction and Major Renovation projects or LEED-NC to the family of segmental concrete pavement products. This family includes interlocking concrete pavements, permeable interlocking concrete pavements, concrete grid pavements and precast concrete paving slabs. The products can also be used to satisfy the requirements in the other rating systems listed above.

LEED-NC version 3 is promulgated by the USGBC and the 2009 NC and CS (Core & Shell Development version) by the CaGBC. Excerpts from each version that relate to segmental concrete pavement are presented in this technical bulletin with application guidance. Each version has similar evaluation criteria for sustainable design and some minor differences. Readers should check with www.usgbc.org and www.cagbc.org for the most current versions including the LEED® Reference Guide (USGBC 2009).

The LEED® Process

The decision to apply for LEED® certification must occur early in the design process. The project owner and designers evaluate categories and associated criteria explained in the rating categories below for compatibility with the project, architectural program, budget and resulting environmental impact. This enables energy and cost-saving synergies for site and building design decisions.

To start the LEED® certification process, the project is registered on the USGBC or CaGBC web site with payment of a fee based on the total area of the project plus a registration fee. The web site specifies materials to be submitted such as project plans and documentation. The person seeking LEED® certification is sent a project checklist to evaluate aspects of the project might be eligible for LEED® credits. A letter template is also provided to help standardize documentation of credits. The registration fee enables access to the member-only parts of the web site and to access to the history of credit interpretations.

LEED® documentation can come from all involved on the project team including product manufacturers, contractors, cost estimators, specification writers and designers. Responsibility for managing this process will vary with each project. However, this effort is often coordinated by a LEED® Accredited Professional, one who has taken a course sponsored by USGBC or CaGBC and an exam on the credits and their requirements.

Once documentation is submitted with the LEED® application, they are reviewed for acceptance for LEED® credits. Additional documentation can be requested from the USGBC (or CaGBC) as needed and the project team has a specified amount of time to provide this. Final certification is granted within 30 days of receipt of all necessary documentation. LEED® certificates and a plaque are issued to the project design team.

LEED® Credits

For new commercial construction or LEED®-NC, the US and Canadian Green Building Councils grant certification based on the same number of points earned from each rating system. The minimum number of required points is 40. Higher ratings are shown in Table 1.

Table 1. LEED®-NC Points

Level	Points
Certification	40-49
Silver	50-59
Gold	60-79
Platinum	80 or more

New projects and major renovations earn points from six broad rating categories with specific subcategories. The major categories include:

- Sustainable Sites
- Water Use Efficiency (for building)
- Energy and Atmospheric Pollutants
- Materials and Resources
- Indoor Air Quality
- Innovative Ideas and Designs

The two primary categories that pertain to segmental concrete paving are Sustainable Sites and Materials and Resources. Within these categories, there are several subcategories for rating various aspects of the building and site for LEED® points. Key requirements and application guidance are provided in this bulletin. Blue typeface is quoted from the USGBC and CaGBC Reference Guides. The reader is encouraged to obtain the full documents and review them thoroughly.

LEED® in Specifications and Project Management

Upon registering a project for LEED® certification, a project checklist is provided by the USGBC or CaGBC that lists all of the LEED® credits in a table. The project is compared to the applicable LEED® credits thereby identifying which credits will require the appropriate documentation or tests. This evaluation helps scope the level of certification to be attained by the project. Generally, the higher the certification, the more effort is placed into documentation and into building and site systems that comply with LEED® requirements. The LEED® project checklist can also be used to identify responsibility among the architect, contractor or owner for complying with applicable credits.

Besides identifying which parts of the building or site could comply with LEED® requirements, the project checklist identifies which sections of the specification will need to be written to include LEED® requirements, and into Part 1, 2 or 3 of each Section in the project specifications. Division 01, General Conditions should include the owner's goals for achieving LEED® credits, substitution procedures for green building products that contribute to LEED® points, submittal procedures (which may be covered in greater detail for each product in the relevant specifications sections), and a waste management plan. Submittals should occur before construction begins and substitutions should be conducted at the bid stage rather than during construction. The latest specification formats include sections for specifying sustainable building products.

Specific requirements and procedures for compliance to LEED® credits for segmental concrete paving products for sustainable sites and materials and resources should be included in the specifications. Examples include a letter from the manufacturer stating the recycled content of the paving units could be a required submittal, waste management goals, or drainage calculations showing the required reduction of stormwater runoff contributed by permeable interlocking concrete pavement or grid pavements. If segmental paving is indoors and sealed, or the joint sand stabilized with a liquid, such materials should comply with indoor air quality construction requirements in LEED®.

Many projects have a pre-bid conference where the scope of the project is presented with details on the bid documents. The person running the conference should be familiar with LEED® goals for the project and also review submittal requirements and substitution request procedures with prospective bidders. During construction, the owner's representative or contractor should appoint someone responsible for enforcing the contract provisions pertaining to achieving LEED® requirements and documentation. The importance and role of this person should be presented at the pre-bid conference. This person could be responsible fulfilling contractor related items on the project checklist.

The additional project cost for compliance to LEED® certification is small and segmental concrete paving products used in the normal course of project design (roads, plazas, sidewalks, roof decks, etc.) can earn LEED® credits. Higher levels of certification (Silver, Gold, etc.) will likely increase project costs. However, the initial investment in sustainable design and construction should be returned to the owner in lower maintenance costs during the life of the building and site. When properly designed and installed, segmental concrete pavement has very low maintenance.

Life Cycle Assessment

According to Trusty and Horst (Trusty), "LCA is a methodology for assessing the environmental performance of a service, process, or product, including a building, over its entire life cycle. Although the technique is still maturing, especially the aspects dealing with ultimate impacts on human and ecosystem health, it has become the recognized international approach to assessing the comparative environmental merits of products or processes." LCA includes goal and scope definition, inventory analysis, impact assessment, and interpretation of social, environment and economic impacts of a project. The method is described in detail in the ISO 14000 series of standards (see ISO references). LCA has been used by major corporations to reduce costs for products through creating efficiencies that generate less impact on human and natural systems.

LCA consists of analyzing environmental impacts of a product or system. Impacts are weighted and their weightings are justified as part of the analysis. The impacts include:

- Global warming (from greenhouse gases)
- Acidification (typically from acid rain)
- Eutrophication (aging of water bodies through excess nutrient intake)
- Fossil fuel depletion
- Indoor air quality

- Habitat alternation
- Water intake
- Criteria air pollutants
- Smog
- Ecological toxicity
- Ozone depletion
- Human health

LEED® has developed a process that integrates LCA into their credit system. The credit is entitled Pilot Credit 1: Life Cycle of Building Assemblies and Materials. This methodology was developed for evaluating the environmental impacts of building structure and envelope assemblies. It can be used to evaluate roofing systems that include segmental concrete pavement systems. The current method develops an LCA score from an environmental impact calculator or EcoCalculator developed by the Athena Institute and USGBC credit calculator. LCA scores are then converted into LEED® points. For more information visit www.usgbc.org.

While this pilot LCA approach has not yet expanded to include site assemblies such as pavement, the user can develop an LCA-based rationale and receive points for non-structural and non-envelope materials. One point can be earned for assembly materials (such as pavements) that meet the requirements of Materials and Resources Credit 4 for recycled content. Another point is available for assembly materials that meet the requirements of Materials and Resources Credit 5 for regional materials. LEED® is expected to include LCA into building site and neighborhood rating systems in the next three to five years.

LCA is incorporated into British and European green building guides. The British Green Guide to Specification (BREAM 2009) is an LCA based methodology for assessing the human and environmental impacts of many building systems. Consideration is given to impacts from "cradle to grave" or from the energy used to extract natural resources to make the products, as well as manufacturing and recycling impacts. The Green Guide uses an A, B, C rating system where an A rating notes a low environmental impact, B is moderate and C is high. Table 2 illustrates the evaluation criteria and ratings of various pavement types with segmental concrete products receiving favorable ratings.

Another LCA example was conducted in Germany in 2009 (BFT 2009) which compared cradle to grave energy use and pollutants from asphalt pavement, interlocking concrete pavement, clay brick paving and natural stone paving. The study compared the base and surface paving materials in typically used in a parking lot or residential street over their life (typically 30 years). The research was sponsored by the SLG Precast Concrete Association and the Beton (Concrete) Marketing Deutschland GmbH. The results found that inter-

Table 2. British Green Guide Life Cycle Assessment Rating of Various Pavement Materials

Environmental Impacts	Summary Rating	Climate change	Water Extraction	Mineral resource extraction	Ozone Depletion	Human Toxicity	Ecotoxicity to fresh-water	Nuclear waste	Ecotoxicity to land	Waste Disposal	Fossil Fuel Depletion	Eutrophication	Photochemical ozone creation	Acidification	Typical replacement interval, years	Embodied CO2 (kg CO2 equivalent)	Recycled content, kg	Recycled content, %	Recycled currently at EOL %
Weightings, %		21.6	11.7	9.8	9.1	8.6	8.6	8.2	8.0	7.7	3.3	3.0	0.2	0.05					
Paving Type																			
Asphalt, 85 mm	A	A	A+	B	B	A+	A	A	A+	A+	D	A+	A+	A+	35	45	7.5	2	51
Clay pavers, 50 mm	A	B	A+	B	A	E	A	C	A	A	A	B	A+	A	60	70	0	0	90
Concrete pavers, 60 mm	A	A	A+	B	A+	A+	B	B	A	A	A	A+	A+	A+	60	57	6.6	1	90
Concrete paving slabs, 60 mm	A	A	A+	A	A+	A+	A	A	A	A	A+	A+	A+	A	60	47	6.8	2	90

All surfaces are on a prepared base

Application is lightly trafficked areas

Last 4 columns: assessed per square meter

EOL = End of Life

locking concrete pavement had the lowest energy use and pollution potential. The study made reasonable assumptions about pavement sources, manufacturing, hauling distances, and construction methods/equipment, as well as rehabilitation and recycling. Table 3 illustrates the LCA results in for a 1000 sf (100 m^2) area of each paving. The LCA for the natural stone was sensitive to transportation distances which can be significant for imported stone sources.

Other Evaluation Systems

Besides LEED®, there are other environmental assessment programs such as Green Globes (www.greenglobes.com). According to their web site Green Globes has an on-line auditing tool that enables designers, property owners and managers to assess and rate existing buildings against best practices and standards for sustainable design. Evaluations are done by those using their web site and third party assessments are at the user's option.

Table 3. Life cycle analyses results for various pavement systems in Germany (BFT 2009)

	Asphalt pavement	Interlocking concrete pavement	Brick paving	Natural stone paving
Primary energy consumption, non-renewable (MJ)	117,903	44,347	87,513	46,839
Primary energy consumption, renewable (MJ)	608	3,343	913	596
Global waming potential GWP (kg CO_2e)	4,040	3,169	5,485	3,025
Ozone depletion potential ODP [kg R11-equivalent]	1.19 E-04	1.24 E-04	1.74 E-04	1.19 E-04
Acidification potential EP [kg SO_2-equivalent]	12.8	9.72	15.6	16.3
Eutrophication potential EP [kg PO_4-equivalent]	1.60	1.38	1.91	1.93
Summer smog potential POCP [kg ethylene equivalent]	5.68	0.98	1.57	1.24

Abbreviations: megajoule (MJ), CO_2 equivalent (CO_2e)

Tech Spec Guide

icpi

Interlocking Concrete Pavement Institute®

Your requested ICPI Tech Spec 20 follows this page.

Design and Installation Professionals frequently turn to interlocking concrete pavements and permeable interlocking concrete pavements because they offer lower initial and life cycle costs and provide environmentally sustainable solutions.

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Tech Spec 20

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Construction of Bituminous-Sand Set Interlocking Concrete Pavement

Although sand-set applications represent the majority of interlocking concrete pavements with a flexible base, there are times when a project benefits from a bitumen-sand setting bed or a rigid concrete base. Bitumen-sand set applications on a rigid concrete base have a proven track record of superior performance under heavy vehicular traffic, especially in urban settings. Such applications include crosswalks and intersections subject to concentrated truck traffic. This type of rigid pavement construction has replaced mortar or sand-cement bedding materials in many pedestrian applications and in all vehicular ones. Mortar set pavers have not performed well under vehicular traffic and are not recommended. In addition, mortar-set pavers should not be used in pedestrian applications exposed to freeze-thaw and deicing salts. Mortar tends to deteriorate in such environments.

Bitumen-sand set applications emerged some thirty years ago from the defunct Hastings Brick Company in New York. This setting technique was used as a means to differentiate the Hastings clay brick paving system to win project specifications. Over the years, bitumen-sand set paving specifications moved into concrete paver project specifications and have seen many derivations in architectural specifications. This *Tech Spec* provides current and proven installation techniques.

Typical Cross Section —Bitumen-sand set applications for vehicular traffic consist of $3\frac{1}{8}$ in. (80 mm) thick pavers set on a nominal $\frac{3}{4}$ in. (20 mm) thick bitumen-sand setting bed for particles up to $\frac{1}{4}$ in. (6 mm). If the maximum particle size is $\frac{3}{8}$ in. (9 mm) then the bitumen-sand setting bed should be increased to to $1\frac{1}{8}$ in. (28 mm) or 3 times the largest particle size.

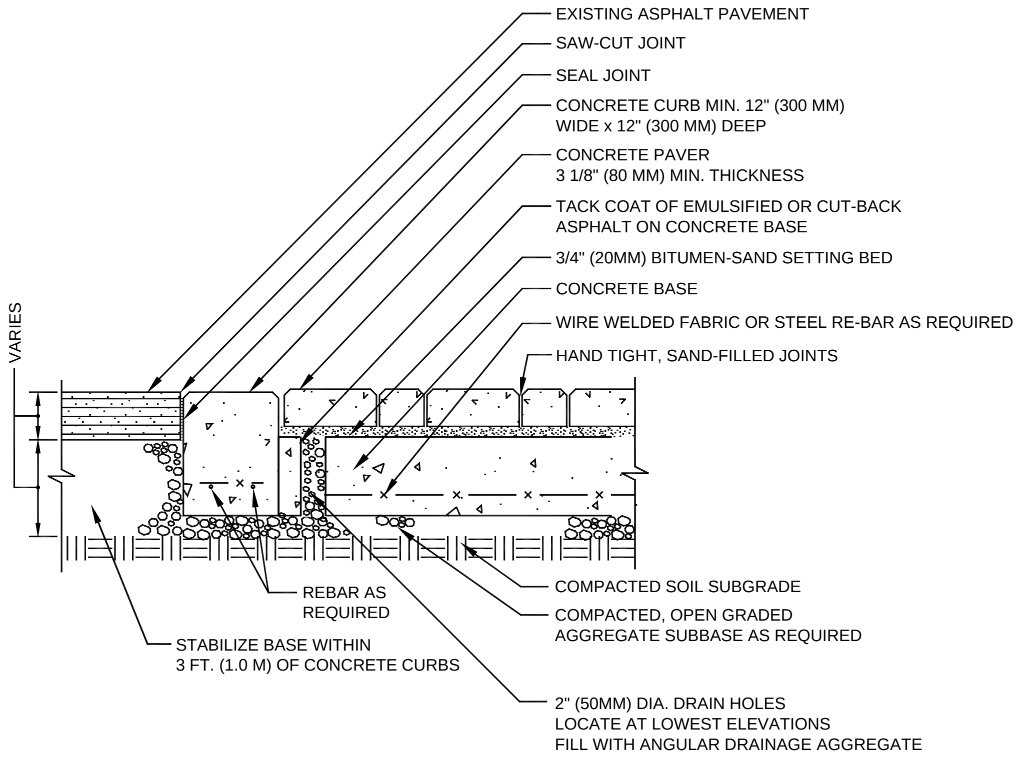
Neoprene-modified asphalt adhesive is applied to the surface of the thin setting bed and bonds the pavers to it. The setting bed rests on a thin layer of emulsified asphalt spread over a concrete base. The emulsified asphalt provides additional adhesion of the bitumen-sand bedding to the concrete. Figure 1 shows a typical crosswalk section.

The concrete base is designed to support anticipated traffic. Unlike interlocking concrete pavers on a flexible aggregate base, those on concrete bases are typically given little or no credit for their structural contribution to the pavement cross section. The concrete base distributes wheel loads to a subbase and the soil subgrade. For bituminous-sand set applications, concrete bases are recommended in vehicular and pedestrian areas. Asphalt bases should only be used in pedestrian areas.

The tack coat enhances the bond of the setting bed to the underlying base. For residential and pedestrian applications with no vehicular traffic, the tack coat may be omitted. Typical highway tack coat materials can be used, including diluted asphalt emulsions. The type of tack coat will be based upon the environmental conditions and the procedure used by the installer. Emulsified asphalt should comply with ASTM D977, such as Type SS-1 or SS-1h.

In most cases, the tack coat material will be supplied in pails or drums. They should be stored in accordance with the manufacturer's directions and be thoroughly mixed before application.

The bituminous setting bed is a mixture of asphalt cement and coarse sand (or fine aggregate). In most cases the maximum particle size should be less than $\frac{1}{4}$ in. (6 mm). The mix detailed here may not be available from all hot mix asphalt plants and a suitable alternate will have to be selected. In these areas, it may be necessary to select a sand-aggregate mixture with a maximum particle size of $\frac{3}{8}$ in. (9 mm).



NOTES:
1. BASE THICKNESS AND REINFORCING VARIES WITH TRAFFIC, CLIMATE, AND SUBGRADE CONDITIONS.
2. CONCRETE BASE MINIMUM 2% SLOPE FROM CENTERLINE TO CURB.
3. DO NOT PROVIDE WEEP HOLES TO SUBGRADE WHEN WATER TABLE IS LESS THAN 2 FT. (0.6 M) FROM TOP OF SOIL SUBGRADE. PROVIDE DRAIN HOLES TO CATCH BASINS.

Figure 1. Typical cross section of a bitumen-sand set paver street

Hot-mix plants typically use one or two different grades of asphalt cement to suit local highway construction requirements. When available, AC 20 or AR-8000 viscosity graded asphalt cements complying with ASTM D3381 can be used. These materials have a long record of success, but are gradually being replaced with performance grade, PG 58-22, binders complying with ASTM D6373 that provide similar characterisitcs.

Although this grade of asphalt cement is used throughout the United States and Canada, other grades are available to meet local design temperatures and traffic characteristics. Areas with colder climates may use grade PG 58-28 asphalt cement, and those with hotter climates may use grade PG 70-16 asphalt cement.

Fine aggregate materials available at hot mix plants are typically natural or manufactured sands. Fine aggregates should comply with ASTM D1073. When identifying an acceptable source for the bituminous-sand bedding material, refer to local department of transportation specifications for the materials they use as the surface layer on asphalt roads.

The sand should meet the gradation requirements of ASTM C33 or CSA A23.1-FA1 and consist of clean, hard, durable particles free from adherent coatings of clay, organic matter and salts. In some areas it may be difficult to find an asphalt producer that provides a product that meets the recommended sand gradation. In these areas it may be necessary to use a mix design that has particles up to 3/8 in. (9 mm) as identified in ASTM D1073. This coarser material will have a more textured surface. The aggregate should have a verifiable history of being resistant to stripping. Manufactured sands typically have a higher stability than natural sands.

The bituminous setting bed material should be mixed at a hot-mix asphalt plant. The dried aggregates and asphalt cement are heated to the appropriate temperatures and are mixed thoroughly. This will produce a uniform mixture with all of the aggregate particles evenly coated with asphalt cement. The supplier should determine the exact proportions to achieve the best mix to suit the materials, the site and the installation conditions. Typical mix proportions are approximately 6 to 8 percent asphalt cement by weight.

The pavers are bonded to the bituminous setting bed using an neoprene modified asphalt adhesive. Typical proprietary materials contain 75 percent solids in a mineral spirit solvent. The solids consist of 2 percent neoprene, 10 percent asbestos free fibers and 88 percent asphalt. The adhesive is typically supplied in pails or drums. The material should be stored in accordance with the manufacturer's recommendations and be thoroughly mixed before application.

The concrete pavers selected for vehicular applications should comply with the requirements of ASTM C936 or CSA A231.2 with the additional requirement that the thickness tolerances be +/- $^{1}/_{16}$ in. (1.6 mm). Some manufacturers may need to gauge or grind the units to achieve this tolerance.

The joint sand should meet the gradation requirement of ASTM C33 or ASTM C144 or CSA A23.1-FA1 or CSA A179.

Pavers in bitumen-sand set applications will settle only slightly when compacted as the thin bitumen-sand bedding material is already compacted while hot. Pavers are set a few millimeters above the curb edge before compaction so that they sit just above or level with the curb after compaction. Pavers should be set higher if some settlement of the concrete base is expected, relative to the curb, due to traffic, soil settlement or both.

As with all overlays on concrete, attention should be given to draining water from the setting bed through the base. Figure 1 shows a 2 in. (50 mm) diameter drain hole pre-formed in the concrete base with plastic pipe and filled with open-graded, free-draining angular gravel. Holes are typically placed every 10 ft (3 m) along the perimeter and at the lowest elevations. While the amount of water that weeps through the bedding material is minimal, drain holes help assure its removal. If water remains on the bedding layer, the water can freeze and loosen the pavers from expansion. Care should be taken during construction to prevent clogging of the drain holes with bitumen-sand setting bed material.

Construction Sequence

Figures 2 through 12 demonstrate the bitumen-sand set interlocking concrete pavement installation sequence for a crosswalk. Once the concrete base is in place and cured for at least 24 hours, a tack coat of emulsified asphalt is applied on the concrete base (Figure 2). For maximum adhesion it is important to create a thin layer of uniform thickness. To achieve this it is best to dilute the asphalt emulsion with water at a ratio of 1:1. Estimated application rates are listed in Table 1.

Table 1. Emulsified aspha5-6lt tack coat application rate

	Concrete Base	
	[gal per 100 ft^2]	[liters per 10 m^2]
Undiluted	0.9 to 1.3	3.6 to 5.3
Diluted (1:1)	1.2 to 1.5	4.8 to 6.1
	Asphalt Base	
	[gal per 100 ft^2]	[liters per 10 m^2]
Undiluted	0.6 to 1.0	2.5 to 4.1
Diluted (1:1)	1.0 to 1.3	4.1 to 5.3

Figure 2. Emulsified asphalt tack coat is applied to a concrete base prior to applying the bitumen-sand mix.

Figure 3. Confirming the tack coat has cured and is no longer wet to the touch.

Figure 4. The hot bitumen-sand bedding material is dumped from a truck onto the concrete base.

Figure 5. While the bitumen-sand is still hot, it is screeded to an uncompacted thickness of about ¾ in. (20 mm).

Figure 6. A hand tamper is used to compact in areas that cannot be reached with the roller compactor.

Figure 7. The compacted bedding elevation at the edge is checked with a paver.

Figure 8. After the bitumen-sand mix cools, a 2% neoprene-asphalt adhesive is applied. The material can be trowel-applied as shown here. Adhesives with a lower viscosity can be spread with a squeegee.

Figure 9. Perpendicular chalk lines are snapped and the pavers placed on the adhesive after the neoprene-asphalt adhesive dries (cloudy black surface).

Figure 10. Cut pavers are added along the edges.

Best application results are typically achieved using a synthetic paint roller with a short nap. Once applied the tack coat should not be disturbed and should be allowed to cure before covering with the setting bed material. As the asphalt emulsion cures it should turn from a brown to black color (Figure 3). This may take a few hours depending on weather conditions. When using SS-1 and SS-1h asphalt emulsions the temperature should be between 70 and 160° F (20 to 70° C) to allow for proper curing. Asphalt tack coats are recommended for vehicular applications. They are typically not required in pedestrian applications.

The hot bitumen-sand bedding layer is placed, screeded to about 3/4 in. (20 mm) thick and compacted while remaining above 250° F (120° C) (Figures 4 and 5). This layer typically compacts about 1/8 in. (3 mm). The depth of this layer must be consistent. If the area does not have a curb to support a screed, screed bars are placed directly on the concrete base to guide the screed. The bars are removed immediately after screeding and the narrow void spaces left from the removed bars are filled with additional, hot bitumen-sand mix and troweled smooth. The compacted bitumen-sand bedding layer can compensate for only very small surface variations in the concrete base and cannot be used to make up for a rough surface finish on the concrete. The bitumen-sand mix is placed, screeded and compacted in one small area at a time (typically a 100 to 300 sq. ft. or 10 to 30 m^2) in order to screed and compact the mix while hot. Areas that can not be compacted with the roller compactor should be compacted with a hand tamper (Figure 6). Before spreading the asphalt adhesive it is advisable to confirm the bedding elevation using a paver (Figure 7). If it cools prior to compaction, it is impossible to compact and will require reheating prior to compaction.

A thin layer of neoprene-asphalt adhesive is then applied with a squeegee to the top of the bedding layer, and allowed to cure (typically 1 to 2 hours). Adhesives with a high viscosity are applied with a straight edged towel as shown in Figure 8. Adhesives with a low viscosity can be applied with a squeegee. The adhesive takes a hazy appearance when ready to mark baselines and place the concrete pavers (Figure 9). Only enough adhesive should be applied that will be covered with pavers in a day's work. Figure 10 shows the paver installation. Once the pavers are placed on the adhesive, they are very difficult to remove. If removed, they can pull up the adhesive and bitumen-sand bedding under the paver. Once all the pav-

Figure 11. Sweeping in joint sand

Figure 12. Once the pavers are in place, the joints are filled with dry joint sand and the surface is compacted.

Figure 13. Crosswalk in use under heavy traffic.

Figure 14. A water-filled roller compactor for compacting the bitumen-sand bedding.

ers are in place including cut units, sand is swept into the joints and pavers are compacted until the joints are full (Figures 11 and 12). For more efficient work, sand sweeping and compaction can be simultaneous. Unlike sand-set pavers, there is no need to compact the pavers without sand in the joints first. When completed, the pavement can accept traffic loading immediately (Figure 13).

Should the surface of the pavers be stained with adhesive during installation, it is very difficult to remove and fresh replacement pavers are required. In-service reinstatement of installed bitumen-sand set pavers is practically impossible because the bitumen-sand material adheres to the bottom of the pavers when removed. It is less expensive to discard the pavers rather than remove the asphalt from the units and attempt to reinstate them.

Specialty Tools —Some specialty tools are required to successfully install bitumen-sand set pavers. For example, Figure 14 shows a roller modified with a long handle welded or bolted to the frame. The drum of the roller should be smooth with no rust, preferably with sharp edges (not rounded). Other specialty tools are shown in Figures 15, 16 and 17.

Cost and Performance —Bitumen-sand set pavers are significantly more expensive (typically 30-50% higher) than sand-set pavers due to additional material and labor costs. However, the additional costs incurred with bitumen-sand set concrete pavers for vehicular traffic are often balanced with the long-term performance characteristics when compared to sand-set installations under the same wheel loads. As noted in Tech Spec 19(ICPI 2013), interlocking concrete pavement crosswalks with bituminous-sand setting beds on concrete bases were estimated to have a life span of 7.5 million ESALs.

Pedestrian Areas —Bitumen-sand set applications are sometimes used in public pedestrian areas with concrete paving slabs. Paving slabs used in sidewalks and plazas are often larger than 12 in., typically having one or both dimensions at 16, 18 or 24 in. (400, 450 or 600 mm) and are generally 1.5 to 2 in. (38 to 50 mm) thick. Often the paving units are "gauged" or ground on the bottom by the manufacturer to ensure consistent thicknesses among all the units. These types of paving slabs require a very smooth and even concrete base. A tack coat is typically not used prior to placing, screeding and compacting the hot

Figure 15. Walking on the hot bitumen-sand bedding with regular construction grade, steel-toed boots is discouraged. For limited walking on this layer, workers should wear boot sole covers shown here that resist damage and better distribute weight to prevent dentations.

Figure 16. Occasionally, uneven bedding surface occurs and it is necessary to re-heat the bitumen-sand bedding with a propane heater tool.

Figure 17. On larger projects, thick steel screed bars are placed on the concrete base to ensure a uniform bitumen-sand bedding thickness.

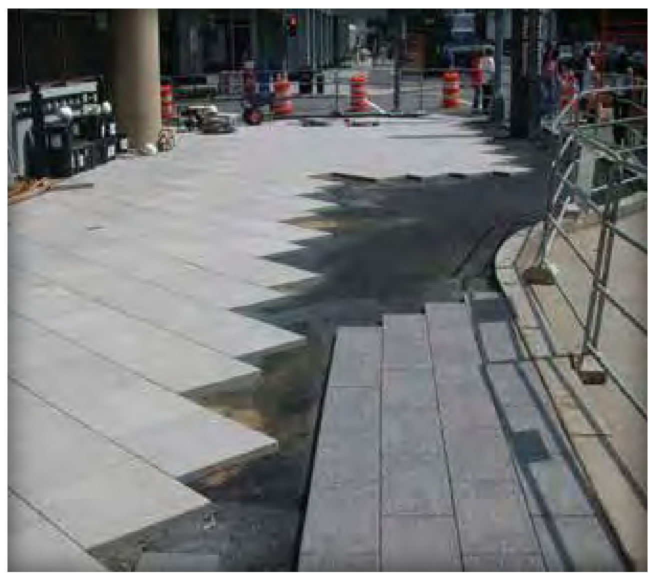


Figure 18. Paving slabs adhered to a bitumen-sand bedding in a Washington, DC, sidewalk.

bitumen-sand mix. A neoprene adhesive can be applied to the bituminous-sand bedding, after it has cooled, to create a securely bonded system. However, the adhesive can be omitted to help simplify future repair procedures. Figure 18 illustrates paving slabs placed on the adhesive over the bitumen-sand bedding. After placement of the slabs directly on the bituminous-sand or on the adhesive, the joints are typically filled with concrete sand or stabilized joint sand. The slabs are compacted with a roller compactor or small plate compactor with rollers attached to help spread the compaction force and prevent cracking of the paving slabs.

This method is superior to using a sand-cement mixture for the bedding over a concrete base as the sand-cement can be subject to deterioration from water, deicing salts and freeze-thaw cycles. Like its counterpart for vehicular applications, a bitumen-sand bedding with neoprene adhesive is more expensive, but it provides a very low-maintenance solution to rigid segmental concrete pavements, even in severe climates.

Maintenance of Bituminous-set Installations

The neoprene-asphalt adhesive bonds to the concrete pavers and bitumen-sand extremely well. This will make it almost impossible to remove from the concrete paver after it is applied, even if done so accidentally. Once installed and allowed to cure, it will be very unlikely that a paver can be removed without pulling up some of the bitumen-sand bedding material. Repair will typically require the removal and disposal of the pavers and bitumen-sand bedding and replacement with new material. Use of a propane torch as shown in Figure 16 along with a scraper may be required to soften and effectively remove the bitumen-sand from the concrete base. It is unlikely that the bitumen-sand hot mix will be available in a small batch so it may be necessary to use a fine gradation cold-patch material. Cold-patch can only be used in repairs and is not an acceptable substitution for hot-mix in the initial installation. Follow manufacturer's installation instructions. Allow the cold-patch material to fully cure before applying the neoprene asphalt adhesive.

Additional information on the repair and reinstatement is available in Refer to Tech Spec 6: Operation and Maintenance Guide for Interlocking Concrete Pavement. This reference includes information on preventative maintenance, identifying and remedying aesthetic and structural distresses and best practices for the disassembly and reinstatement of interlocking concrete pavement.

References

Refer to the latest published ASTM and CSA standards and ICPI Tech Specs.

ASTM–American Society for Testing and Materials International, Conshocken, PA. www.astm.org

CSA–Canadian Standards Association, Rexdale, ON. www.csagroup.org

ICPI–Interlocking Concrete Pavement Institute, Chantilly, VA. www.ICPI.org

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Interlocking Concrete Pavement Institute®

13750 Sunrise Valley Drive
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

Tel: 703.657.6900
Fax: 703.657.6901
E-mail: icpi@icpi.org
www.ICPI.org

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- Tech Spec 16: Achieving LEED Credits with Segmental Concrete Pavement
- Tech Spec 17: Bedding Sand Selection for Interlocking Concrete Pavements in Vehicular Applications
- Tech Spec 18: Construction of Permeable Interlocking Concrete Pavement Systems
- Tech Spec 19: Design, Construction and Maintenance of Interlocking Concrete Pavement Crosswalks
- Tech Spec 20: Construction of Bituminous-Sand Set Interlocking Concrete Pavement
- Tech Spec 21: Capping and Compression Strength Testing Procedures for Concrete Pavers
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Capping and Compressive Strength Testing Procedures for Concrete Pavers

Background

First approved in 1982, ASTM C936 Standard Specification for Solid Interlocking Concrete Paving Units (ASTM 2013) established acceptance criteria for the compressive strength of concrete pavers. Concrete pavers meeting this product standard require a minimum average of 8,000 psi (55 MPa) with no individual unit below 7,200 psi (50 MPa). Concrete paver sizes are defined in this standard as having a minimum thickness of 2^3/$_8$ in. (60 mm), an aspect ratio (length divided by thickness) not exceeding 4, and a maximum surface area of 101 in.^{2} (0.065 m^2).

ASTM C936 references the compressive strength test procedure in ASTM C140 Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units (ASTM 2014a). This test method was revised to account for differences in compressive strength due to paver thickness starting in the ASTM C140-12a revision (ASTM 2012a). Prior to this revision, compression testing of thicker concrete pavers resulted in lower measured compressive strengths than thinner ones solely due to the increased thickness of the pavers. Relationships between specimen thickness and compressive strength for concrete have been summarized by the U.S. Department of the Interior Bureau of Reclamation (Reclamation 1975). Precedence in national standards for adjusting the compressive strength of concrete pavers based on their thickness/width ratio is in the 1993 British Standards Institute standard for concrete block paving (BSI 1993).

Decreasing compressive strength due to increasing thickness is not unique to concrete; increasing the height or thickness of any material tested for compressive strength results in lower measured strengths. To address this, ASTM C140 now adjusts the compressive strength of all concrete pavers with an aspect ratio (thickness divided by width) factor to that of a 2^3/$_8$ (60 mm) by 3^7/$_8$ (98 mm) thick concrete paver. This thickness was selected because the 8,000 psi (55 MPa) compressive strength requirement was originally written for this paver thickness. The rationale and calculations for adjusting concrete paver compressive strength from paver aspect ratio (thickness/width) was developed for ASTM in ICPI research (NCMA 2010) and discussed in an ASTM publication (Walloch 2014). The guidance in this technical bulletin is based on these research reports.

Prior to testing concrete pavers in compression, their top and bottom surfaces are thinly capped with gypsum. This material is applied as a paste and allowed to cure or harden up to 24 hours prior to compression testing. This capping provides a smooth and parallel surface on the concrete paver to uni-

Figure 1. A concrete paver capped on the top and bottom with gypsum and positioned in a compressive strength machine for testing.

formly engage the platen in the compression testing machine, helping to ensure even distribution of applied loads during testing. See Figure 1. ASTM C140 Annex A4, Test Procedures for Concrete Interlocking Paving Units, provides detailed instructions on capping for the concrete pavers as well as on compressive strength testing of the capped specimens. This technical bulletin covers these procedures in a step-by-step guide that testing laboratories, paver manufacturers and specifiers can use to better understand the new testing process.

Compression Testing Procedures

The process for compressive strength testing of concrete pavers consists of seven steps. By following these steps, testing laboratories can help ensure compliance with ASTM C140 Annex A4, Test Procedures for Concrete Interlocking Paving Units.

Figure 2 provides a flow chart/decision tree for determining the dimensions of the test specimen and determining if cutting is required as detailed in Step 1. Figure 3 summarizes Steps 2 through 7 described in detail below.

Step 1–Determine the Dimensions of the Compressive Strength Specimens

ASTM C140 Annex A4 requires that full size paver test specimens must meet the following criteria:

- A smooth top surface. If there is a surface texture, the height difference between the highest and lowest

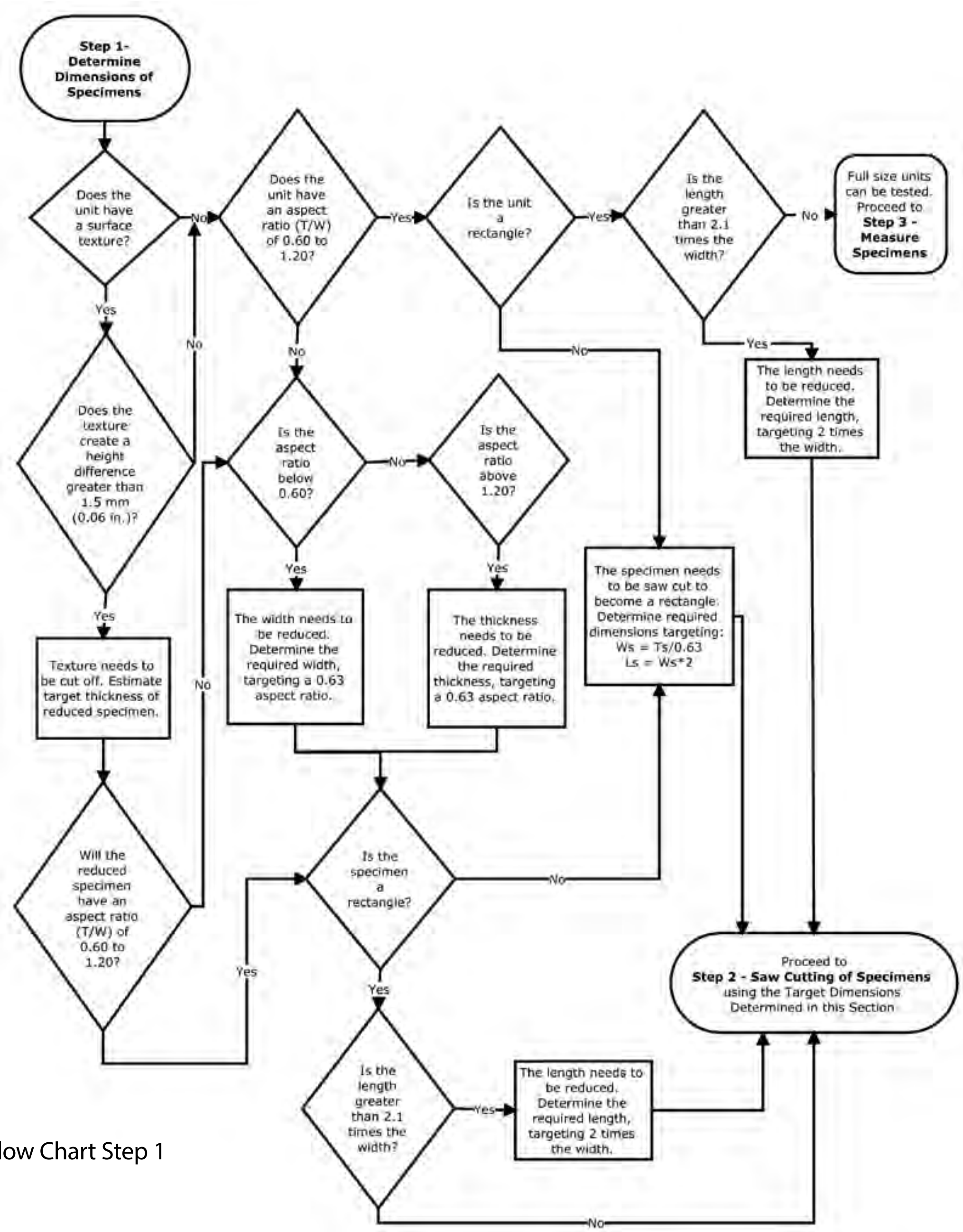


Figure 2: Flow Chart Step 1

points on the surface cannot exceed 0.06 in. (1.5 mm). Grooves on pavers that imitate joints are not allowed in the test specimens. Only chamfers intentionally manufactured into the edge of the pavers are allowed.

- An aspect ratio (thickness/width) of between 0.60 and 1.20
- Rectangular shape
- Length cannot exceed 2.1 times the width.

If the full-size test specimen meets all of the criteria listed in Step 1, then it is tested full-size. It does not require cutting and the testing technician can proceed to Step 3–Measure SpecimensIf the full-size test specimen does not meet all of these criteria, the specimen needs to be cut as described below. The testing technician should proceed as follows:

A. Some concrete pavers are textured to simulate stone surfaces. If the paver has surface texture that exceeds 0.06 in. (1.5 mm) in difference between the highest and lowest point on the surface, then the surface must be saw cut and discarded. (This also applies to grooves on pavers that imitate joints.) Prior to cutting, the technician estimates the thickness remaining

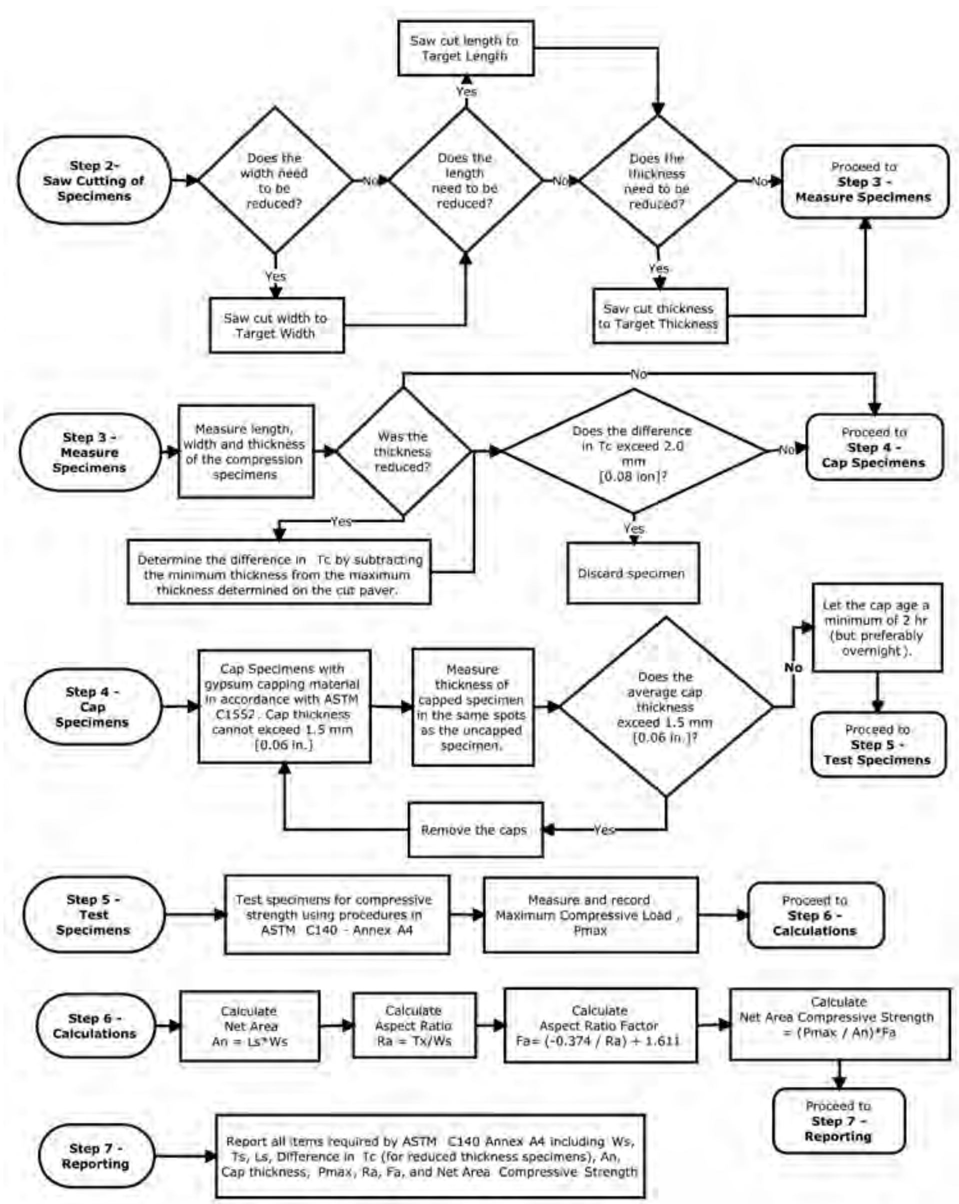


Figure 3: Flow Chart Steps 2 to 7

after saw-cutting the surface to obtain a smooth surface texture. The amount cut off is typically 0.4 to 0.6 in. or 10 to 15 mm thick. The estimated thickness of the final specimen should be used in the steps below.

B. The approximate aspect ratio (thickness/width) of the cut testing specimen should be determined prior to cutting. If the cut test specimen with no surface texture has an aspect ratio between 0.60 and 1.20, then the technician moves to step 3 below. If not, then follow the next steps:

- If the aspect ratio is below 0.60, then the paver width must be reduced by saw cutting. Determine the required width by targeting a 0.63 aspect ratio. By targeting an aspect ratio of 0.63, the final specimen likely has an actual aspect ratio of 0.60 to 0.66 and the aspect ratio factor to adjust the compressive strength test results is between 0.988 and 1.044.
- If the aspect ratio is above 1.20, then the overall thickness of the paver must be reduced with saw cutting. The technician should determine the required thickness by targeting a 0.63 aspect ratio.

C. If the paver has a rectangular shape the laboratory can then proceed to Step D. If it is not a rectangle, then a rectangular test specimen must be cut from the paver. Determine the required dimensions by targeting a width equal to the thickness/0.63 and a length equal to two times the width. If the thickness or width must be reduced, use the targeted thickness and/or width in the calculations. The technician should now have width, length and heights targets for the final specimen and can proceed to Saw Cutting Specimens

D. If the paver or test specimen is a rectangle, then the technician determines if the length is less than or equal to 2.1 times the width of the specimen. If it is less than 2.1 times the width of the specimen, the technician can proceed to Saw Cutting Specimens. If the length is greater than 2.1 times the width of the specimen, the technician should determine the required length of the specimen for saw cutting aiming for two times the length. The technician should determine the final width, length and height targets for the final test specimen and can proceed Step 2–Saw Cutting Specimens

Figure 4. Saw cutting a paver to comply with the aspect ratio (thickness/width) requirements in ASTM C140.

Step 2–Saw Cutting Specimens

Based on the above, the test specimen needs to be saw-cut from the full-size specimen. A diamond-tipped saw blade is required on a water-cooled or dry cut table saw, both with dust controls. The technician performing the cutting should be experienced in cutting concrete pavers. Figure 4 illustrates saw cutting. The saw-cutting should be performed in the following order, which typically results in the highest quality test specimen:

- If the width of the specimen needs to be reduced, make this the first saw-cut.
- If the length of the specimen needs to be reduced, make this the next saw-cut.
- If the thickness of the specimen needs to be reduced, this should be the final saw-cut. This facilitates easier handling, since cutting the thickness can be more difficult than other cuts, and extra care is required by the technician for this operation.

Once the technician has saw-cut the specimen, proceed to Step 3–Measure Specimens with the reduced-size compression specimen.

Step 3–Measure Specimens

The next step is measuring the compression specimen. When tested at full size, measure full-size specimens. When specimen sizes have been reduced by cutting per Step 2, measured these specimens as well. Make all measurements using a caliper readable to 0.002 in. or 0.1 mm and record them. The following measurements are taken for compression specimens:

- Width: measured across the top and bottom surface at mid-length
- Length: measured across the top and bottom surface at mid-width.
- Thickness: measured at mid-length on each side of the paver. If the paver has a chamfer, measure the top to the bottom surfaces of the paver without measuring the chamfer.

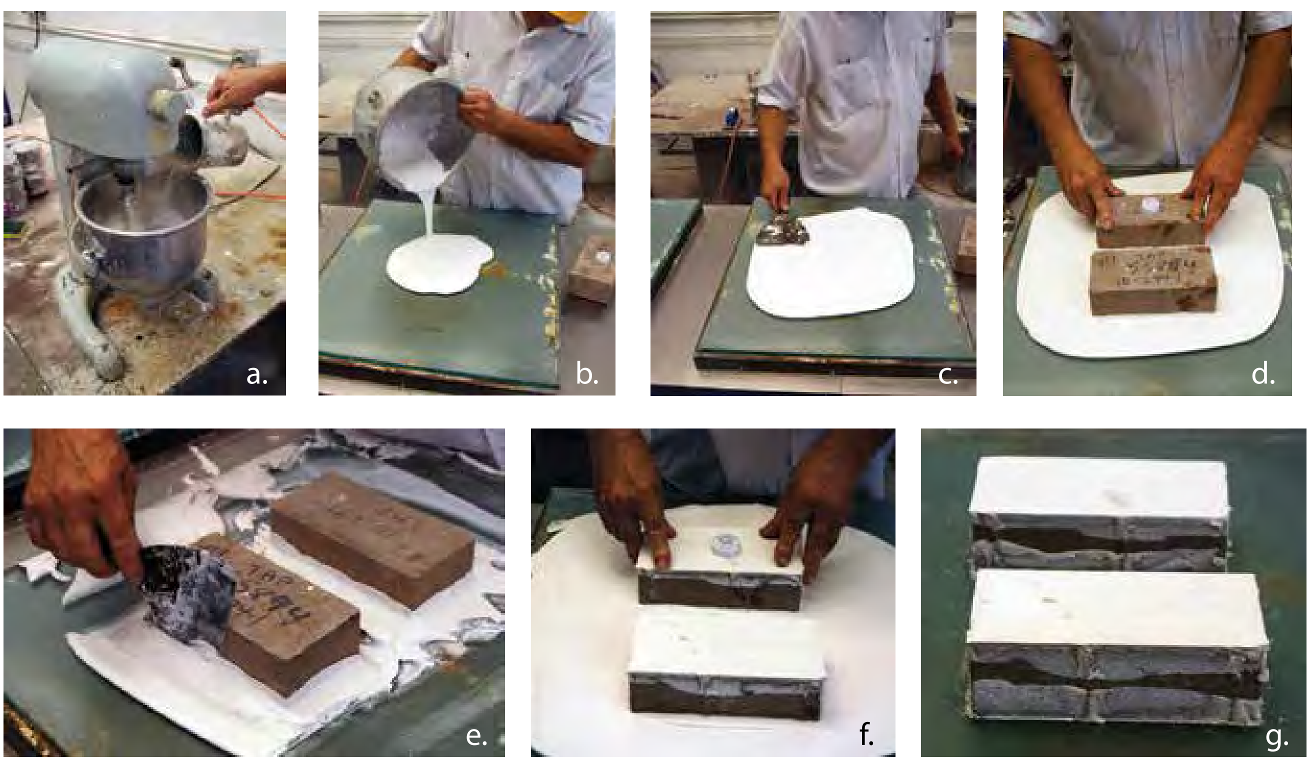
When the thickness of the units has been cut and reduced to remove surface texture or to meet the aspect ratio (thickness/width) requirements, an additional comparison is necessary. The measured thicknesses from each side of the paver must be compared. If the difference in thickness is greater than 0.08 in. (2.0 mm), this wedge-shaped unit must be discarded and a new specimen cut. A cut paver with a wedged shape results in lower compressive strengths due to force applied to only one side of the specimen. Once measurements are completed, the technician continues to Step 4–Cap Specimens

Step 4–Cap Specimens

Prior to compressive strength testing, the paving units must be capped with gypsum. Similarly, compression testing of concrete cylinders are typically capped with a sulfur-based material. Research (NCMA 2008) (Walloch 2014) investigated and compared the variability of sulfur and gypsum based capping materials on compressive strength test results. The research indicated lower variability in compression testing results by using gypsum capping. Besides limiting capping materials to gypsum for concrete pavers, the research presented additional recommendations now included in ASTM C140, Annex A4.

ASTM C140, Annex A4 now requires that paver compression specimens be capped according to ASTM C1552 Standard Practice for Capping Concrete Masonry Units, Related Units and Masonry Prisms for Compression Testing (ASTM 2014) with two additional restrictions. First, the capping material must be high-strength gypsum cement. While ASTM C1552 allows for gypsum and sulfur capping material, only gypsum is acceptable for capping concrete pavers for compressive strength testing.

Second, the final cap thickness cannot exceed 0.06 in. (1.5 mm). This is half of the allowable thickness for other caps per ASTM C1552. In order to achieve thin caps, the plastic gypsum is mixed to a consistency that simultaneously achieves two objectives: (1) sufficient fluidity for spreading thinly on the capping plate while (2) having sufficient viscosity that allows the paver surface to be pushed



Figures 5a-g. Capping test specimens: (a) Mixing the gypsum; (b) Pouring it on flat plate glass; (c) Spreading the mix; (d) Placing the pavers; (e) Removing excess material; (f) Repeating the capping procedure on the opposite surface; (g) Thin, cured caps ready for measurement into the plastic gypsum, thereby forming a consistent thin cap. The technician must also be careful not to exceed the water to cement ratio determined to provide needed capping material compressive strength. Figure 5 illustrates settng test specimens into the plastic capping material which has the consistency of thick pancake batter.

In order to determine an acceptable cap thickness after capping, the specimen is measured again for thickness after the capping has hardened. Measurements are taken in the same locations as before capping. At each point, the before capped thickness is subtracted from the capped thickness. This value is divided in half (there are two caps) and then the resulting cap thickness is determined by averaging the measurement in each location. The average cap thickness cannot exceed 0.06 in. or 1.5 mm. If the cap thickness is greater, the technician must remove the caps and repeat the capping operation.

If the caps have an acceptable thickness upon hardening, i.e., less than or equal to the maximum average thickness, the caps must age before performing compressive strength testing. The minimum time required between capping specimens and testing them is two hours, but overnight aging is preferred. The curing time begins when the second cap is placed on each paver specimen. Following curing of caps, the technician can proceed to Step 5–Test Specimens

Step 5–Test the Specimens

Perform compression testing according to ASTM C140. Center the paver specimen in the testing machine and estimate the expected load. Load each specimen to half the expected breaking load at a convenient rate. The second half of the expected breaking load is applied in no less than one minute and no longer than two minutes. Figure 4 shows the capped paver loaded and then breaking. Record the total load (P_{max}). Proceed to Step 6–Calculations

Step 6–Calculations

- Calculate the reported compressive strengths using the following procedures:
- Determine the net area, A_n, by multiplying the specimen length by its width.
- Determine the aspect ratio, R_a, by dividing the specimen thickness by its width.
- Determine the aspect ratio factor, F_a, using the following equation:

$$F_a = (-0.374 / R_a) + 1.611$$

- Determine the net area compressive strength by dividing the maximum load by the net area, then multiply-

Figure 6. Left: a capped concrete paver under load in a compression testing machine; Right: a paver tested in compression; the moment it breaks is the recorded load.

ing by the aspect ratio factor.

- The above procedures relate to the following equations and definitions of variables in C140:
  - Determine compressive strength using the following calculations:

    Net Area, mm^2 ($in.^2$) = L_s x W_s

    Aspect Ratio (R_a) = T_s / W_s

    Aspect Ratio Factor (F_a) = (-0.374 / R_a) +1.611

    Net Area Compressive Strength, MPa (psi) = (P_{ma}/A_n) x F_a

    Where:

    A_n = average net area of the specimen, mm^2 ($in.^2$)

    L_s = average length of final test specimen, mm (in.)

    W_s = average width of final test specimen, mm (in.)

    R_a = aspect ratio

    T_s = average thickness of final test specimen, mm (in.)

    F_a = Aspect Ratio Factor

    P_{max} = maximum compressive load, N (lb)

Step 7–Reporting

The following information is reported by the testing laboratory for compressive strength as required by ASTM C140 Annex A4:

- The average width, W, thickness, T, and length, L, to the nearest 0.002 in or 0.1 mm. These dimensions are reported separately for each full-sized, sampled unit and as the average for the three units tested.
- The dimensions of the compression specimens (W_s, T_s, and L_s), to the nearest 0.002 in. or 0.1 mm, if different from the full-size units. This includes the difference among the four thickness measurements taken across the face of the paver if the specimen was cut to reduce its thickness.
- The net area to the nearest 0.01 $in.^2$ or 10 mm^2 separately for each compression specimen and as the average for the three specimens tested
- The average cap thickness to the nearest 0.002 in. or 0.1 mm for each compression specimen and as the average for the set of three specimens tested
- The maximum load, separately for each specimen and as the average for the three specimens tested. Report the load as indicated to the nearest 10 lb or 50 N or the minimum resolution of the test machine as used during testing, whichever is greater.
- The aspect ratio, R_a, and aspect ratio factor, F_a, for each compressive strength test specimen.
- The net area compressive strength to the nearest 10 psi or 0.1 MPa separately for each specimen and as the average for three specimens tested.

Conclusions

Since its initial approval in 1982, ASTM C936 is being applied to a wider range of paver shapes and thicknesses. Initially, ASTM C936 did not anticipate or account for the differences in compressive strength due to various shapes, thicknesses and resulting thickness-to-width ratios. Additionally, concrete paver manufacturers indicated high variability in test results especially between different testing laboratories. This technical bulletin addresses these differences based on comprehensive testing research conducted by ICPI, review of the research and balloting of revisions to ASTM C140 and C936 by ASTM C15.03 Subcommittee on Concrete Masonry Units and Related Units and ASTM C15 Committee on Manufactured Concrete Masonry Units. This bulletin presents a step-by-step guide for use by testing laboratories to better understand ASTM requirements. In addition, the information supports more consistent test results from concrete paver manufacturers and for project specifiers and contractors.

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icpi
Interlocking Concrete Pavement Institute®

13750 Sunrise Valley Drive
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

Tel: 703.657.6900
Fax: 703.657.6901
E-mail: icpi@icpi.org
www.icpi.org

BOD Approved: September 2014

Tech Spec Guide

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- Tech Spec 19: Design, Construction and Maintenance of Interlocking Concrete Pavement Crosswalks
- Tech Spec 20: Construction of Bituminous-Sand Set Interlocking Concrete Pavement
- Tech Spec 21: Capping and Compression Strength Testing Procedures for Concrete Pavers
- Tech Spec 22: Geosynthetics for Segmental Concrete Pavements
- Tech Spec 23: Maintenance Guide for Permeable Interlocking Concrete Pavements
- Tech Spec 24: Structural Design of Segmental Concrete Paving Slab and Plank Pavement Systems
- Tech Spec 25: Construction Guidelines for Segmental Concrete Paving Slabs and Planks in Non-Vehicular Residential Applications

Tech Spec 22

Interlocking Concrete Pavement Institute®

Geosynthetics for Segmental Concrete Pavements

This Tech Spec provides fundamental information on geosynthetics including a brief history, uses, and basic applications for interlocking concrete pavements (ICP) and permeable interlocking concrete pavements (PICP). While this Tech Spec provides some general guidelines on engineered applications, it is not intended to provide geosynthetic engineering design advice. While many of the general principles and applications of geosynthetics are easily understood, the field of geosynthetics and the technical information available is too voluminous for a single technical bulletin. This Tech Spec is presented as an introduction to the wide range of geosynthetic materials available, as shown in Figure 1, for readers interested in this subject and its application to segmental concrete pavements.

The term geosynthetics derives its meaning from Greek word "geo" meaning of the earth or ground, and the synthetic referring to materials formed through a chemical process by human action rather than by nature. The term geosynthetic is defined in ASTM D4439 Standard Terminology for Geosynthetics (ASTM 2015) as "a planar product manufactured from polymeric material used with soil, rock and earth or other geotechnical engineering related material as an integral part of a man-made project, structure, or system." Geosynthetics are predominantly manufactured from polymers and may also include fiberglass, rubber, or other natural materials.

History

Various materials have been placed on or in soils under pavements for thousands of years. Compacted stones were used in roadway construction in Roman days to stabilize roadway soils and their edges. Natural fibers and fabrics were later mixed with soil to improve road quality, particularly when built on unstable soil. Such materials were also used to stabilize steep slopes and walls such as ancient ziggurats. While many of the earliest attempts to improve or reinforce soil were not recorded, there is some evidence. Some of the oldest roads in Britain utilized split logs, or a 'corduroy' road, laid over peat bogs to provide a stable platform. There is also evidence that in some cases a stabilized soil mixed with paving stones or paving blocks were placed over the corduroy road.

Obviously, natural materials in soils led to biodegradation from microorganisms. The advent of polymers in the mid-twentieth century provided longer lasting and more stable materials for pavements.

Even before the term geosynthetics existed, synthetic materials were being used in the field. In the early 1960s, the Dutch used geotextiles in the design of the Delta

Figure 1. Different types of geosynthetics

Figure 2. Different types of geotextiles

Figure 3. Geogrid examples

Figure 4. Geomembrane examples

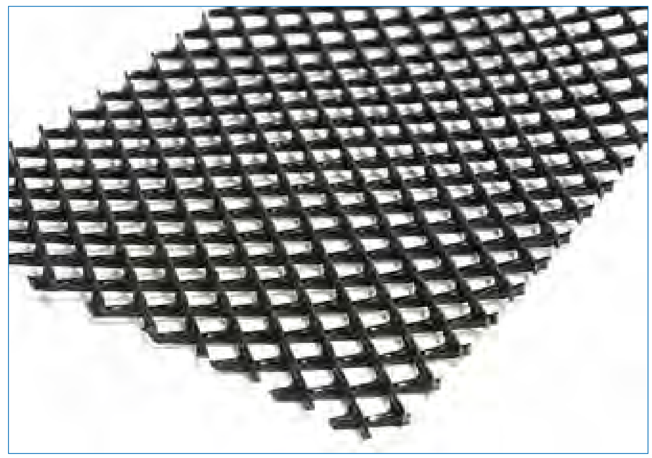


Figure 5. Geonet example

Works flood protection project as a response to deadly North Sea flooding there in 1953. The terms "geotextile" and "geosynthetics" were introduced by Dr. J.P. Giroud in a Paris engineering conference in 1977 (Kelsey 2014). Compared to other paving materials, geosynthetics have a short history of about 50 years, even though improving the load bearing capacity and strength of soil has been occurring for thousands of years.

Types of Geosynthetics

Geosynthetics can be grouped in several product categories, i.e. geotextiles, geogrids, geomembranes, geonets, geosynthetic clay liners, geopipes, geofoam, geocells and geocomposites. Polymer materials make them suitable for use in applications where high durability is required. They can also be used in exposed, above ground applications. With their range of materials and products, this enables geosynthetics to have a wide range of applications in many civil, geotechnical, transportation, geo-environmental, hydraulic, and private development applications. These include roads, airfields, railroads, embankments, retaining structures, reservoirs, canals, dams, erosion control, sediment control, landfill liners, landfill covers, mining, aquaculture and agriculture.

Geotextiles

Geotextiles form one of the two largest groups of geosynthetics. They are fabrics consisting of synthetic fibers predominantly made of polypropylene (PP) rather than natural fibers making them less susceptible to biodegradation. Synthetic fibers are made into flexible, porous sheets, made by standard weaving machinery, are called slit film, monofilament or multifilament. Another subset of geotextiles are matted together randomly and not woven. These nonwoven materials are made with processes called needle punched or heat bonded. There is also a very small subset of geotextiles that are knitted. Examples are shown in Figure 2.

Geotextiles are permeable to liquids and gases, but vary to a wide degree. These variations produce materials with a wide range of mechanical and hydraulic properties. As a result, there are at least 100 specific application areas for geotextiles. However, these can be simplified to four discrete functions: separation, reinforcement, filtration, and/or drainage.

Geogrids

Rather than being a continuous fabric, geogrids are polymers formed into an open, small grid-like configurations with apertures between individual ribs as illustrated in Figure 3. Geogrids typically consist of polyethylene (PE), polypropylene (PP), or polyester (PET). They are typically classified as being bidirectional, with equal strength in both directions, or unidirectional, with a greater strength in one direction. Geogrids are made by one of three methods; (1) stretching a polymer sheet in one, two or three directions for improved physical properties; (2) woven or knit using standard textile manufacturing methods; or (3) laser or ultrasonically bonded rods or straps. While there are many applications, geogrids function almost exclusively as reinforcement.

Geomembranes

Geomembranes represent the largest group of geosynthetics, and see higher sales than geotextiles. Geomembranes grew rapidly in the United States and Germany when government regulations in the early 1980s required lining of solid waste landfills. Uses expanded to all types of landfills, surface impoundments, canals, and containment of vapors, liquid or solid materials. Geomembranes are typically made from polyvinyl chloride (PVC), ethylene propylene diene monomer (EPDM), high-density polyethylene (HDPE) and linear lower density polyethylene (LLDPE) as shown in Figure 4. The range of applications extend beyond environmental management to geotechnical and transportation uses, including roles in hydraulic designs.

Geonets

Geonets, also called geospacers by some, are formed by a continuous extrusion of parallel sets of polymeric ribs at acute angles to one another. See Figure 5. When the ribs are opened, relatively large apertures are formed into a netlike configuration. Two types are most common, either bi-planar or tri-planar designs. Many different types of drainage cores are available consisting of nubbed, dimpled or cuspated polymer sheets, three-dimensional networks of stiff polymer fibers in different configurations and small drainage pipes or spacers within geotextiles. In most cases their surfaces are covered with a geotextile as a component in a geocomposite. The typical polymer is polypropylene (PP). They function by providing planar or lateral movement of liquids (or gasses) and are also called drainage mats. ICPI Tech Spec 14 Concrete Paving Units for Roof Deckscovers the use of drainage mats in detail. Use of geonets under segmental pavement must be done so with caution. Geonets can compress significantly or even collapse under heavier loads. This compression, if significant, can lead to movement in the segmental pavement elements leading to breakage, joint or bedding sand loss and eventual failure of the system.

Geosynthetic clay liners

Geosynthetic clay liners (GCLs) sandwich a thin layer of bentonite clay between two geotextiles or bonded to a geomembrane as shown in Figure 6. Structural integrity of the composite is obtained by needle-punching, stitching or adhesive bonding. GCLs are used as a component beneath a geomembrane or alone in containment, hydraulic, transportation and geotechnical applications. GCLs are a competitive alternative to compacted clay liners.

Figure 6. Geosynthetic clay liners

Figure 7. Various geopipes

Figure 8. Geofoam examples

Figure 9. Geocells partly filled with aggregate

Geopipe

Geopipe is another name for drainage pipe and is manufactured from high-density polyethylene (HDPE) and polyvinylchloride (PVC) as shown in Figure 7. Versions are available with rigid, smooth walls or flexible corrugated pipe. The geopipes may be perforated to allow liquids or gases to enter or exit the pipe as well as non-perforated to transfer them. There has been enormous growth in the use of corrugated HDPE and large diameter pipe in recent years.

Geofoam

Geofoam is created by a polymer expansion of polystyrene (EPS) resulting in a "foam" consisting of many closed, gas-filled, cells as shown in Figure 8. The skeletal nature of the cell walls is the unexpanded polymer material. The resulting product is generally in the form of large, but extremely light, blocks which are stacked side-by-side providing lightweight fill in numerous applications. Geofoam is also used for insulation of frost-sensitive soil applications. In some areas, geofoam is being used as a substitute for compacted dense-graded aggregate base in mostly residential, pedestrian-only applications. This new application requires further research and evaluation of field performance on various soils and climates.

Geocells

Geocells (also known as cellular confinement systems) are three-dimensional honeycombed structures that confine compacted soil or base materials within them as shown in Figure 9. Extruded polymer strips ultrasonically welded together in series are expanded on site form stiff walls (typically textured and perforated) that create a three-dimensional cellular mattress. Infilled with soil or base materials, a more stable structure is created. The cellular confinement reduces the lateral movement of materials, thereby maintaining compaction and stiffness capable of distributing loads over a wide area. Traditionally used in slope protection and earth retention applications, geocells are increasingly used for long-term road and railroad support. Much larger geocells are also made from stiff geotextiles sewn into similar, but larger, unit cells that are used for protection bunkers and walls. Geocells have been used on a limited basis to strengthen open-graded aggregate bases used in PICP systems. This new application is being evaluated in full-scale test.

Geocomposites

A geocomposite combines geotextiles, geogrids, geonets and/or geomembranes in a factory fabricated unit as shown in Figure 10. GCLs are an example of a geocomposite as are geonets covered with geotextile. Applications are numerous and constantly growing and cover the range of functions for geosynthetics.

Figure 10. Geocomposite examples

Table 1. Geosynthetic functions

Geosynthetic	Separation	Reinforcement	Filtration	Drainage	Containment
Geotextile	✓	✓	✓	✓	
Geogrid	✓	✓			
Geomembrane					✓
Geonet				✓	
Geosynthetic clay liner					✓
Geopipe				✓	
Geofoam	✓				
Geocell		✓		✓	
Geopipe				✓	
Geocomposite	✓	✓	✓	✓	✓

Handling Geosynthetics

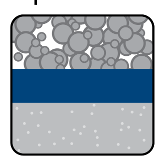
Many geosynthetics are supplied in rolls with unique serial numbers for manufacturer quality control. Installation contractors should remove these labels from delivered materials and keep them with other project records.

Geosynthetics will degrade when exposed to ultra-violet rays in sunlight over long time periods so they should remain in their packaging, covered, or stored inside until use. While additives are in the polymers that provide some resistance, continued exposure weakens them and they may not perform as expected. Excessive heat can also damage geosynthetics which provides another reason to store geotextiles away from sunlight in places with air circulation. On a hot sunny day, placing a heavy tarp over geosynthetics rolls can heat it and reduce strength and performance. To maintain their performance, geotextiles are best stored elevated above the ground in their original packaging out of direct sunlight, protected from precipitation and excessive heat. Further information is available in ASTM D4873 Standard Guide for Identification Storage & Handling of Geotextiles

Geosynthetic Functions

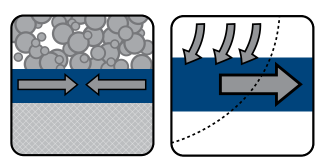
Geosynthetics are generally selected and designed for a particular application by considering their primary function or functions. Table 1 illustrates functions of various geosynthetics. The functions are defined below.

Separation



Separation places a flexible geosynthetic material such as a permeable geotextile between dissimilar materials so the integrity and function of both materials remain intact or even be improved. Paved roads, unpaved roads, and railroad bases are common applications. Also, the use of thick nonwoven geotextiles for cushioning and protection of geomembranes is in this function category. In addition, for most applications of geofoam and geocells, separation is the major function.

Reinforcement



Reinforcement synergistically improves a system's strength when introduced to a geotextile, geogrid or geocell all of which function well in tension. These can strengthen a soil that is otherwise weak in tension. Applications include mechanically stabilized and retained earth walls and steep soil slopes. Such walls can be connected to concrete units to create vertical retaining walls. Other applications are reinforcement of weak soils and over deep foundations for embankments with heavy surface loads. Unlike geotextiles, stiff polymer geogrids and geocells do not have to be in tension to provide soil reinforcement. Stiff two-dimensional geogrids and three-dimensional geocells interlock with the aggregate particles, providing reinforcement through confinement of the aggregate. The resulting mechanically stabilized aggregate layer provides improved loadbearing performance. Stiff polymer geogrids with very open apertures in addition to three-dimensional geocells made from various polymers are increasingly specified in unpaved and paved roadways, within dense and open-graded aggregate bases, and especially in railroad ballast where the improved loadbearing characteristics can significantly reduce the need for high-quality, expensive imported aggregate.

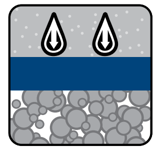
Filtration

Filtration allows water or gases to move through the plane of the material without the undesired movement or loss of soil. Filtration applications are highway underdrain systems, retaining wall drainage, landfill leachate collection systems, silt fences and curtains, and flexible forms for bags, tubes and containers.

Drainage

Drainage allows water or gases to move within the plane of the material without the undesired movement or soil loss. Geopipe highlights this function, and also geonets, geocomposites, and very thick geotextiles. Drainage applications for these different geosynthetics are retaining walls, sport fields, dams, canals, reservoirs, and capillary breaks. Sheet, edge and wick drains are geocomposites for various soil and rock drainage applications.

Containment



Containment is achieved with geomembranes, geosynthetic clay liners, or some geocomposites which function as liquid or gas barriers. Landfill liners and covers rely on their continued containment. All hydraulic applications (tunnels, dams, canals, surface impoundments, and floating covers) use these geosynthetics as well.

Use of Geotextiles

Typical pavement applications achieve separation, filtration and possibly reinforcement. Geotextiles can help provide a longer service life and reduce pavement material use. Understanding geotextile properties is fundamental to selecting them for pavement applications. Properties are listed below and [illegible]h are associated with an ASTM test method.

- Grab tensile strength
- Wide width tensile strength
- Trapezoidal tear strength
- CBR puncture
- UV resistance
- Apparent opening size
- Permittivity
- Flow Rate
- Transmissivity

While there is a broad range of geotextiles properties, some are more appropriately applied for a given application. In general, the grab tensile strength and wide width tensile strength tests provide the ultimate strength and

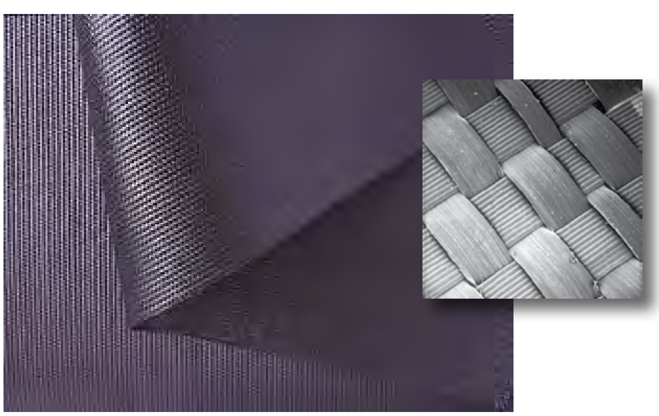


Figure 11. Woven slit-film geotextile with close-up

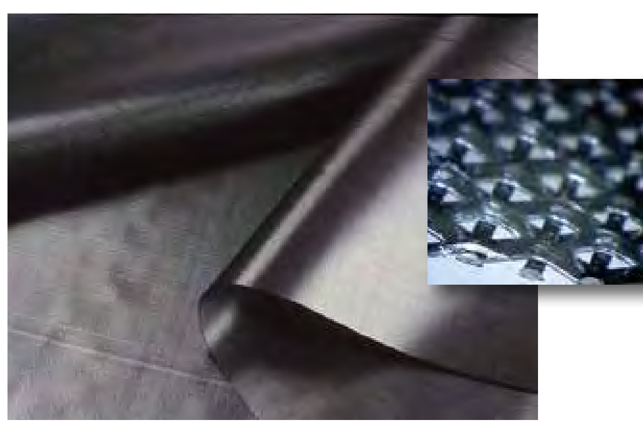


Figure 12. Woven mono-filament geotextile with close-up

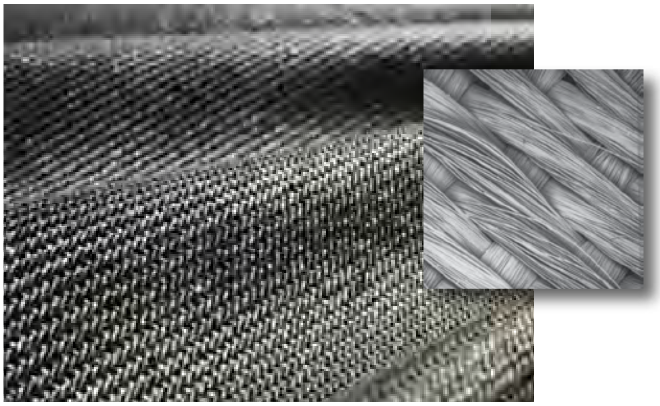


Figure 13. Woven multi-filament geotextile with close-up

Figure 14. Non-woven needle punched geotextile with close-up

strain values at specified elongation rates. Trapezoidal tear and CBR puncture characterize resistance to installation damage. The CBR puncture test measures the force required to push a 2 in. (50 mm) piston through a geotextile similar to a 2 in. (50 mm) rock interaction with a geotextile in the field. Permittivity, flow rate, and transmissivity are hydraulic properties on how readily water moves through or within a given geotextile.

Geotextile Properties

Geotextiles are classified into two main categories based on their method of manufacture: woven and non-woven.

Woven geotextiles

Woven geotextiles are manufactured from various polymers with increasing strengths typically increasing their cost. Woven geotextiles typically provide good resistance to abrasion from bedding materials and bases. They also provide strength with minimal elongation (stretching) because of the orientation of the individual fibers. This allows woven geotextiles to function as a good reinforcement. Woven geotextiles are classified into subcategories based on the shape of the fibers used to construct them.

Woven Slit-film —Also known as woven slit-tape geotextile, this fabric is made from long, continuous wide fiber relative to their thickness. See Figure 11. When woven together the fibers create very small openings that impede water movement to a slow rate while preventing the passage of fine soil particles. The weave creates lower filtration and greater separation, as well as being a relatively economical material. The fabric is for applications where separation with some reinforcement and lower water filtration volumes are required.

Woven mono-filament —This weave is constructed using similar techniques to slit-film geotextiles but with round or oval individual fibers resulting in a tight, stable geotextile. See Figure 12. This creates larger holes and a higher water flow through it. Because of the higher fiber cost and specialized machinery used to weave it, mono-filament geotextiles are typically the most expensive woven geotextiles.

Woven multi-filament —These are manufactured using bundles of fibers that opens up the weave so more water can pass compared to a slit-film geotextile. See Figure 13. The multi-filament fiber material cost is also lower than a monofilament fiber. When compared to a slit-film or mono-filament geotextiles, multi-filament geotextiles provide filtration at a rate and cost between them.

Nonwoven Geotextiles

The other main category of geotextiles is nonwoven where the fibers are laid out randomly and run through one of two secondary processes called needle-punching or heat bonding to give the material its structure.

Nonwoven needle-punched is created by pushing needles with barbs at their tips through the mass of random fibers. See Figure 14. This process forces some of the fibers through the matrix which binds the fibers together. This creates a material with many small openings through the mass of fibers that allow water to flow a high rate while filtering the water. The mass also creates loft or thickness that allows water to travel laterally within the plane of the geotextile which provides drainage. Some nonwoven needle-punched geotextiles are thicker which increases their drainage capacity. Unfortunately, the random fiber mat gives needle-punched geotextile a relatively low strength. When a heavy load is applied, the fabric can stretch

Table 2. Geotextile types and function ratings

Type	Separation	Reinforce	Filtration	Drainage	Cost
Woven Slit-film	Excellent	Good	Poor	Poor	Low
Woven Mono-filament	Good	Good	Good	Poor	Medium
Woven Multi-filament	Excellent	Excellent	Good	Acceptable	High
Non-woven Needle-punched	Good	Poor	Excellent	Good to Excellent	Low
Non-woven Heat-bonded	Good	Acceptable	Acceptable	Acceptable	Low

significantly before it tears. For some applications its ability to stretch or elongate is a desirable feature.

The thickness of a nonwoven needle punched geotextile is identified by the weight per unit area. For example, a 4 ounce per square yard is considered a typical, lightweight material approximately 2 mm thick. Whereas a 20 oz/sy would be a very thick material probably over 10 mm. Thick needle-punched geotextiles are used for demanding applications like landfill sites and the material can be expensive. Nonwoven needle-punched geotextiles are sometimes used to provide a separation layer for a geomembrane to prevent punctures from aggregates during compaction or from other objects.

Nonwoven heat bonded geotextiles are created using polymer fibers with a high melt temperature in their core encapsulated by a second polymer with a lower melt temperature. See Figure 15. The fibers are laid out in a random layer and then run through heated

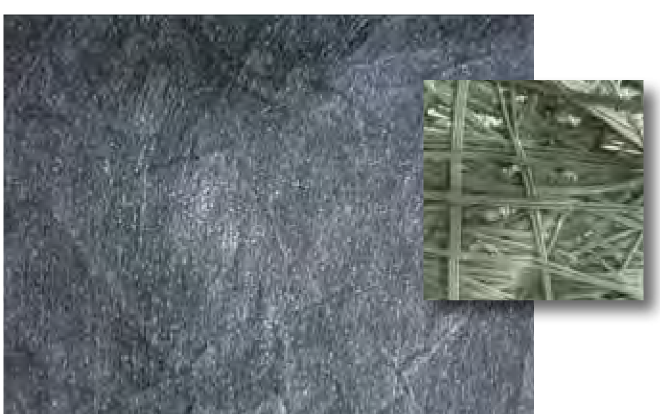


Figure 15. Non-woven heat bonded geotextile with close-up

rollers, called calendaring, that melts the outer layer of the fibers and presses them together. Heat bonded geotextiles have higher strength compared to non-woven needle-punched fabrics because the individual fibers are welded together. However compressing the fibers together reduces the openings in the matrix and this restricts water flow and its filtration function. The compressed matrix minimizes its ability for water to flow within the layer and provide drainage. Table 2 summarizes functions and relative cost for the different types of geotextiles presented.

Basic Design Concepts for Geotextiles

The American Association of State Highway and Transportation Officials (AASHTO) M-288 Standard Specification for Geotextile Specification for Highway Applications is a widely accepted geotextile specification by provincial and state departments of transportation as well as municipalities. M-288 covers six geotextile applications: subsurface drainage, separation, stabilization, permanent erosion control, sediment control, and fabrics used within paving materials. M-288 is not a design guideline and places design and selection decisions on the engineer who considers site-specific soil and water conditions.

M-288 includes three survivability classes for geotextiles, i.e. Class 1, 2 and 3. Class 1 is the most severe and Class 3 represents least severe site conditions. Potential damage during construction and use is considered in selecting a class. Each class subdivides geotextiles according to elongation, greater or less than 50%, and the designer can select nonwoven or woven geotextiles for each class based on various characteristics listed in Table

Table 3. Selection criteria for geotextiles in separation functions per AASHTO M-288

Geotextile Class	ASTM Test Method	Class I [a]		Class II [a]		Class III [a]	
Elongation	ASTM D4632	< 50%	> 50%	< 50%	> 50%	< 50%	> 50%
Grab Strength [b]	ASTM D4632	315 lb [1400 N]	202 lb [900 N]	247 lb [1100 N]	157 lb [700 N]	180 lb [800 N]	112 lb [500 N]
Sewn Seam Strength [b,c]	ASTM D4632	283 lb [1260 N]	182 lb [810 N]	223 lb [990 N]	142 lb [630 N]	162 lb [720 N]	101 lb [450 N]
Tear Strength [b]	ASTM D4533	112 lb [500 N]	79 lb [350 N]	90 lb [400 N] [d]	56 lb [250 N]	67 lb [300 N]	40 lb [180 N]
Puncture Strength [b]	ASTM D6241	618 lb [2750 N]	433 lb [1925 N]	495 lb [2200 N]	309 lb [1375 N]	371 lb [1650 N]	223 lb [990 N]
Permitivity [b,e]	ASTM D4491	0.02 sec^{-1}					
Apparent Opening Size	ASTM D4751	0.024 in [0.60 mm] maximum average roll value					
Ultraviolet Stability	ASTM D4355	> 50% after 500 h exposure					

[a] The severity of the installation conditions generally dictates the required geotextile class. Class 1 is the most severe and Class III is the least severe.
[b] All numeric values represent MARV in the weaker principal direction.
[c] When sewn seams are required.
[d] The required tear strength for woven monofiliment geotextiles if 250 N.
[e] Default Value. Permittivity of the geotextile should be greater than the soil.

2. For stabilization and separation applications, a woven fabric is typically less expensive than nonwoven options. For subsurface drainage and erosion control, woven fabrics are more expensive than non-woven.

When selecting a geotextile primarily for its separation function, it is important to make sure that it exceeds these minimum criteria specified in M-288 as shown in Table 3, also provided in ICPI Tech Spec 2 Construction of Interlocking Concrete Pavements

AASHTO M-288 also provides guidance on the overlapping of geotextile pieces necessary to achieve continuous coverage as shown in Table 4, also provided in ICPI Tech Spec 2

Table 4. Geotextile overlap recommendations in AASHTO M-288

Soil CBR, %	Overlap
> 3.0	1.0 ft [0.3 m] to 1.5 ft [0.45 m]
1.0 to 3.0	2.0 ft [0.6 m] to 3.0 ft [1.0 m]
0.5 to 1.0	3.0 ft [1.0 m] or sewn
< 0.5	Sewn
All roll ends	30 ft [1.0m]

In March 2012, the AASHTO National Transportation Product Evaluation Program (NTPEP) approved the adoption of a work plan for the evaluation of geotextile materials in highway applications. NTPEP is an AASHTO program that evaluates materials and products of common interest for use in highway and bridge construction. The program provides cost-effective evaluations for state DOTs by eliminating duplication of testing and auditing by the states, and duplication of effort by the manufacturers that provide products for evaluation. The NTPEP work plan establishes a list of manufacturing facilities, private label

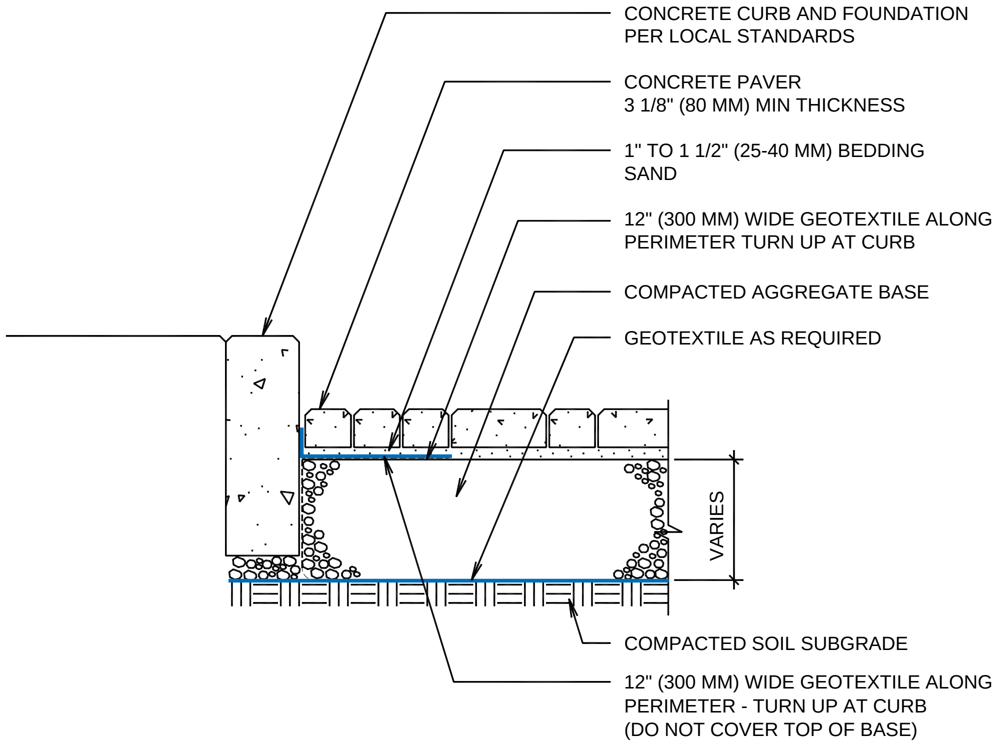


Figure 16. Geotextile in an interlocking concrete pavement over a flexible base

Table 5. Geotextile application guidelines for applications illustrated in Figure 16.

Site conditions and requirements	Recommended geosynthetics
Separate base from subgrade • Soil is a fine-grained silt or clay with little potential to infiltrate water and alternate drainage provided	Woven slit-film geotextile • Filtration not as important • Reinforcement is beneficial • Separation is important
Separate base from subgrade • Soil is sandy or gravelly with good potential to infiltrate water	Woven multi-filament geotextile or woven mono-filament geotextile • Filtration important • Reinforcement is beneficial • Separation is important
Prevent Bedding Sand Loss • Structures adjacent to bedding sand could crack, gaps and/or drain holes	12 in. (300 mm) strip of non-woven needle-punched geotextile • Filtration important

companies, geotextile converters and their associated geotextile products that conform to the quality control and product testing requirements of the work plan and AASHTO M-288. This provides a resource on companies that can provide geotextiles that conform to AASHTO M-288. Visit www.ntpep.org for additional information.

Geotextile Applications for Segmental Concrete Pavements

The following provides examples of where geotextiles might be used in segmental concrete pavements. Recommendations are provided on the type of geotextiles best suited to site conditions. While these are general guidelines, contractors should follow the recommendations and use materials specified in the construction documents.

When placing geotextile avoid wrinkles in the fabric. Follow the overlap recommendations specified in ASSHTO M-288 as noted in Table 4 above and avoid excessive overlapping of edges. Make sure the geotextile is placed in full contact with the surrounding soils or aggregates. Voids,

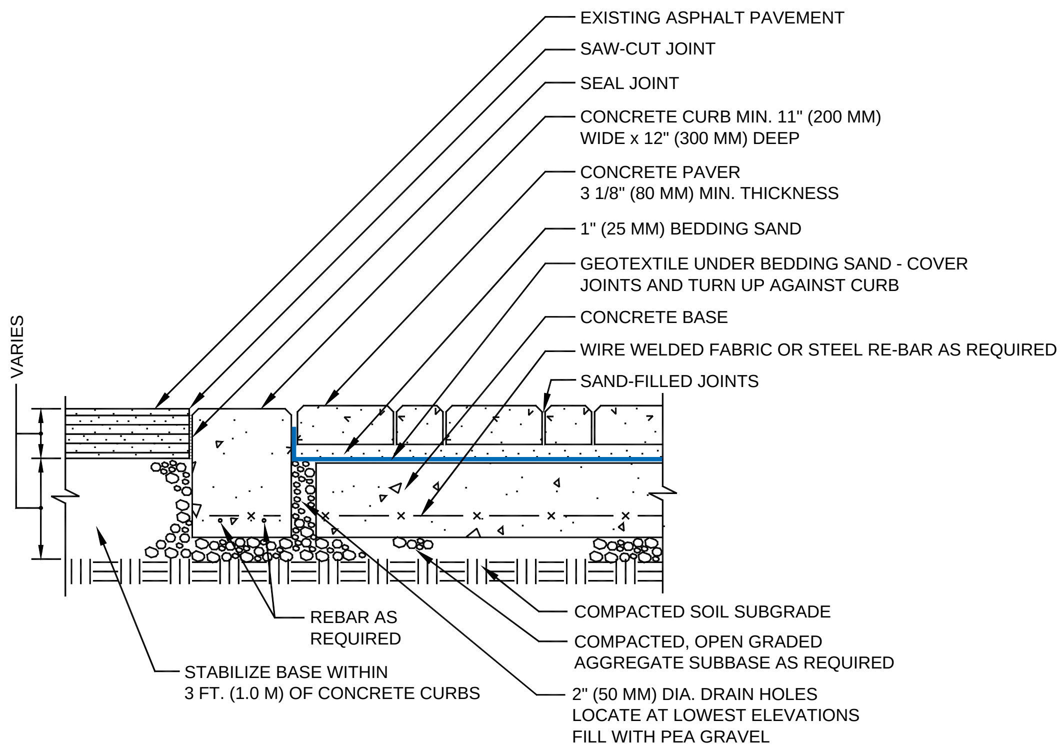


Figure 17. Interlocking concrete pavement overlay on a rigid concrete base

Table 6. Geotextile options for Figure 17.

Site conditions and requirements	Recommended geosynthetics
Prevent Bedding Sand Loss • Concrete base with potential to crack • Lower load applications	Non-woven needle-punched geotextile • Filtration important
Prevent Bedding Sand Loss • Concrete base with potential to crack • High traffic (truck) load applications	Woven multi-filament geotextile or woven mono-filament geotextile • Filtration important • Abrasion resistance * Include engineer familiar with geosynthetics in design process

hollows or cavities from wrinkles created under or beside the geotextile compromises its intended function.

Figure 16 illustrates geotextiles separating the compacted aggregate base from the soil subgrade. This can help maintain consolidation of the base materials over time by preventing intrusion of fines in the bottom and sides. This slows the rate of rutting in the base and on the soil subgrade.

Geotextile placed under the bedding sand next to the curb provides a 'flashing' function. This separates the sand from the base and prevents sand loss into joints between the concrete curb and the compacted aggregate base, as they are two structures that can move independently of each other. Table 5 provides guidelines for geotextile selection depending on conditions and requirements.

Figure 17 illustrates geotextile on a concrete base in a crosswalk applications. For new sidewalks, crosswalks, and streets, 12 in. (300 mm) wide strips of geotextile are recommended over all joints in new concrete bases to prevent loss of bedding sand, as well as over weep holes. New asphalt generally should not require geotextile on it except at curbs, structures and pavement junctions where bedding sand might enter. For existing asphalt and concrete bases, the surface of each should be inspected

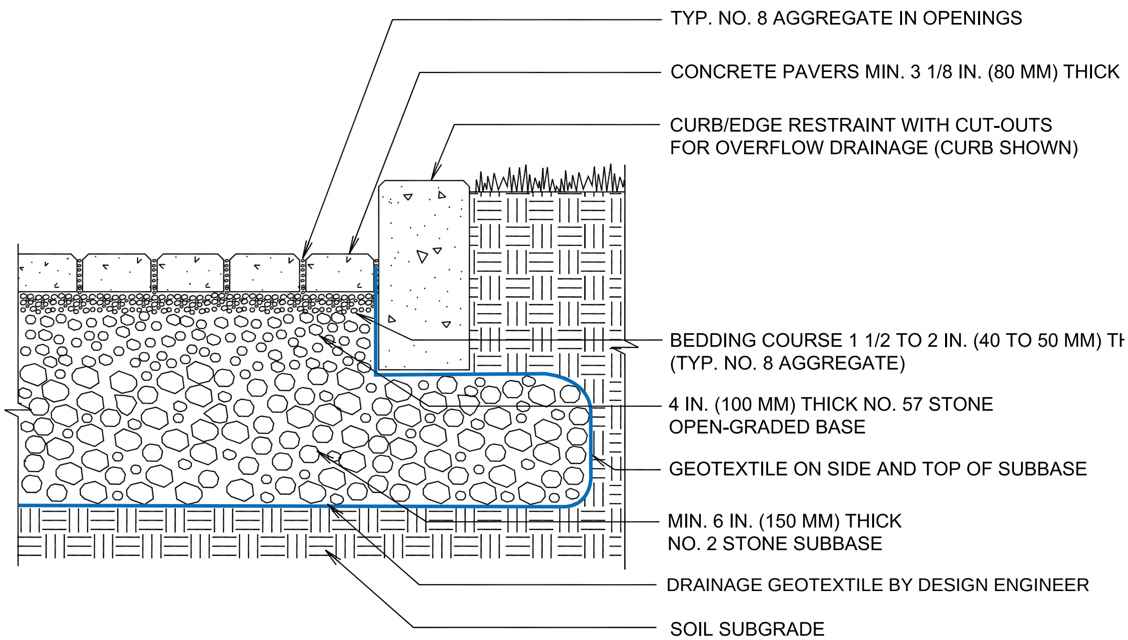


Figure 18: Permeable Interlocking Concrete Pavement geotextile locations

Table 7. Geotextile options for PICP in Figure 18

Site conditions and requirements	Recommended geosynthetics
Prevent migration of site soil into PICP base • Open graded aggregate base	Non-woven needle-punched geotextile • Filtration important
Separate base from subgrade • Open graded aggregate base • Infiltration of water from base into subgrade	Non-woven needle-punched geotextile, Woven multi-filament geotextile or Woven mono-filament geotextile • Filtration important • Separation important * Include engineer familiar with geosynthetics in design process

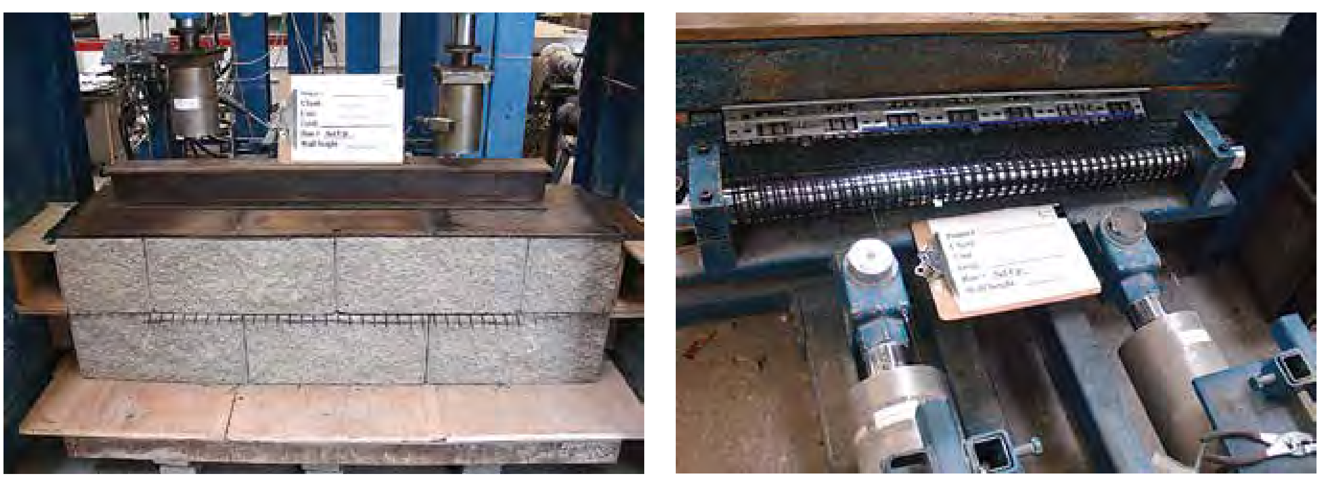


Figure 19. Geogrid connection testing with SRW units

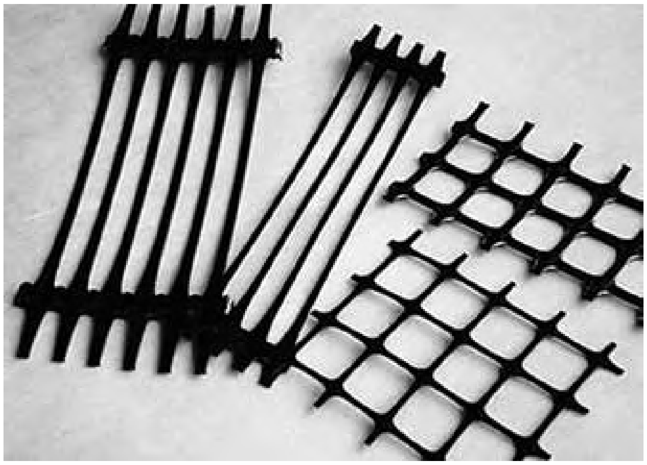


Figure 20. Uniaxial and biaxial, punched and drawn geogrids

for cracks, and their severity and extent determined for repairs. If cracks are few and minor (suggesting substantial remaining life in these bases), geotextile should be placed over the cracks to prevent potential future loss of bedding sand. Table 6 provides guidelines for geotextile selection for overlay applications depending on the conditions and requirements.

Figure 18 illustrates a typical application of geotextile in PICP. Its application against the sides of the subbase against the excavated soil is essential in all PICP projects that do not use full-depth concrete curbs that completely confine open-graded aggregates at the pavement perimeter. The design and selection of geotextiles for PICP is covered in detail in the ICPI manual, Permeable Interlocking Concrete Pavements—Design, Specification, Construction, and Maintenance. Table 7 provides recommendation for the selection of a geosynthetic in PICP applications based on the conditions and requirements

Use of Geogrids

Geogrids typically reinforce applications such as mechanically stabilized earth (MSE) and weak soil subgrade improvement for roadway applications. Geogrid properties include the following:

- Wide width tensile strength
- Strain
- UV resistance
- Aperture size
- Coefficient of interaction

For MSE applications, long term design strength (LTDS) in pounds per foot or kilonewtons per meter is determined in the design process to represent the effective strength of the geogrid over the design life of the structure. Additional properties are evaluated and applied to determine the LTDS. These include creep, i.e. the amount of deformation under sustained load; durability, the resistance to degradation; and installation damage, or strength reduction that occurs during installation. Creep, durability, and installation damage factors are applied to the ultimate strength of the geogrid as reduction factors to determine the LTDS.

If the geogrids is to be used with a segmental retaining wall (SRW) system additional tests related to the connection strength and shear strength are performed as shown in Figure 19. The connection strength test determines the maximum load that can be applied to the connec-

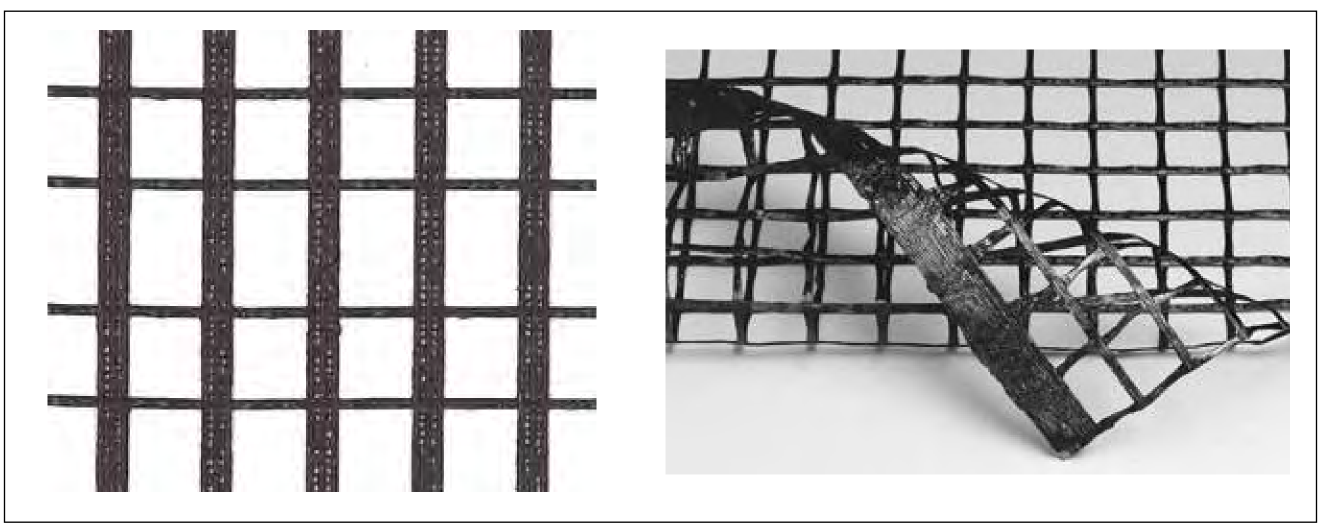


Figure 21. Uniaxial and biaxial, knitted and woven geogrids

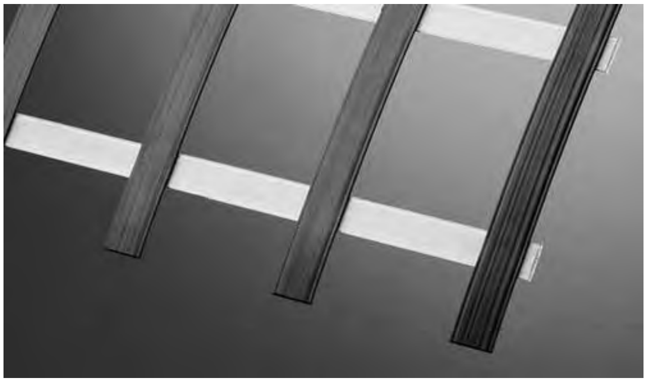


Figure 22. Uniaxial bonded geogrid

tion between the SRW units and the geogrid. The shear strength test considers the reduction in shear strength between SRW courses with the geogrids inclusion.

Geogrid Properties

Geogrids are divided in to three categories: 1) punched and drawn, 2) woven or knitted and 3) bonded. These groupings are based on their manufacturing method. As mentioned above geogrids are also classified on their load carrying ability. If the geogrid is designed to carry load in one principal direction, typically along its length, it is referred to as a uniaxial geogrid. If the geogrid is designed to carry load along its length and width it is called biaxial.

Punched and Drawn Geogrids

The first category of geogrid, punched and drawn, is a sheet of plastic with punched holes, heated and stretched in one or more directions. Uniaxial geogrids are stretched in one direction as shown in the two samples on the left of Figure 20. Biaxial geogrids are stretched in two or more directions as shown in the two samples on the right of Figure 20. Polymers typically are polypropylene (PP) or high density polyethylene (HDPE). This type of geogrid is stiff, allowing it to anchor in the soil to carry large loads with minimal movement.

Woven or Knitted Geogrids

The second category of geogrid is woven or knitted. The fibers are typically made from polyester with variations made from polyvinyl alcohol and fiberglass. Once the fibers are woven or knitted, they are coated with polyvinyl chloride (PVC) or similar materials to bind them together and increase durability. Uniaxial (shown on the left in Figure 21) and biaxial woven or knitted geogrids (right in Figure 21) are possible. The more fibers in one direction, the higher the strength. Woven and knitted geogrids tends to be more flexible which making them easier to manipulate on the jobsite.

Bonded Geogrids

The third category of geogrid is bonded which represents a small portion of geogrids. Figure 22 show a geogrid made from polyester ribbons welded together ultrasonically to form a very stiff mat. Uniaxial and biaxial varieties are available.

Biaxial geogrids are best suited to aggregate base reinforcement in pavement applications whereas uniaxial geogrid are optimized for MSE (soil subgrade) applications. However, biaxial geogrids may have some installation advantages when used in MSE applications. Table 8 compares geogrid types and applications. The cost of each geogrid depends on the strength required from the grid material.

Basic Design Concepts with Geogrids

When designing with a geogrid, the manufacturer can provide and ultimate strength of the material. However site conditions degrade the geogrid over its life due to loads within the pavement or wall structure. The designer must consider the effects of creep (i.e., slow elongation), installation damage and durability to determine a maximum allowable long term design strength (LTDS).

$$LTDS = \frac{T_{ult}}{(RF_{CR} \times RF_{ID} \times RF_{D})}$$

Table 8. Geogrid comparisons

Type	Aggregate Base Reinforcement	Soil Slope/Wall Reinforcement
Punched & Drawn Uniaxial	Poor	Excellent
Punched & Drawn Biaxial	Excellent	Poor
Woven/Knitted Uniaxial	Poor	Excellent
Woven/Knitted Biaxial	Excellent	Poor
Bonded Uniaxial	Poor	Excellent
Bonded Biaxial	Excellent	Poor

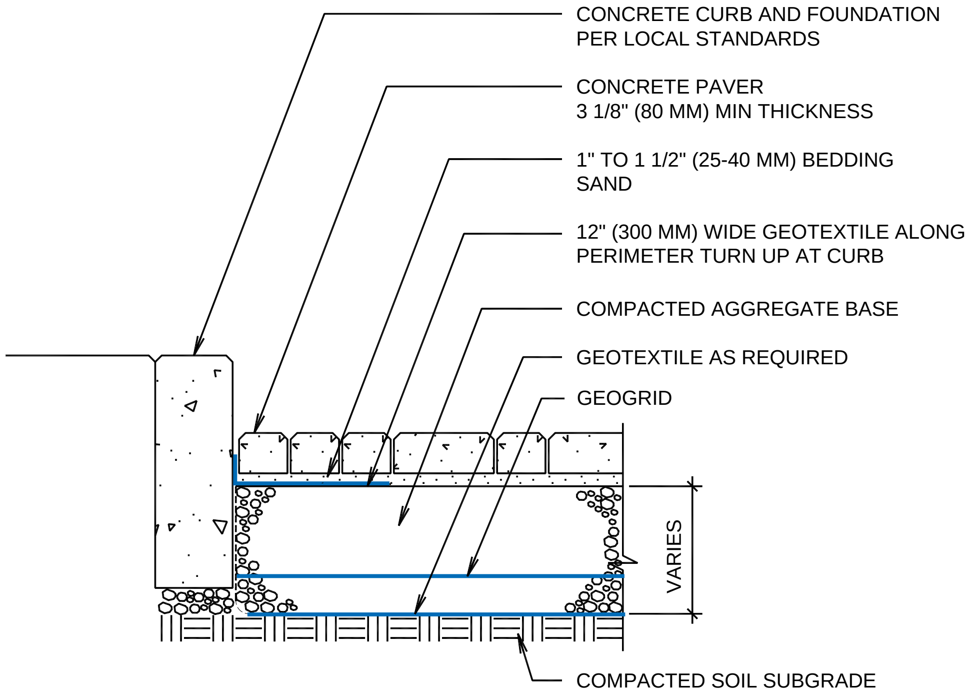


Figure 23. Interlocking concrete pavement with geogrid in the base for reinforcement

Table 9. Geogrid applications for Figure 23

Site conditions and requirements	**Recommended geosynthetics**
Reinforce aggregate base • Weak subgrade • Higher load applications	Biaxial geogrid • Reinforcement in length and width important

Where;

T_{ult} = ultimate tensile strength, pounds per foot or kilonewtons per meter

RF_{CR} = Reduction factor due to creep

RF_{ID} = Reduction factor due to installation damage

RF_D = Reduction factor due to durability

Creep occurs in polymer materials when subject to a sustained load over a long period of time. If the load is too great, the polymer will continually stretch and eventually break. The load must be limited to prevent this unrestricted creep. This is considered in the design as the RF_{CR} factor. When aggregate is compacted on the geogrid it is damaged and the strength reduced. Different types of aggregates will create different amount of damage. This affect is considered in the strength calculation as the RF_{ID} factor. Lastly, chemical and biological agents may affect the geogrid over the life of the geogrid causing it to lose strength. These affects are considered in the strength equation by including the RF_D factor. An experienced design engineer can apply appropriate reduction factors in estimating the LTDS.

Geogrid Applications with Segmental Concrete Pavements

Geogrids are designed to provide reinforcement, and can enhance the strength and longevity of interlocking concrete pavements. Some examples are presented below. Recommendations are also provided for the type of geogrid best suited to the site conditions. Nonetheless, contractors should always follow recommendations for materials specified in the construction documents.

When placing geogrids they should be installed with a small amount of tension. Wrinkles in the geotextile should be removed. When placing aggregate on top of a geogrid, spread it out so it will keep the tension the geogrid

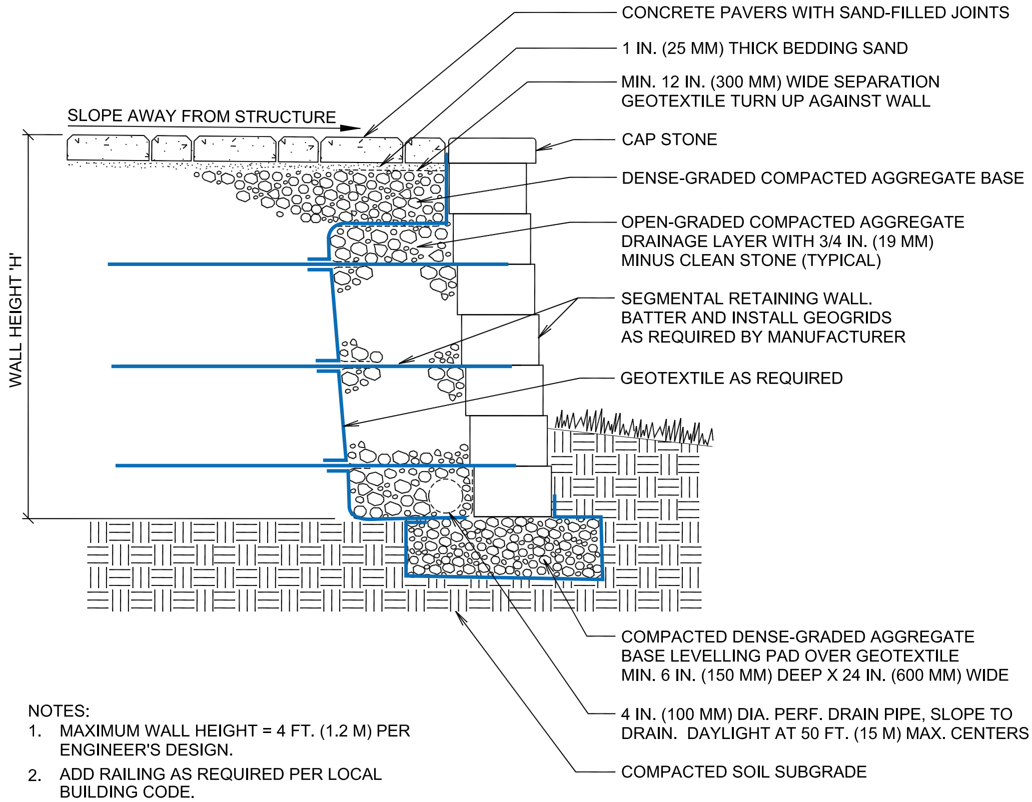


Figure 24. Raised patio with geogrid reinforced segmental retaining wall

Table 10. Geogrid applications for Figure 24 with segmental retaining walls and concrete pavers

Site conditions and requirements	Recommended geosynthetics
Reinforced segmental retaining wall • Total SRW height exceeds 2 x depth of SRW units	Non-woven needle punched geotextile • Separation and Filtration are important Uniaxial geogrid • Reinforcement perpendicular to wall face important and length as specified in engineered drawings Biaxial Geogrid • Only if roll width exceeds minimum specified length and cross roll strength exceeds deign requirements

instead of releasing the tension, i.e. place the aggregate and spread it towards the free ends of the geogrid. For SRWs, do not overlap geogrid between block courses. This will push the units above the overlap out of horizontal alignment.

Figure 23 illustrates using a geogrid layer to improve the strength and load distribution characteristics of a compacted aggregate base. This method of construction would be appropriate for low strength soils. It is important to note that the geogrid will typically be placed within the aggregate base and not at the base – subgrade interface. This will optimize the reinforcement function of the geogrid. If a minimal level of containment is desirable, and a less than optimized reinforcement function is allowable the geogrid may be placed at the subgrade – base interface. Table 9 provides recommendations for geogrids used in base reinforcement applications depending on the conditions and requirements.

Figure 24 is a cross section detail of a raised patio. This application can benefit from reinforcement by using a

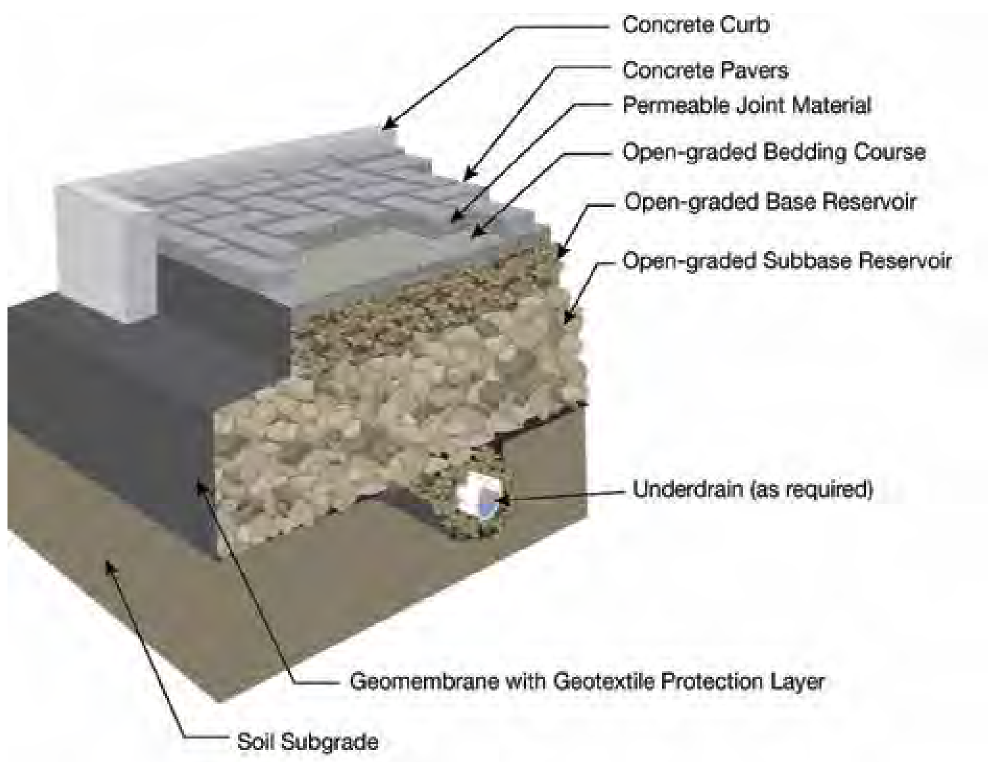


Figure 25. Typical geomembrane application in a no infiltration PICP design

geogrid to create a mechanically stabilized earth retaining wall. Additionally filtration is necessary to prevent fine soil particles from being washed out of the backfill and pavement base, which can lead to settlement over an extended period. Confinement of the aggregate used to construct the retaining wall base can also be advantageous when building over weaker fine grained soils like silts and clays. Table 10 provides recommendations for geotextiles and geogrids used in SRW applications depending on the conditions and requirements.

Use of Geomembranes

Geomembranes create an impermeable barrier that prevents the flow of liquid or gas. Geomembranes are manufactured from polyvinyl chloride (PVC), ethylene propylene diene monomer (EPDM), high-density polyethylene (HDPE) and linear lower density polyethylene (LLDPE). Other polymers that may be used for special applications include chlorosulfonated polyethylene (CSPE), chlorinated polyethylene (CPE), polypropylene (PP), and very flexible polyethylene (VFPE). Each of these polymers is unique and provides varying levels of resistance to acids, alkalis or petrochemicals. Some polymers can also function in extreme heat or cold. Normally, the surface of a geomembrane is smooth, but some sloped applications can benefit from a textured surface that provides greater friction with the adjacent geotextiles or soil.

PICP systems can be designed and constructed to accommodate three drainage conditions:

- Full infiltration of water into to a high infiltration rate soil subgrade with no underdrains;
- Partial infiltration of water into a low infiltration rate soil subgrade with some outflow through underdrains; and
- No infiltration into a soil subgrade with all outflow exiting through underdrains.

All conditions have similar surfacing, and base/subbase reservoir construction. In some PICP designs, a geomembrane is used next to building foundations or adjacent pavements with dense graded bases to prevent them from saturation and damage. Geomembranes may

Figure 26. Geomembrane protected with a nonwoven geotextile for a PICP alley.

used for water harvesting. The water may be piped to an underground cistern for re-use on site. Harvested rainwater can be used to reduce landscaping water requirements and in some cases it can be used for gray water within buildings.

Geomembrane Properties

Geomembrane thicknesses depend on the polymers and the manufacturing process. For example, HDPE geomembrane is typically available in 40, 60 and 80 mil (1.0, 1.5 and 2.0 mm) thicknesses and in a range of roll widths. Geomembranes have different engineering properties depending on polymer type, thickness and manufacturing process. Properties typically provided by the manufacturers' literature and referenced in project specifications include,

- nominal thickness,
- density,
- tensile strength,
- tear resistance,
- dimensional stability and puncture resistance

be used within a PICP subbase on sloped applications as check dams to slow the flow of water and encourage infiltration between each vertical liner. Additionally, no infiltration systems make use of a geomembrane on the sides and bottom of the base/subbase reservoir to contain stormwater and prevent it from infiltrating into the soil subgrade as shown in Figure 25.

A no-infiltration PICP design with a geomembrane is typically used in the following conditions:

- The soil has very low permeability, low strength, or is expansive;
- High depth to a water table or bedrock;
- To protect adjacent structures and foundations from water; or
- When pollutant loads are expected to exceed the capacity of the soil subgrade to treat them.

By storing water in the base/subbase and then slowly draining it through pipes, the design behaves like an underground detention pond with the added benefit of filtering some pollutants. A no infiltration design may be

Geomembrane Applications for Permeable Interlocking Concrete Pavements

Geomembranes for PICP are typically fabricated on the job site and this requires cutting, fitting and seaming to create waterproof joints. Different seaming techniques are used depending on the material, environmental conditions and project requirements. Materials like EPDM and PVC are routinely seamed using an adhesive or double sided tape. Before two panels are joined, the areas to be joined are usually cleaned and primed. HDPE and other polymers are typically welded together with extrusion welders or hot wedge welders. Seams for all materials should be field tested to ensure they are waterproof especially around underdrains penetrating the geomembrane. For smaller projects, it might be possible to have the supplier prefabricate the geomembrane to meet site requirements. Prefabricated geomembranes are typically delivered to the site folded on a pallet.

When preparing a site for a geomembrane application, rocks, roots, and other sharp objects are removed that can damage the geomembrane during installation

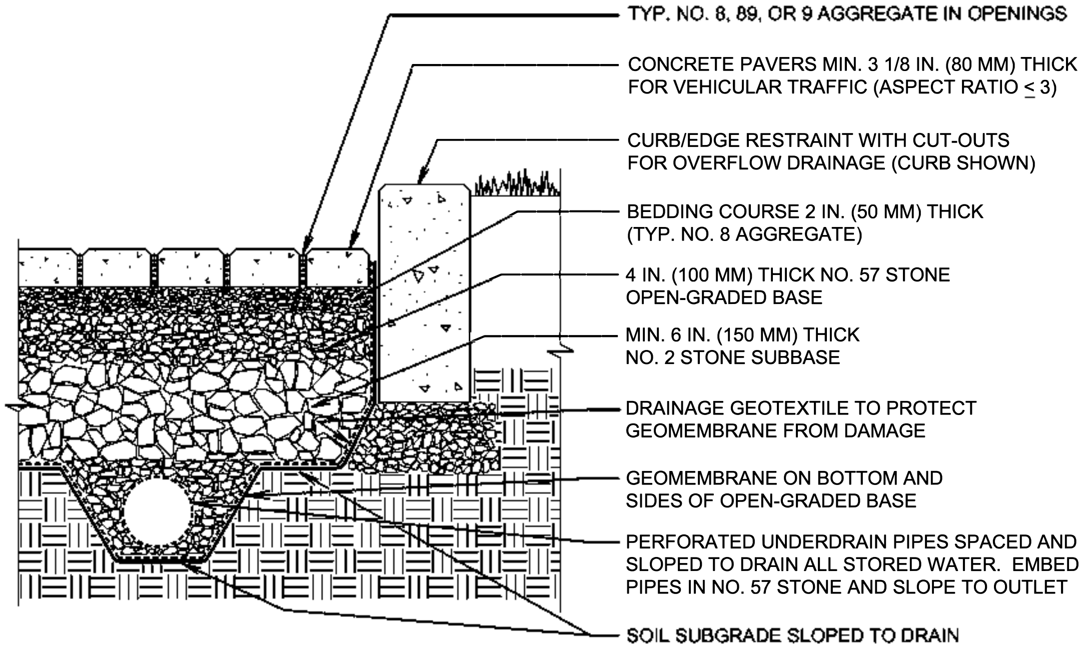


Figure 27: No infiltration Permeable Interlocking Concrete Pavement

Table 11. Geosynthetics used in No Infiltration PICP shown in Figure 27

Site conditions and requirements	Recommended geosynthetic
No Infiltration PICP system • Open graded aggregate base	Geomembrane with a non-woven needle-punched geotextile • Protection important • Containment important

(especially from aggregate compaction) or use. Such protrusions should be removed and voids filled with dense-graded aggregate base and compacted before placing the geomembrane over them. A layer of non-woven geotextile is commonly used to protect one or both sides of the geomembrane. The thickness of the geotextile is typically selected based on the materials placed next to the geomembrane and the degree of risk for punctures. Figure 26 illustrates a green alley in Richmond, Virginia with a geomembrane protected by a nonwoven geotextile. Both are placed before placing and compacting the open-graded aggregate subbase. Figure 27 shows the typical cross section for a No-exfiltration PICP system.

When designing a no infiltration PICP system there are many factors that must be considered in selecting the geomembrane and protection materials. In addition, geomembranes may be wrapped around utility lines to protect them from exposure to water within PICP bases/subbases. For most projects, consultation with an engineer familiar with the design of geomembranes is recommended. Table 11 provides recommendations for geomembrane and geotextile selections based on conditions and requirements.

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icpi
Interlocking Concrete Pavement Institute®

13750 Sunrise Valley Drive
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

Tel: 703.657.6900
Fax: 703.657.6901
E-mail: icpi@icpi.org
www.icpi.org

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Tech Spec Guide

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Design and Installation Professionals frequently turn to interlocking concrete pavements and permeable interlocking concrete pavements because they offer lower initial and life cycle costs and provide environmentally sustainable solutions.

ICPI provides resources for ICP and PICP design, construction, and maintenance. These include: Tech Specs, Guide Specs, Detail Drawings, Construction Tolerance Guides, Fact Sheets, Design Manuals and design software. ICPI also offers several relevant continuing education courses at icpi.org and aecdaily.com

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Tech Spec 23

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Maintenance Guide for Permeable Interlocking Concrete Pavements

Introduction

Permeable interlocking concrete pavements (PICP) are a proven method for reducing stormwater runoff and pollutants while supporting pedestrian and vehicular traffic. Many laboratory and in-situ research projects over the past two decades by universities, government stormwater agencies, and industry have demonstrated significant runoff and pollutant reductions with cost-saving benefits. The U.S. Federal Highway Administration www.fhwa.dot.gov/pavement/concrete/pubs/hif19021.pdf has published information supporting PICP use in walkways, plazas, driveways, parking lots, alleys and streets.

Like all stormwater control measures, PICP requires maintenance as it traps sediment on its surface not unlike an air conditioning filter. Larger particles are initially trapped while allowing water to pass. Some enter the jointing stone and are trapped there. The jointing stone with larger particles eventually captures smaller particles and this decreases the infiltration rate over time. While still infiltrating water, many smaller particles are trapped within the surface and interior joints. Smaller particles are trapped and eventually decrease infiltration which results in surface ponding.

Every PICP site varies in sediment deposition onto its surface, particle size distribution, and the resulting cleaning frequency. For example, beach sand (a coarse particle size distribution) on the surface will not clog as quickly and require less effort removing than fine clay sediment. Besides the particle size distribution, the rate of surface infiltration decline also depends on the traffic, size, and slope of a contributing impervious area, adjacent vegetation and eroding soil, paver joint widths and jointing stone sizes. ICPI offers a PICP site selection

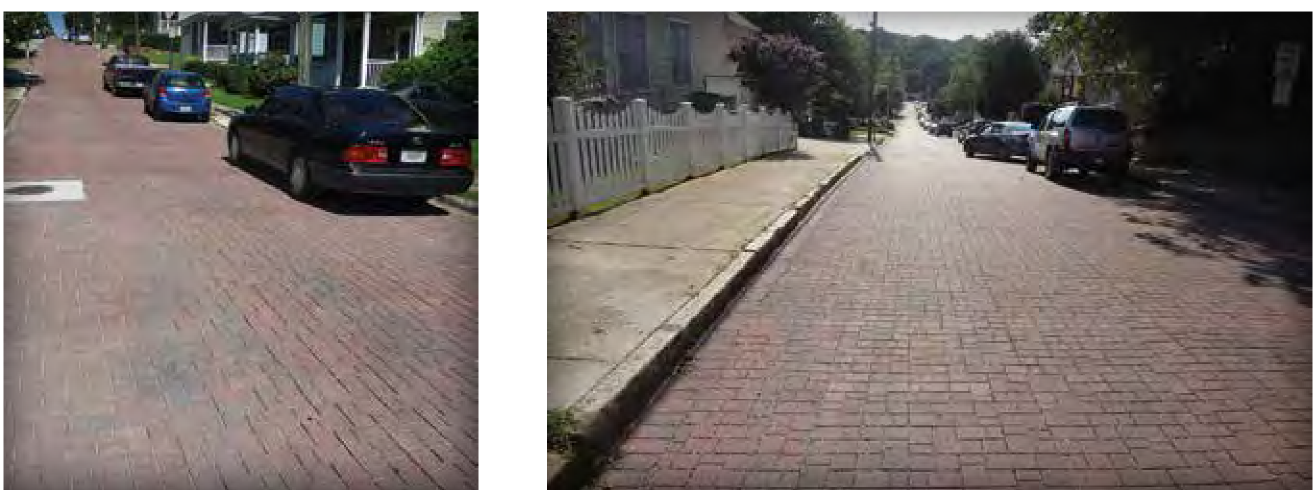

Figure 1. PICP is seeing increased use in municipal streets to reduce stormwater runoff, local flooding, storm pipe upsizing, and combined sewer overflows. These streets are in Atlanta, GA.

Figure 2. Sand-filled joints and bedding common to interlocking concrete pavement are not used in PICP.

tool on www.icpi.org/software to help identify favorable sites and avoid one that may incur additional maintenance.

While routine maintenance assures long-term infiltration, surface infiltration can be restored from neglected maintenance. A significant advantage of PICP is its ability to remove settled or wheel-packed sediment in the joints. This Tech Spec provides guidance on routine and restorative maintenance practices that support surface infiltration. This bulletin also provides guidance on maintaining the surface as an acceptable pedestrian and vehicular surface.

Practices Supporting Surface Infiltration

PICP design and construction that complies with ICPI guidelines are fundamental to long-term surface infiltration. Guidelines are found in ASCE 68-18 standard on PICP, the ICPI manual, Permeable Interlocking Concrete Pavements and in ICPI Tech Spec 18–Construction of Permeable Interlocking Concrete Pavements available on www.icpi.org. Some essential characteristics described below support continued infiltration.

PICP doesn't use sand. Unlike interlocking concrete pavements, sand jointing or bedding materials to support paving units and dense-graded aggregate bases are not used in PICP. Sand joints and bedding allow very little water to enter and often eventually clog for traffic borne detritus and sediment.

Construction E & S control is essential. Erosion and sediment control during construction is covered in the previously mentioned documents, and is customized to each project via the Stormwater Pollution Prevention Plan or SWPPP. An inspection checklist is provided at the end of this bulletin that includes sediment control. If the PICP is built first and construction traffic must use it, then it will very likely require vacuum cleaning upon construction completion. The ideal situation is PICP constructed late in the project such that it will not receive much construction traffic and sediment. This may require using temporary construction roads.

If PICP receives run-on from upslope pervious or impervious areas, inspect these areas for erosion and sediment, yard waste, materials storage, etc. Sweep or vacuum the contributing drainage area clean and free of any dirt, leaves and mulch as they are a major source of PICP clogging. Lawn and planting beds should be sloped away from PICP areas.

Maintain filled joints with stones. The jointing stones capture sediment at the surface so it can easily be removed. If sediment is allowed to settle and consolidate, then cleaning becomes more difficult since the sediment is inside the joint rather than on the surface. Settlement of jointing stones in the first few months is normal to PICP as open-graded aggregates for jointing and bedding choke into the larger base aggregates beneath and stabilize. This settlement often requires the joints to be refilled with aggregates three to six months after their initial installation. If possible, this should be included in the initial construction contract specifications. Aggregate-filled joints facilitate sediment removal at the surface and provide interlock for pavement structural stability.

Keeping the joints filled during the PICP service life is essential to trapping sediment and facilitating its removal at the surface and ensuring long term performance. Permeable segmental paving systems that do not use jointing aggregates may incur higher maintenance time and costs to extract accumulated sediment from deep within the joints and bedding, or eventually move through the base/subbase aggregates onto the subgrade and reduce its infiltration.

Filled paver joints means filled to the bottom of the paver chamfers with jointing stone. If the pavers have very

Figure 3. Whether eroded onto or dumped on PICP, erosion and sediment control are essential during construction.


Figure 4. Keeping PICP joints filled with permeable aggregate facilitates removal of accumulated sediment.

small or no chamfers, then they should be filled within ¼ in. (6 mm) of the paver surface. Should the top of jointing stone settle below ¼ in. (6 mm), vacuum equipment can be less effective in removing sediment and cleaning becomes potentially more expensive.

Manage mulch, topsoil and winter sand. Finally, stockpiling mulch or topsoil on tarps or on other surfaces during site maintenance activities rather than directly on the PICP surface helps maintain infiltration. Figure 5 illustrates an example of correct management of landscaping material on PICP, as well as the need to exposed soil slopes.

Sand used in the winter for traction is not recommended. Figure 6 illustrates the consequence to PICP joints when subjected to winter sand for traction. If used, sand should be removed with vacuuming in the spring to prevent a substantial decrease in surface infiltration. Using jointing aggregate is recommended as a better alternative to using sand for winter traction. In addition, the aggregate can provide some refilling of the joints.

Surface Infiltration Inspection & Testing

Visual Inspection— Effective ways to assess PICP surface infiltration is by conducting visual inspections or tests on the surface before, during and immediately after rainfall.

Inspect Before a Rainfall— Sediment crusted in the joints when dry is the most opportune time to remove it. During dry periods, the sediment layer in each joint can sometimes dry out and curl upward. This layer can be easily loosened by vacuum equipment.

Additionally, deciduous leaves and pine needles eventually get crushed by traffic, degrade, and work their way into the joints, thereby reducing infiltration. See Figures 7 and 8. The site should be inspected for sediments from adjacent eroding areas and those areas stabilized immediately.

Weeds growing from within joints indicate accumulated sediment in the joints and neglected maintenance. See Figure 9. Weeds will not germinate unless there is accu-

Figure 5. Mulch placed on tarps prevents more expensive cleaning of PICP.

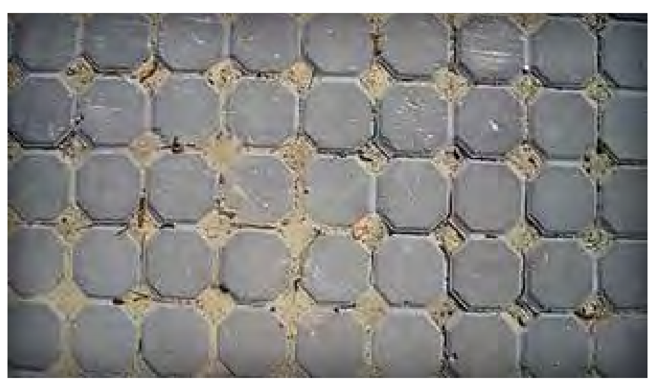

Figure 6. Sand from winter maintenance must be removed the following spring.

Figures 7 and 8. Pine needles and leaves eventually will degrade and get compacted into the joints from traffic. They should be removed by sweeping or vacuuming before that happens.

mulated sediment. Weeds should be removed by hand. Herbicide may kill weeds, but dead vegetation and roots will remain. They typically reduce infiltration and should eventually be removed.

Inspect During and Just After a Rainstorm— The extent of puddles and bird baths observed during and especially after rainstorm indicate a need for surface cleaning.

Table 1. ASTM C1781 test results: relationship between time required to infiltrate and calculated surface infiltration rate

Time to infiltrate water		Approximate surface infiltration rate inches/hr (mm/hr)	
Minutes	Seconds	8 lbs. (3.6 kg) water	40 lbs. (18 kg) water
0.5	30	235 (5,913)	1,175 (29,564)
1	60	117 (2,956)	587 (14,782)
2	120	59 (1,478)	294 (7,391)
4	240	29 (739)	147 (3,696)
6	360	20 (493)	98 (2,464)
8	480	15 (370)	73 (1,848)
15	900	8 (197)	39 (985)
30	1800	4 (99)	20 (493)
60	3600	2 (49)	10 (246)

Note: $I = (K \cdot M)/(D^2 \cdot t)$, where
I = Surface infiltration rate, in./hr (mm/hr)
K = 126,870 for US customary units (4,583,666,000 for metric)
M = water mass, lbs (kg)
D = ring diameter (12 in. or 305 mm)
t = time for water to infiltrate in seconds

Acceptable performance > 100 in./hr (2,500 mm/h)
Plan to clean soon
Clean immediately < 20 in./hr (500 mm/hr)

A minor amount of ponding is likely to occur particularly at transitions from impervious pavement surfaces to PICP. This often occurs first as sediment is transported by runoff and vehicles. See Figures 10 and 11. Should ponding areas occupy more than 20% of the entire PICP surface, then surface cleaning should be conducted. While a rainstorm's exact conclusion is difficult to predict, standing water on PICP for more than 15 minutes during or after a rainstorm likely indicates a location approaching clogging.

Test Surface Infiltration— A quick and subjective test for the amount of surface infiltration is pouring water on PICP. If the water spreads rather than infiltrates, the extent of spreading suggests an area that may be clogging. Should more than approximately 20% of the surface area see ponding during or immediately after a rainstorm, a more objective measure of surface infiltration of these areas can be accomplished using ASTM C1781 Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems. Figure 12 illustrates the test set up using a 12 in. (300 mm) diameter ring set on plumber's putty. (The ring can be metal or plastic.) Figure 13 illustrates the test apparatus in

Figure 9. Weeds indicate sediment accumulation and lack of surface cleaning to remove it.

Figure 10. Erosion of adjacent asphalt and sediment deposition on PICP.

Figure 11. Ponding on PICP typically first occurs at the junction with impermeable pavement.

Figure 12. Steps in setting up test equipment for measuring surface infiltration using ASTM C1781.

place with water poured into it.

ASTM C1781 test method begins with "pre-wetting" an area inside the ring to ensure the surface and materials beneath are wet. This is done by slowing pouring 8 lbs (3.6 kg) of water while not allowing the head of water on the paver surface to exceed $^{3}/_{8}$ in. (10 mm) depth. If the time to infiltrate 8 lbs of water is less than 30 seconds (using a stopwatch typically on a cell phone), the subsequent test is done using 40 lbs (18 kg) of water. If more than 30 seconds, then 8 lbs of water is used in the subsequent tests. Again, a $^{3}/_{8}$ in. (10 mm) head is maintained during the pour while being timed with a stopwatch. The surface infiltration rate is calculated using formulas in the test method.

If infiltration measurements on ponded areas consistently result in rates below 20 in./hour (508 mm/hr), they require immediate surface cleaning. PICP surfaces sloped over 2% with less than 40 in./hr infiltrate rate require immediate surface cleaning. An infiltration rate of 20 in./hr equates to 30 minutes' infiltration time and 40 in./hr results in 15 minutes. Table 1 further illustrates the relationship between time

Figure 13. ASTM C1781: pouring the wanter into a 12 in. (300 mm) inside diameter ring set on plumber's putty.

for 40 lbs (18 kg) of water to infiltrate and the calculated infiltration rate. ICPI offers a downloadable calculator for converting time of infiltration to infiltration rates when using C1781. See www.icpi.org/software.

Surface Infiltration Maintenance Types

Rout ine and Restorative Maintenance— There are two approaches or service types for maintaining PICP surface infiltration: routine and restorative. Routine maintenance is done regularly to maintain infiltration. It removes most loose sediment and debris from the surface before being trapped and stuck in the jointing aggregates thereby causing clogging. Routine maintenance may require reinstatement of a small amount of jointing stones or none at all.

Routine Maintenance Equipment Options for Maintaining Various Sized PICP Applications

Cleaning Small Pedestrian Areas and Driveways

Theas are typically under 2,000 sf or 200 m^2 and include patios, plazas, sidewalks, and driveways. Equipment options follow:

Hand-held Bristle Broom— Sweep as needed to clear the surface clear of loose debris. See Figure 14.

Leaf Blower (electric or gas powered)— A minimum air speed of 120 mph (190 kph) is recommended. Jointing aggregates remain in place while removing loose debris such as leaves from the surface. See Figure 15.

Rotary Brush with Plastic Bristles— These are often used to spread jointing stone during construction. Same equipment can be used to clean surface to top of joints. Bristles can flip debris out of joints (depends on bristle reach into the joints). A small amount of aggregate may need to be replaced in the joints after using. See Figure 16.

Wet/Dry Shop Vacuum or Walk-behind Vacuum— Use equipment with a minimum 4 (peak) HP motor with minimum 130 cubic feet (3.7 m^3) per minute suction. These machines can remove some jointing aggregates so they may require replenishment. See Figures 17 and 18.

Power Washer— This equipment should be capable of 1,400 to 1,800 psi (9.6 to 12.4 MPa) pressure. Apply the spray at a 30° angle approximately 18 to 24 in. (45 to 60 cm) from the surface and adjust as needed. This equipment will evacuate jointing aggregate and replenishment will be required. Power washing alone generally is not an optimal cleaning approach because there is almost no opportunity on most sites to remove the water-suspended sediment before the water is absorbed back into the pavement. See Figure 19.

Cleaning Large PICP Areas

These are typically over 2,000 sf or 200 m^2 such as large plazas, long sidewalks and driveways, parking lots, alleys and streets. Equipment options follow:

Street Sweepers— These typically have rotating plastic bristle brushes positioned near the curb side and center pickup into a hopper at the rear. Do not use water as it slows removal of loose dirt into the machine. This machine does provide a small vacuum force to manage dust, but the cleaning action is provided by the mechanical sweeping, so it is moderately effective among large machines for removing sediment in the joints. Bristles from the the main broom can reach into joints parallel to the direction of the broom rotation, but have little effect on the joints not aligned with the broom rotation. See Figure 20.

Regenerative Air Sweepers— Includes a box positioned under the truck and on the pavement through which air is blown and recirculated (hence the term regenerative air). The pavement must have no convex (or reverse) crown in order to create an adequate seal for suction in the box. Air pressure flowing through it picks up loose debris and sediment. Rotating brushes can be used to direct dirt and debris toward the box. See Figure 21.

Figure 14. Bristle broom for removing loose debris

Figure 15. Blowing debris to curbs or gutters for removal and disposal.

Figure 16. Rotary brushes increase cleaning efficiencies.

Restorative Infiltration Maintenance for Large Clogged Surfaces

Restorative maintenance is conducted when sediment has lodged in the jointing stones from traffic and weather. The condition indicates that the PICP surfaces have not been regularly cleaned. Restorative maintenance requires some or complete removal of the jointing aggregates to increase infiltration. The depth of jointing stone removed depends on the penetration depth of the sediment into the joints. This can be determined on a sample of a few clogged joints (typically where ponding occurred) by prying out stones and sediment with a flat head screwdriver until little or no accumulated sediment appears.

True Vacuum Sweepers —These can withdraw jointing material and even the concrete pavers. Therefore, the vacuum engine revolutions must be adjusted by the machine operator during a few test runs to find the setting that withdraws the needed depth of sediment and jointing aggregate. After withdrawal, jointing aggregates will require replenishment. The suction orifice is typically about a yard (meter) wide and positioned on the curb side of the truck. Extremely clogged surfaces will require two or more passes. Figure 22 shows this machine. It is often used by municipalities to clean out storm drain catch basins and may require a separate vacuum attachment to clean pavements.

High-power Washing and Vacuum Equipment —Figure 23 shows the equipment for restorative cleaning where water is applied to help loosen sediment and stones in the joints. Figure 23 shows a vacuum that withdraws sediment and stones immediately after applying water. The water and debris are drawn into a vac truck.

Figure 17. Wet/dry shop vacuum cleans loose sediment from a PICP residential driveway

Figure 18. Walk-behind vacuum cleans a small parking area.

Figure 19. Power washing requires a little practice to minimize jointing stone removal.

High Pressure Air/Vacuum —High pressure air is blasted into the joints and has been shown to be very effective at dislodging sediment and debris. A second step is then required to vacuum up the debris that is dislodged. In Figure 24, the machine in the foreground blows debris completely out of the joints and the second machine takes up the debris into a vac truck similar to that used to clean catch basins. See Figure 24. As with all restorative cleaning methods, clean jointing stone is spread and the empty joints are filled. After removing excess stones from the surface, the pavers with filled joints are compacted with a minimum 5,000 lbf (22 kN) vibratory plate compactor operating at 75-90 Hz. See Figure 25. This helps settle the stones into the joints. Any joints were stones have settled should be filled with more stones within a $^1/_4$ inch (5 mm) of the paver surfaces.

Maintenance Equipment Performance

In 2020, the University of Toronto completed a two year research project, Maintenance Equipment Testing on Accelerated Clogged Permeable Interlocking Concrete Pavements. This study evaluated maintenance equipment for restoration of infiltration rates of PICP systems when joints become severely clogged. The research was conducted at the Toronto & Region Conservation Authority's Kortright Centre in Vaughn, Ontario. The research scope of work included the construction of seven 10 ft. by 10 ft. PICP partial infiltration test pads. The cells were carefully clogged to a surface infiltration rate of ≤ 10 in/hr. The sediment infill used to clog the system was regional street cleaning sediments with a known particle size distribution. Five different technologies were investigated: full vacuum sweeper, regenerative air sweeper, dry mechanical sweeper, water pressure washing, and a hybrid high pressure air/vac system specifically designed for permeable pavement. The objective of the study was to evaluate the effectiveness of each method at restoring surface infiltration rates. The impact of cohesive soil sediment was also evaluated as part of the study. All cleaning technologies significantly improve surface infiltration rates. However, the high pressure air-vac hybrid had the best and least variable results, and was the only technique able to fully restore surface infiltration rates. Joint penetration depth was generally a good indicator of restoration effectiveness, except if sediment gradation varies. A complete copy of the report can be found at https://tinyurl.com/y67zhydz .

Figure 20. This type of mechanical sweeper removes sediment from joints parallel to the direction of the broom rotation.

Also in 2020 the United States Geological Survey Madison, WI office published results of a four year investigation on cleaning PICP, Assessment of Restorative Maintenance Practices on the Infiltration Capacity of Permeable Pavement Assessment of Restorative Maintenance Practices on the Infiltration Capacity of Permeable Pavement. Since 2014, this research site has collected water quality, temperature, infiltration rates, and surface flow data with three types of permeable pavement sections (pervious asphalt, porous

Figure 21. A regenerative air machine does routine cleaning in a PICP parking lot.

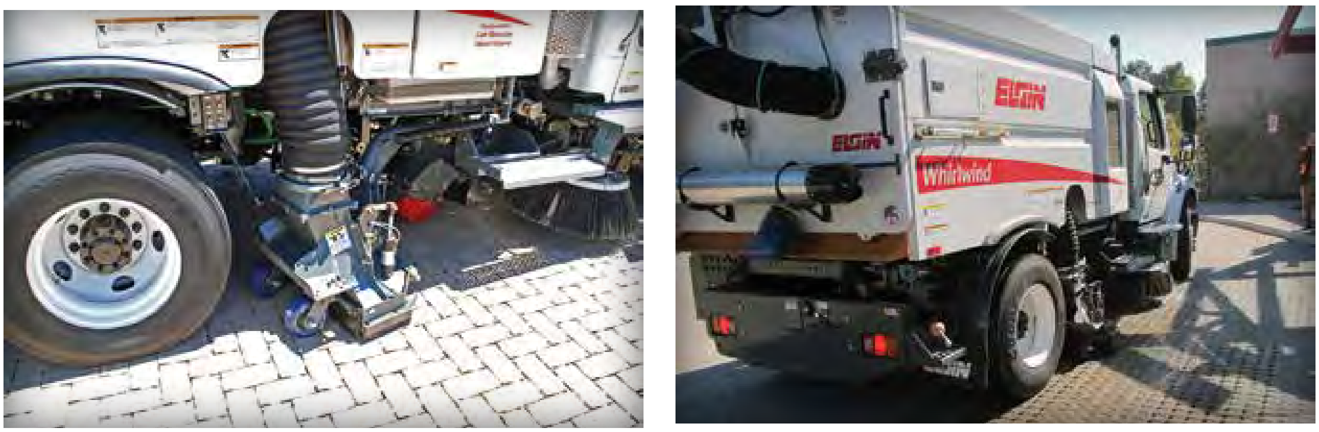

Figure 22. A true vacuum machine cleaning neglected PICP.

concrete, and permeable interlocking concrete pavement). Contributory drainage from an adjacent parking lot provided an opportunity for accelerate clogging and collect data for 9:1 and 5:1 drainage ratios. The following six pavement cleaning methods were evaluated over a 4-year period: manual cleaning with a masonry trowel; Leaf blower and broom; true vacuum; water-enhanced vacuum; high pressure air system; and pressure washer with soil vacuum. An evaluation of the efficiency of each method was based on comparing surface infiltration rates, pre and post cleaning. Surface variability was high due to surface flow patterns across the permeable surfaces. All cleaning methods improved surface infiltration rates. PICP showed the greatest recovery compared to pervious concrete or pervious asphalt. These systems were more difficult to maintain due to sedimentation penetrating into the solid matrix related to the twisting of interconnected pores created during placement. Different cleaning methods produce different results however, in all instances, when the same method was applied, PICP showed the greatest recovery in infiltration capacity. At this particular site the majority of clogging occurred within the top 1 inch. A complete copy of the report can be found at https://tinyurl.com/yy9nhou8 .

Inspection Intervals and Procedures for Maintaining Surface Infiltration

Routine maintenance provides the best infiltration performance by implementing the following procedures:

1. Weekly— Prevent contamination from routine landscape maintenance such as grass clippings from mowing, hedge trimming, mulching plant beds, etc. by:
   - Broom sweep debris from the paver surface, or
   - Blow debris from the paver surface with a powered leaf blower onto other surfaces that will not retransmit it to the PICP surface.
   - Mechanically sweep paver surface.
   - Remove loose debris, leaves, needles, sediment, topsoil, mulch, etc. after severe rain storms using the above procedures.
   - Collect and dispose of debris.
2. Semi-annually— Remove loose surface debris from the pavers and jointing stones (1) when trees have defoliated in the fall and (2) at the end of winter snowfall.
   - Use a wet/dry vacuum for small areas and a regenerative air machine for larger areas.

Figure 23. This equipment provides combined washing and vacuum of unmaintained PICP.

Figure 24. This equipment blows sediment and soiled aggregate from the joints and uses vacuum equipment to remove them.

Figure 25. No matter the equipment used, after removing sediment soiled aggregate, clean aggregate is placed in the joints, the surfaced cleaned and compacted.

- Replenish jointing stone as needed to the bottom of the paver chamfers.
- Check any observation wells and outlet pipes from underdrains to confirm drain down and water outflows.

3. As needed— Based on observation and during rainstorms and subsequent surface infiltration tests, remove and replenish the jointing stones and sediment using restorative cleaning equipment and procedures.

Note: Various factors will affect each project's routine maintenance schedule and each must be reviewed individually.

Winter Maintenance

Snow Removal —Unlike other permeable pavement surfaces, PICP demonstrates durability in the winter. PICP can be plowed with steel or hard rubber blades. Steel blades typically scratch all pavement surfaces. When using commercial snow removal companies, confirm in writing they provide protective edges on the snowplow equipment to avoid scratching the surface. Most pavers have chamfers on their surface edges which can help protect the edges from chipping by snow plows. For smaller areas, use a plastic snow shovel and fit snow blowers with plastic on the scoops and on the gliders. When possible deposit plowed snow onto grassy areas and not on the PICP when the plowed snow is dirty. Such dirt will remain and likely help clog the PICP surface after the snow melts.

Deicers— When used sparingly, deicers should not damage PICP surfaces as the brine typically forms on the surface to lower the freezing temperature of water and eventually moves into the joints with melting ice or snow. Some deicers will accelerate surface wear on some styles of pavers with blasted or hammered surfaces.

A 2020 University of Toronto study on pavement deicing operations quantified some significant winter safety benefits when using PICP. Besides confirming that the use of permeable pavers can eliminate the occurrence of snow melt refreezing and forming black ice, snow and ice can also melt and dry quicker when deicers are used on PICP. More importantly, the research confirmed that a much lower deicing salt application rate is required on PICP compared to impervious asphalt, while still maintaining a high level

Figure 26. This is an example of snow that should have been deposited on a grassy area. If such areas are not available, then vacuum clean the PICP in the early spring.

Table 2. Maintenance guidelines for all PICP distresses

Distress	Activity	Frequency
Clogging	Schedule appropriate routine cleaning method based on site conditions. Utilize restoration cleaning methods as needed when surface infiltration rates decrease below project threshold. Hot spot cleaning may be appropriate.	1 to 2 times annually; adjust frequency based on sediment loading
Clogged/Damaged Secondary Features	Clean out or repair secondary drainage features.	Annually, after major rain event
Depressions	Repair all paver surface depressions, exceeding 0.5 in. (13 mm)	Annually, repair as needed
Rutting	Repair all paver surface rutting, exceeding 0.6 in. (15 mm)	Annually, repair as needed
Faulting	Repair all paver surface faulting, exceeding 0.25 in. (6 mm)	Annually, repair as needed
Damage Paver Units	Replace medium to high severity cracked, spalled or chipped paver units.	Annually, repair as needed
Edge Restraint Damage	Repair pavers offset by more than 0.25 in. (6 mm) from adjacent units or curbs, inlets, etc.	Annually, repair as needed
Excessive Joint Width	Repair pavers exhibiting joint widths exceeding 0.5 in. (13 mm)	Annually, repair as needed
Joint Filler Loss	Replenish aggregate in joints.	As needed
Horizontal Creep	Repair areas exhibiting horizontal creep exceeding 0.4 in. (10 mm)	Annually, repair as needed
Excessive Settlement	For settlements greater than 1 in. consult a pavement engineer versed in OGA design and construction to determine cause and correction.	As needed.
Additional Distresses	Missing pavers shall be replaced. A geotechnical investigation is recommended for pavement heaves.	Annually, repair as needed

of slip and skid resistance. The study also demonstrated that PICP systems can attenuate and buffer the release of salt back into the environment, an important finding since there is concern about snowmelt and stormwater runoff environmentally damaging lakes and rivers.

Deicer types acceptable for use in on PICP surfaces include sodium chloride, calcium chloride and potassium chloride. Do not use magnesium chloride as it will eventually destroy all concrete materials. Anti-icing agents that contain ammonium nitrate and ammonium sulfate should not be used since they can also erode concrete. Always read and follow the manufacturer's recommendations for use and heed all warnings and cautions.

Maintenance for Other Distresses

Over time and traffic, PICP can exhibit other distresses besides surface ponding from clogged joints. These are outlined in Table 2 and remedies are provided.

Utility Restoration Guidelines

1. Remove and store pavers for reuse. Secure undisturbed pavers in opening with wood or metal frame.
2. Remove and dispose of all jointing and bedding aggregate as they typically cannot be re-used.
3. Remove the aggregate base and subbase material. Incidental mixing of base and subbase aggregates is acceptable, but make every effort to separate them. Store in on impermeable pavement or a geotextile to prevent contamination. Do not reuse contaminated aggregate.
4. Re-compact subgrade material as required for stability during utility repairs.
5. Repair or install utility as required.
6. If below the bottom of the subbase, place and compact dense-graded road base in lifts not exceeding 6 in. (150 mm) and compact to 100 percent of standard Proctor maximum dry density. The top of the dense-graded aggregate should be at the same elevation as the bottom of the open-graded subbase aggregate. Alternately flowable fill could be used to reestablish the subgrade surface.
7. Reinstate and compact the subbase aggregate in minimum 6 in. (150 mm) lifts. Use a minimum 13,500 (65 kN) plate compactor with a compaction indicator. Add new subbase aggregate if needed.
8. Reinstate and compact the base aggregate as one 4 in. (100 mm) lift. Use a minimum 13,500 lbf (65 kN) plate compactor with a compaction indicator. A lightweight deflectomer (LWD) can be used to ensure that deflections of the compacted base aggregate are below an average of 0.5 mm (assuming a minimum 12 in. (300 mm)) compacted aggregate subbase. An LWD should be used according to ASTM E2835.
9. Place and screed new bedding aggregate in a consistent thickness layer between 1.5 and 2 in. (38 and 50 mm).
10. Reinstate pavers with at surface at least 1 in. (25 mm) higher than the final elevation. Compact the pavers in two perpendicular directions with a minimum 5,000 lbf (22 kN) plate compactor. Fill joints with aggregate, sweep away excess, and compact the pavers in two perpendicular directions again. Compact pavers so they are level with surrounding pavers.
11. Sweep surface clean and remove any excess aggregate and debris.

Other recommendations include keeping all removed materials clean and free of sediment and debris. Minimize excess debris from construction activities and equipment entering the permeable surface. Store all materials away from the permeable surface, otherwise separate materials from the permeable surface with geotextile. Pavement cuts located parallel and close to the wheel path should be extended to include the wheel path. Cuts located within 3 ft (1 m) of a curb or construction joint should include the removal of the adjacent base and subbase to the edge of the curb or construction joint.

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Drake, et al. (2020), "De-icing Operations for Permeable Interlocking Concrete Pavements", University of Toronto, Dept. of Civil and Mineral Engineering

Danz, et al. (2020), "Assessment of Restorative Maintenance Practices on the Infiltration Capacity of Permeable Pavement", U.S. Geological Survey, Middleton, WI

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Interlocking Concrete Pavement Institute®

13750 Sunrise Valley Drive
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

Tel: 703.657.6900
Fax: 703.657.6901
E-mail: icpi@icpi.org
www.icpi.org

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Tech Spec Guide

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- Tech Spec 21: Capping and Compression Strength Testing Procedures for Concrete Pavers
- Tech Spec 22: Geosynthetics for Segmental Concrete Pavements
- Tech Spec 23: Maintenance Guide for Permeable Interlocking Concrete Pavements
- Tech Spec 24: Structural Design of Segmental Concrete Paving Slab and Plank Pavement Systems
- Tech Spec 25: Construction Guidelines for Segmental Concrete Paving Slabs and Planks in Non-Vehicular Residential Applications

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Tech Spec 24

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Structural Design of Segmental Concrete Paving Slab and Plank Pavement Systems

Introduction

Project owners and designers specify segmental concrete paving slabs and planks due to their unique visual appeal and finishes. Their large or linear format often fits a particular dimensional module for the design of the project, complements the architectural character of adjacent buildings, or enhances the landscape architecture of the site. Some designers understate the visual pattern of a segmental pavement surface by using paving slabs with fewer joints. In other situations, designers may mix smaller and larger slab units to create strong visual effects. Planks or linear paving units are often used to suggest visual movement and direction. While most applications are for pedestrian uses, paving slabs and planks are seeing increased use in areas with vehicular traffic.

This technical bulletin provides structural design guidance on paving slabs and planks for at-grade applications. This Tech Spec introduces structural design tables that provide guidance on maximum vehicular traffic loads for various unit sizes and thicknesses, as well as selected base materials and thicknesses. Roof applications using paving slabs for pedestrian applications is covered in ICPI Tech Spec 14–Concrete Paving Units for Roof Decks.

When properly designed and constructed, slab and plank pavement systems can withstand a limited amount of automobile and truck traffic. Unlike interlocking concrete pavements, slab and plank systems offer little to no vertical, horizontal or rotational interlock. They do not transfer applied loads to neighboring units, thereby limiting their application to areas with little traffic. Besides appropriate structural design provided in this bulletin, selection, testing, and installation of base and paving materials requires a high level of competency in order to assure successful performance. For areas with higher traffic loads than those provided in the design tables in this

Figure 1. Concrete paving slabs can create certain moods and enhance the character of a project.

technical bulletin, interlocking concrete pavement or permeable interlocking concrete pavement should be considered. Structural design for interlocking concrete pavement is covered in ICPI Tech Spec 4 and in ASCE 58-16 Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways. This Tech Spec and all others are available for free on www.icpi.org. Permeable interlocking concrete pavement structural design is covered in the ICPI manual, Permeable Interlocking Concrete Pavements and in ASCE 68-18 with the same name.

Paving Slab Systems

Product Definitions— In the U.S. ASTM C1782 Standard Specification for Utility Segmental Concrete Paving Slabs defines their dimensional envelope as having an exposed face area greater than 101 in.^{2} (0.065 m^2) and a length divided by thickness greater than four. The minimum thickness is 1.2 in. (30 mm), and maximum length and width dimensions are 48 in. (1220 mm). C1782 was first issued by ASTM in 2016.

In Canada, CSA A231.1 Precast Concrete Paving Slabs defines the dimensional envelope with a face area greater than 139.5 in.^{2} (0.09 m^2) and a length divided by thickness of greater than four. The minimum thickness is 1.2 in. (30 mm), and the maximum length and width dimensions are 39.37 in. (1000 mm). This product standard was first issued by CSA in 1972.

Strength Requirements— Laboratory flexural or bending strength requirements are provided in ASTM C1782 and CSA A231.1 paving slab standards. Figure 2 illustrates the flexural strength test method. Laboratory tests for flexural or bending strength is determined by suspending the paving slab between two rollers and applying a load across the center until failure. The flexural strength in pounds per square inch or megapascals is calculated using a modulus of rupture formula. A noteworthy aspect of the flexural strength formula is doubling the thickness of a paving slab increases the flexural (bending) strength by four times. This suggests that units may need increased thicknesses in order to withstand vehicular traffic. This need is addressed in the design tables presented later in this bulletin. In addition, concrete paving slabs may use fibers to increase their flexural strength.

ASTM C1782 and CSA A231.1 require an average minimum flexural strength of 725 psi (5 MPa) with no individual unit less than 650 psi (4.5 MPa). Unlike interlocking concrete pavers, compressive strength testing is not used to establish the strength of paving slabs. The reason for this is paving slabs are larger and often thinner than concrete pavers. If slabs are tested in compression, they will render a misleading higher compressive strength than concrete pavers. This principal applies to all concrete materials: as they become thinner, they render increased compressive strengths (while increasingly subject to failure in bending). The higher compressive strengths in slabs must be reduced to accurately compare that strength to a similar thickness and length of concrete pavers or other concrete products. Flexural strength testing for paving slabs provides a more realistic characterization of field conditions as the primary failure mode is bending which results in cracking from repeated vehicular wheel loads.

Freeze-thaw durability requirements in ASTM C1782 references ASTM C1645 Standard Test Method for Freeze-thaw and De-icing Salt Durability of Solid Concrete Interlocking Paving Units This test method involves cutting coupons (test specimens) of a specified dimensional range from the corner of paving slabs. The coupons are immersed in water or a 3% saline solution and subjected up to 49 freeze-thaw cycles. The mass lost from the coupons are measured at

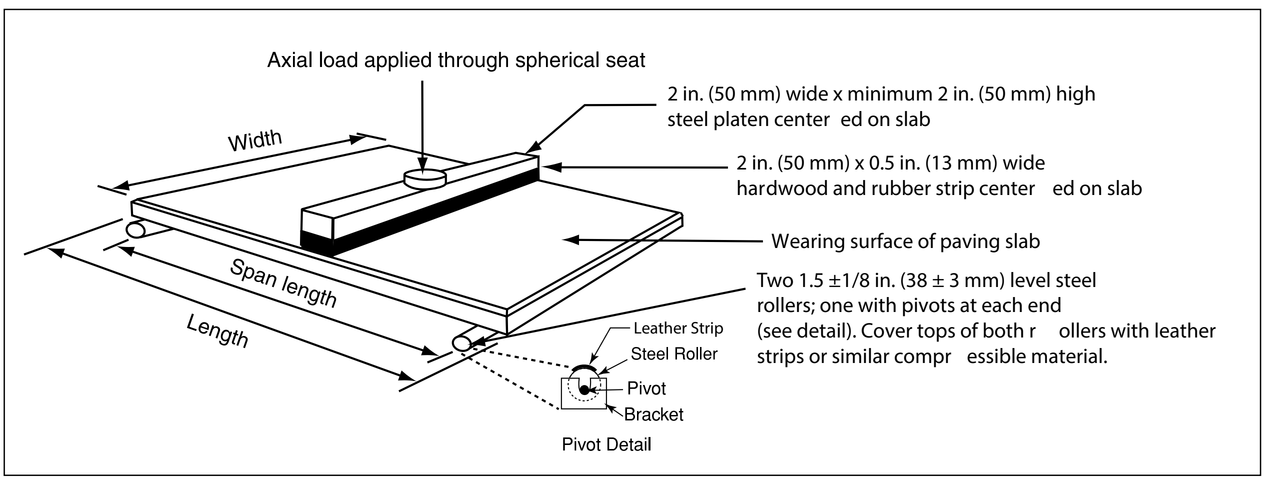

Figure 2. Flexural or bending test to determine the modulus of rupture.

28 and 49 cycles. If no more than an average of 225 grams per square meter of surface area are lost after 28 cycles, the paving slab passes this requirement in C1782. If not, the freeze-thaw cycles continue to a maximum of 49. If no more than an average of 500 grams per square meter of surface is lost after 49 cycles, the paving slab passes this requirement. The lowest temperature used in this freeze-thaw test is 23°F or -5° C. Figure 3 illustrates a test specimen in saline solution prepared for this test.

Freeze-thaw durability testing in CSA A231.1 is the same as in ASTM C1782. However, the lowest temperature in the CSA standard is 5° F or -15° C.

Dimensional tolerances are similar in ASTM and CSA paving slab standards. Dimensional tolerances are determined from unit dimensions provided by the manufacturer for specific products. Tolerances for length, width and height and for convex and concave warpage are as follows:

- Length and width: –0.04 and +0.08 in. (–1.0 and +2.0 mm)
- For units over 24 in. (610 mm), ASTM C1782 allows –0.06 and +0.12 in. (–1.5 and +3.0 mm)
- Height: ±0.12 in (±3.0 mm)
- Concave or convex warpage in units up to and including 18 in. (450 mm) in length or width: 0.08 in. (2.0 mm): units over 18 in. (450 mm): 0.12 in. (3.0 mm)

Paving slabs meeting these tolerances can be installed on a sand setting bed (i.e., sand-set) in residential applications, but are not suitable for more accurate sand-set, bitumen-set or pedestal-set deck commercial applications. These installation methods typically require length, width, thickness and warpage tolerances of ±0.06 in. (±1.5 mm) than the specified dimensions. In some cases, paving units may require post-production grinding to achieve these tolerances. This treatment is sometimes called gauging.

The Importance of Nomenclature

Segmental concrete paving slabs are sometimes mistakenly called concrete pavers or simply pavers. This has led to past misapplication of paving slabs in areas with substantial vehicular loads where interlocking concrete pavers should have been used. While concrete pavers and paving slabs are used in pedestrian applications, slabs are primarily for pedestrian use and limited vehicular traffic. Very large and thick slabs (called mega-slabs or large format paving units) have been used in some urban vehicular applications. A practical, construction-related difference between concrete pavers and paving slabs is the former generally requires one hand to install a unit and the latter requires at least two hands to lift and place.

Figure 3. Test specimen from a slab immersed in a 3% saline solution ready for exposure to laboratory freeze-thaw cycles.

To emphasize differences in their ability to receive repeated vehicular loads, compare the total number of lifetime 18,000 lb. (80 kN) equivalent single axle loads (ESALs) in the base thickness design tables in ICPI Tech Spec 4–Structural Design of Interlocking Concrete Pavement to those in this bulletin. Tech Spec 4provides structural designs up to 10 million ESALs whereas the maximum in this bulletin for paving slabs and planks is 30,000 ESALs. This indicates that paving slabs and planks are exposed to limited vehicular traffic, and especially a limited number of trucks.

Types of Finishes

Slab and plank manufacturing methods can include dry cast (zero slump) or wet cast concrete, or hydraulically pressed units. Like concrete pavers, concrete paving slabs can be manufactured with a variety of colors, special aggregates, and architectural finishes to enhance their appearance. Surface finishes include formed, shot-blasted, hammered, polished and tumbled. Blasted finishes are created by rapidly discharging small steel pellets on the surface to create a roughened, stone like appearance. Hammered finishes rely on knurled steel hammers to roughen the surface. Rotating disk grinders create polished surfaces that smooth the surface even to the point where units appear as terrazzo. Architectural finishes typically rely on special aggregates and pigment in the surface that become more pronounced after surface treatments. All of these finishes provide visually attractive alternatives superior in appearance to many other types of pavement materials. See Figure 4.

Structural Design

Pedestrian Applications —For pedestrian applications, units up to 12 x 12 in. (300 x 300 mm) in length and width can be placed on a minimum 6 in. (150 mm) thickness of compacted aggregate base under a 1 in. (25 mm) thick sand setting bed with jointing sand. Thicker bases (generally 8 to 12 in. or 200 to 300 mm thick) should be used in freezing climates and/or on weak clay soils (CBR < 3%). For units larger than 12 x 12 in., designers should consider using a concrete base because achieving a very smooth, compacted aggregate base surface can be difficult and time consuming. If the paving units are in commercial sand-set or bitumen-set pedestrian applications, they will likely require higher (closer) tolerances than ASTM or CSA product standards require as previously noted. For additional information on bitumen-set applications, read ICPI Tech Spec 20€onstruction of Bituminous-Sand Set Interlocking Concrete Pavement.“Dry pack” bedding layers consisting of a sand-cement mix on any base are not recommended for pedestrian or vehicular applications. There is little assurance of a consistent sand-cement mix (typically done on the job site). This mixture does not keep out water which can weaken it over time, especially in freezing climates.

Vehicular Applications —A civil engineer should be consulted to assist with structural designs for vehicular applications as noted below.

1. Determine the anticipated traffic use in Table 1 . The maximum allowable 18,000 lb (80 kN) equivalent single axle loads or ESALs for paving slabs is 30,000 or a Caltrans Traffic Index (TI) of 6.

2. Determine the soil streng th. The minimum values for designs is a resilient modulus of 5,100 psi (35 MPa), 3% California Bearing Ratio, or an R-value = 7. Determine the resilient modulus, M_r, per AASHTO T-307 Determining the Resilient Modulus of Soils and Aggregate Materials Surrogate test methods may be used including ASTM D1883 Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils AASHTO T-193 The California Bearing Ratio The CBR test should be a 96-hour soaked test to represent subgrade strength in its weakest condition. Test methods can include R-Value using ASTM

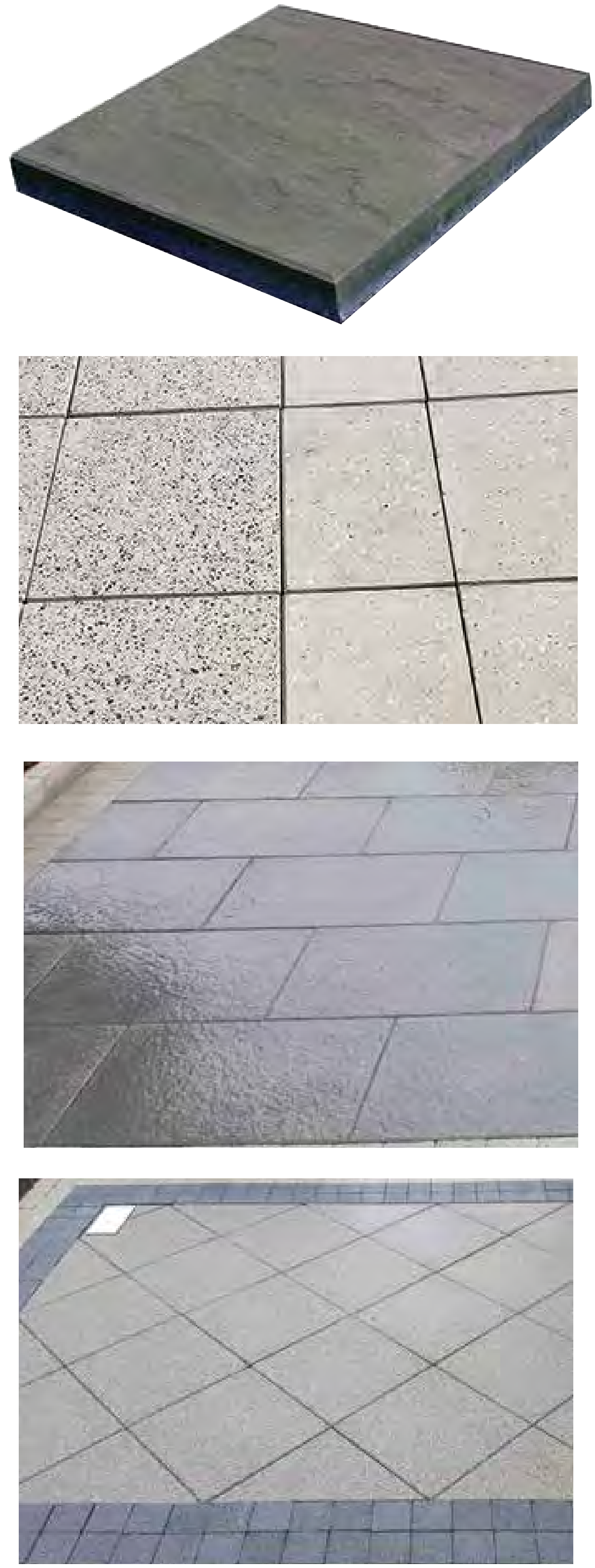

Figure 4. Some examples of paving slab finishes (top to bottom): textured, polished, hammered, and shot blasted.

D2844 Standard Test Method for Resistance R-Value and Expansion Pressure of Compacted Soils or AASHTO T-190 of the same title. CBR and R-Values are correlated to resilient modulus, M_r, using the equations below:

M_r in psi = 2,555 x (CBR)$^{0.64}$ M_r in MPa = 17.61 x CBR$^{0.64}$

M_r in psi = 1,155 + 555 x R M_r in MPa = (1,155 + 555 x R)/145

3. Determine the paving slab length and width. This may be influenced by architectural design considerations. Such considerations must align with the structural design guidelines in this bulletin. This may require using a smaller and/or thicker unit configuration in some traffic situations. Square units are recommended in vehicular traffic with placement in a running bond pattern. Rectangular units should be subject only to pedestrian traffic.

4. Select one of two base options . Tables 2 and 3 correspond to the base options listed below. Note that Tables 2 and 3 apply to units with a minimum flexural strength of 725 psi (5 MPa) required in ASTM C1782 and CSA A231.1.

Base options:

(a) A 12 in. (300 mm) thick compacted aggregate base whose gradation conforms to provincial, state or municipal specifications for road base used under asphalt pavement. If there are no standards or guidelines, use the gradations in ASTM D2940 Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports and as described in ICPI Tech Spec 2–Construction of Interlocking Concrete Pavements Construction should include compacting the soils subgrade and bases/subbases to at least 95% of standard Proctor density per ASTM D698 Standard Test Methods for Laboratory Compaction of Soil Standard Effort.

(b) A 4 in. (100 mm) thick concrete base over a 6 in. (150 mm) compacted aggregate base. The concrete (typically ready-mixed) minimum compressive strength is 3,000 psi (20 MPa) per ASTM C39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens Concrete bases are required for bitumen-set applications.

5. Find the paving slab length, width and thickness in the table that corresponds to the base type selected. If the paving slab length and width are not in the table, find the next closest with the same length and width or smaller, and the same thickness or thicker.

6. From the table and slab configuration row selected, go across to intersect the column that best represents the soil characteristics from laboratory testing. If the exact soil characteristics do not match those in the table, then use the closest lower (conservative) values. Soils with values exceeding those on the tables should not be exposed to higher traffic than as indicated in the tables. In other words, use the configurations under the highest soil subgrade resilient modulus of 11,600 psi (80 MPa), 10% CBR or R-value = 18.

Table 1. Traffic categories and limits

Traffic Limits	Category Symbol	Stress Ratio	Lifetime ESALs** (TI)	Equivalent Heavy Vehicles/Day
Do Not Subject to Vehicles	No	>0.7	0	0
Primarily Pedestrian*	P	0.7	1,000 (4)	0.1
Cars only (< 4500 lbs or 2000 kg)	C	0.5	7,500 (5)	0.5
Cars and Light Trucks (< 10,000 lb or 4500 kg)	LT	0.4	30,000 (6)	2.0

*This includes applications with extremely rare use by emergency vehicles. Maintenance vehicles are not allowed. This traffic category includes residential driveways. Caution: Units larger than 12 x 12 in. (300 mm x 300 mm) may shift under tires.
**ESALs = 18,000 lb (80 kN) equivalent single axle loads.

7. If the traffic category symbol in Table 1 matches the number of ESALs for the anticipated traffic selected, then the selected paving slab configuration may be used.

8. If the traffic category symbol in Table 1 represents a lower number of ESALS for the anticipated traffic selected, then find a traffic limit symbol that matches the original selection by:

   (a) checking another table with a different base;
   (b) select a thicker paving slab, or
   (c) select a smaller paving slab.

9. If the traffic category symbol in Table 1 represents a higher number of ESALS for the anticipated traffic selected , the designer has the option of finding a traffic limit symbol that matches the original selection by:

   (a) checking another table with a different base;
   (b) select a thinner paving slab; or
   (c) select a larger paving slab.

Tables 2 and 3 were developed by Applied Research Associates, Inc. using finite element modeling of a dual truck tire (40 kN or 9,000 lb load) passing over the paving slabs, an inch of bedding sand, and the bases noted on the tables (ARA 2016). Resulting slab stresses were divided by the paving slab flexural strengths noted on the tables to render stress ratios. Low stress ratios were applied to the higher ESALs to reduce the risk of paving slab cracking and higher ratios applied to lower ESAL traffic. Additionally, stress ratios lower than those associated with concrete road pavements were applied to higher ESALs as a conservative design measure because lateral forces from truck tires turning, braking or accelerating were not modeled.

Full-scale load testing was conducted on a limited number of slabs. The slab sizes tested are noted with asterisks on Tables 2 and 3 and the rest developed using finite element modeling. Full-scale load testing was done across a test pad subject to slowly moving truck traffic with no turning and little braking forces. The slabs on aggregate and concrete bases were subject to 75,000 ESALs with some performing adequately. However, the design tables reflect a 30,000 ESAL limit. This conservative limit is provided because the test pad was not subject to turning and little braking forces which can be significantly higher than wheel loads simply passing over the pavement. (Horr 2022). The designs presented in Tables 2 and 3 are more conservative than those from overseas (CMAA 2000, Interpave 2010, SLG 2013) as well as from performance under full-scale load testing.

Table 2 represents designs for segmental paving slabs set on an inch (25 mm) of bedding sand over 12 in. (300 mm) of compacted aggregate base. Table 3 includes the same 1 in. (25 mm) thick sand setting bed over 4 in. (100 mm) thick concrete base on a 6 in. (150 mm) thick compacted aggregate subbase. Table 3 also applies to structural design of paving slabs in a bitumen-sand bed (typically ¾ to 1 in. or 20 to 25 mm thick) since bitumen-set applications require a concrete base. Table 3 applied to bitumen-set applications introduces an additional measure of conservative design since bitumen-sand materials provide a modest increase in stiffness and increased stability resisting repeated turning, accelerating and braking tire lateral loads. See ICPI Tech Spec 20 Construction of Bituminous-Sand Set Interlocking Concrete Pavement for construction guidance.

No tables in this Tech Spec apply to mortar-set applications as they are not recommended for vehicular applications.

All design tables are based on the flexural strength of slabs and planks in full contact with the bedding and base beneath. The tables assume bending or flexural strength per ASTM or CSA test methods. Because these tests suspend a paving unit between two rollers, this creates a more concentrated stress condition than applying a wheel load to a paving slab or plank fully supported on its entire bottom area. This difference provides a more conservative approach in the design tables.

Table 2. Traffic load limits for concrete paving slabs on a minimum 12 in. (300 mm) thick aggregate base . No = Do not subject to vehicles; P = Primarily pedestrian; C = Cars only; and LT = Cars and light truck per Table 1.

Paving Slab Length in. (mm)	Paving Slab Width in. (mm)	Paving Slab Thickness in. (mm)	SQUARE PAVING SLABS ON A MINIMUM 12 IN. (300 MM) THICK AGGREGATE BASE			
			Paving Slab Minimum Flexural Strength = 725 psi (5.0 MPa) Subgrade Modulus, PSI (MPa) CBR, R-Value			
			5100 (35) 3%, 7	7200 (50) 5%, 10	8700, (60) 6.8%, 13	11,600 (80) 10%, 18
12 (300)	12 (300)	2 (50)	P	P	P	P
*12 (300)	12 (300)	3 (75)	LT	LT	LT	LT
12 (300)	12 (300)	4 (100)	LT	LT	LT	LT
16 (400)	16 (400)	2 (50)	P	P	P	P
16 (400)	16 (400)	3 (75)	LT	LT	LT	LT
16 (400)	16 (400)	4 (100)	LT	LT	LT	LT
18 (450)	18 (450)	2 (50)	No	No	No	P
18 (450)	18 (450)	3 (75)	C	C	C	C
18 (450)	18 (450)	4 (100)	LT	LT	LT	LT
24 (600)	24 (600)	2 (50)	No	No	No	No
*24 (600)	24 (600)	3 (75)	P	P	P	P
24 (600)	24 (600)	4 (100)	C	C	C	C

*Subject to full-scale load tests

Table 3. Traffic load limits for concrete paving slabs on a minimum 4 in. (100 mm) thick concrete base over a 6 in. (150 mm) thick aggregate subbase . LT = Cars and light trucks per Table 1.

Paving Slab Length in. (mm)	Paving Slab Width in. (mm)	Paving Slab Thickness in. (mm)	SQUARE PAVING SLABS ON A MINIMUM 4 IN. (100 MM) THICK CONCRETE BASE AND 6 IN. (150 MM) THICK AGGREGATE SUBBASE			
			Paving Slab Minimum Flexural Strength = 725 psi (5.0 MPa) Subgrade Modulus, PSI (MPa, CBR, R-Value)			
			5100 (35) 3%, 7	7200 (50) 5%, 10	8700 (60) 6.8%, 13	11,600 (80) 10%, 18
*12 (300) to 24 (600)	12 (300) to 24 (600)	2 (50) to 4 (100)	LT	LT	LT	LT

*12 x 12 x 3.125 in. (300 x 300 x 80 mm) slabs were subject to full-scale load tests.
*24 x 24 x 3.125 in. (600 x 600 x 80 mm) slabs were subject to full-scale load tests.

Concrete Planks

Product Definition— Concrete planks or linear paving units are between 11.75 in. (298 mm) and 48 in. (1200 mm) in length. Their minimum width is 3 in. (75 mm) and maximum width is 6 in. (100 mm). Additionally, their plan ratio, or length divided by width, and aspect ratio, or length divided by thickness, are both equal to or greater than four. Their minimum thickness is 2.36 in. (60 mm). (Tables 4 and 5 start at 3 in. (75 mm) minimum thickness for vehicular applications.) Dimensional tolerances can follow that in ASTM C1782 or CSA A231.1. Planks meeting dimensional tolerances in these standards can be installed on a sand setting bed (i.e., sand-set), but are generally not suitable for bitumen-set applications. This installation method requires length, width, thickness and warpage tolerances not exceeding ±0.06 in. (±1.5 mm) than the specified dimensions. In some cases, paving units may require post-production grinding or gauging to achieve these tolerances.

Product Standards in the U.S.— While there is no ASTM standard for planks, the following guidance for product testing and specifications is recommended. Plank units can be tested in flexural strength according to ASTM C1782. They should have an average minimum flexural strength of 725 psi (5 MPa) in order to correspond to the same on Tables 4 and 5. Dimensional tolerances follow C1782. Likewise, freeze-thaw durability requirements should also conform to the mass loss specified in C1782 using test method C1645.

Product Standards in Canada— While there is no CSA standard for planks, the flexural strength testing method CSA A231.1 Precast Concrete Paving Slabs is recommended. Planks should have a minimum average flexural strength of 725 psi (5 MPa) in order to correspond to the same on Tables 4 and 5. Dimensional tolerances in A231.1 can be applied to planks as well. Freeze-thaw deicer resistance testing should follow that in CSA A231.1 and meet the mass loss requirements as well.

Plank Structural Design

Pedestrian Applications —For pedestrian applications, units up to 12 in. (300 mm) long can be placed on a 1 in. (25 mm) thick layer of coarse, washed bedding sand conforming over a minimum 6 in. (150 mm) thickness of compacted aggregate base. Thicker bases (generally 8 to 12 in. or 200 to 300 mm thick) should be used in freezing climates and/or on weak clay soils (CBR < 3%). For paving units over 12 in. (300 mm) long on a 1 in. (25 mm) thick sand setting bed, a minimum 4 in. (100 mm) thick concrete base on a 6 in. (150 mm) thick aggregate subbase should be considered. Compacted aggregate bases should not be used with paving units longer than 12 in. (300 mm) due to the difficulty of creating a smooth base surface to accommodate bedding sand.

If the planks are bitumen-set for pedestrian or vehicular applications, higher (closer) dimensional tolerances than those noted under Product Definition are recommended, i.e., ± 0.12 in. or ±1.5 mm for length, width, height, and warpage. Bitumen-set units should be set on a concrete base regardless of their length. For additional information on bitumen-set applications, read ICPI Tech Spec 20–Construction of Bituminous-Sand Set Interlocking Concrete Pavement.

Structural Design Steps for Planks in Vehicular Applications

1. Determine the anticipated traffic use in Table 1. The maximum allowable 18,000 lb (80 kN) equivalent single axle loads or ESALs for planks is 30,000 or a Caltrans Traffic Index (TI) of 6.
2. Determine the soil strength. As with concrete paving slabs, planks in vehicular applications should not be subject to resilient modulus values lower than 5,100 psi (35 MPa), 3% California Bearing Ratio, or an R-value = 7. The recommendations for soil testing for concrete paving slabs also apply to concrete planks.
3. Determine the plank length, width and thickness. This may be influenced by architectural design considerations. Such considerations must align with the design guidelines in this bulletin. This may require using a different unit configuration. Shorter, thicker units are recommended over longer ones in vehicular traffic.
4. Select one of two base options. Tables 4 and 5 correspond to the base options listed below. Two base options presented for supporting planks are the same as those for concrete paving slabs:
   (a) A 12 in. (300 mm) thick compacted aggregate base.
   (b) A 4 in. (100 mm) thick concrete base over a 6 in. (150 mm) compacted aggregate base. This option is required when using bitumen-set planks.
5. Find the plank length and width and thickness in the table that corresponds to the base type selected. If the plank length, width, and thickness are not in the table, find the closest with the same length and width or smaller, and the same thickness or thicker.

6. From the table and slab configuration row selected, go across to intersect the column that best represents the soil characteristics from laboratory testing. If the exact soil characteristics do not match those in the table, then use the closest lower (conservative) values. If the soil subgrade strength is higher and does not appear in the table, use the slab configurations under the highest soil subgrade resilient modulus of 11,600 psi (80 MPa), 10% CBR or R-value = 18.
7. If the traffic limit symbol matches the ESALs of the anticipated traffic selected, then the selected plank length, width and thickness can be used.
8. If the traffic category symbol in Table 1 represents a lower number of ESALs for the anticipated traffic selected, then find a traffic limit symbol that matches the original selection by:
   (a) checking another table with a different base;
   (b) select a thicker plank, or
   (c) select a smaller (shorter) plank.
9. If the traffic category symbol in Table 1 represents a higher number of ESALs for the anticipated traffic selected, then find a traffic limit symbol that matches the original selection by:
   (a) checking another table with a different base;
   (b) select a thinner plank; or
   (c) select a longer plank.

Like the tables for paving slabs, Tables 4 and 5 were developed using finite element modeling of a dual truck tire passing over the planks, an inch of bedding sand, and various bases noted on the tables (ARA 2016). Stresses recorded were divided by the flexural strength of a 725 psi (5 MPa) plank slab to render stress ratios. Low stress ratios were applied to the higher ESALs to reduce the risk of a plank cracking and higher ratios applied to lower ESAL traffic. Additionally, low stress ratios were applied to higher ESALs as a conservative design measure because lateral forces from truck tires from turning, braking or accelerating were not modeled.

Limited full-scale testing was conducted on a few plank sizes. These plank sizes are noted with asterisks on Tables 4 and 5 and the rest developed using finite element modeling. As previously noted, the planks on aggregate and concrete bases were subject to 75,000 ESALs with some performing adequately. However, the design tables reflect a 30,000 ESAL limit. This conservative limit is provided because the test pad was not subject to turning and little braking forces which can be significantly higher than wheel loads simply passing over the pavement. (Horr 2022). Therefore, Tables 4 and 5 represent conservative designs using the finite element modeling by Applied Research Associates, Inc. for concrete planks set on an inch (25 mm) of bedding sand. Table 5 using a concrete base applies to sand-set and bitumen-set applications since a concrete base is required for the latter.

Table 4. Traffic load limits for concrete planks on a minimum 12 in. (300 mm) aggregate base . P = Primarily pedestrian use; C = Cars only; and LT = Cars and light trucks per Table 1.

Plank Length in. (mm)	Plank Width in. (mm)	Plank Thickness in. (mm)	CONCRETE PLANKS ON A MINIMUM 12 IN. (300 MM) AGGREGATE BASE			
			Paving Minimum Flexural Strength = 725 psi (5.0 MPa) Subgrade Modulus, PSI (MPa) CBR, R-Value			
			5100 (35) 3%, 7	7200 (50) 5%, 10	8700 (60) 6.8%, 13	11600 (80) 10%, 18
12 (300)	3 (75)	3 (75)	C	C	C	C
12 (300)	3 (75)	4 (100)	LT	LT	LT	LT
12 (300)	4 (100)	3 (75)	C	C	C	LT
*12 (300)	4 (100)	4 (100)	LT	LT	LT	LT
12 (300)	5 (125)	3 (75)	LT	LT	LT	LT
12 (300)	5 (125)	4 (100)	LT	LT	LT	LT
12 (300)	6 (150)	3 (75)	LT	LT	LT	LT
12 (300)	6 (150)	4 (100)	LT	LT	LT	LT
18 (450)	3 (75)	3 (75)	P	P	P	P
18 (450)	3 (75)	4 (100)	C	C	C	C
18 (450)	4 (100)	3 (75)	P	P	P	P
18 (450)	4 (100)	4 (100)	C	C	C	C
18 (450)	5 (125)	3 (75)	P	P	P	P
18 (450)	5 (125)	4 (100)	C	C	C	LT
18 (450)	6 (150)	3 (75)	P	P	P	P
18 (450)	6 (150)	4 (100)	C	C	LT	LT
24 (600)	3 (75)	3 (75)	P	P	P	P
24 (600)	3 (75)	4 (100)	P	P	P	P
24 (600)	4 (100)	3 (75)	P	P	P	P
24 (600)	4 (100)	4 (100)	C	C	C	C
24 (600)	5 (125)	3 (75)	P	P	P	P
24 (600)	5 (125)	4 (100)	C	C	C	C

Note: 16 x 4 x 4 in. (400 x 100 x 100 mm) units were subject to full-scale tests can be rated suitable for LT traffic.

*Subject to full-scale load tests

Table 4 continued on next page

Table 4. Traffic load limits for concrete planks on a minimum 12 in. (300 mm) aggregate base (continued) . P = Primarily pedestrian use; C = Cars only; and LT = Cars and light trucks per Table 1.

Plank Length in. (mm)	Plank Width in. (mm)	Plank Thickness in. (mm)	CONCRETE PLANKS ON A MINIMUM 12 IN. (300 MM) AGGREGATE BASE Paving Minimum Flexural Strength = 725 psi (5.0 MPa) Subgrade Modulus, PSI (MPa) CBR, R-Value			
			5100 (35) 3%, 7	7200 (50) 5%, 10	8700 (60) 6.8%, 13	11600 (80) 10%, 18
24 (600)	6 (150)	3 (75)	P	P	P	P
24 (600)	6 (150)	4 (100)	C	C	C	C
30 (750)	3 (75)	3 (75)	P	P	P	P
30 (750)	3 (75)	4 (100)	P	P	P	C
30 (750)	4 (100)	3 (75)	P	P	P	P
30 (750)	4 (100)	4 (100)	C	C	C	C
30 (750)	5 (125)	3 (75)	P	P	P	P
30 (750)	5 (125)	4 (100)	C	C	C	C
30 (750)	6 (150)	3 (75)	P	P	P	P
30 (750)	6 (150)	4 (100)	C	C	C	C
36 (900)	3 (75)	3 (75)	P	P	P	P
36 (900)	3 (75)	4 (100)	C	C	C	C
36 (900)	4 (100)	3 (75)	P	P	P	C
36 (900)	4 (100)	4 (100)	C	C	C	C
36 (900)	5 (125)	3 (75)	P	P	P	P
36 (900)	5 (125)	4 (100)	C	C	C	C
36 (900)	6 (150)	3 (75)	P	P	P	P
36 (900)	6 (150)	4 (100)	C	C	C	C

Table 5. Traffic load limits for concrete Planks on a minimum 4 in. (100 mm) concrete base and 6 in. (150 mm) aggregate subbase LT = Cars and light trucks per Table 1.

Plank Length in. (mm)	Plank Width in. (mm)	Plank Thickness in. (mm)	CONCRETE PLANKS ON A MINIMUM 4 IN. (100 MM) CONCRETE BASE AND 6 IN. (150 MM) AGGREGATE SUBBASE Paving Minimum Flexural Strength = 725 psi (5.0 MPa) Subgrade Modulus, PSI (MPa) CBR, R-Value			
			5100 (35) 3%, 7	7200 (50) 5%, 10	8700 (60) 6.8%, 13	11,600 (80) 10%, 18
*12 (300) to 36 (900)	3 (75) to 6 (150)	3 (75) to 4 (100)	LT	LT	LT	LT

*12 x 4 x 4 in. (300 x 100 x 100 mm) units and 16 x 4 x 4 in. (400 x 100 x 100 mm) units subject to full-scale tests can be rated suitable for LT traffic.

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icpi
Interlocking Concrete Pavement Institute®

13750 Sunrise Valley Drive
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

Tel: 703.657.6900
Fax: 703.657.6901
E-mail: icpi@icpi.org
www.icpi.org

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Design and Installation Professionals frequently turn to interlocking concrete pavements and permeable interlocking concrete pavements because they offer lower initial and life cycle costs and provide environmentally sustainable solutions.

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Construction Guidelines for Segmental Concrete Paving Slabs and Planks in Pedestrian Applications

This Tech Spec provides installation guidelines for products defined in ASTM C1782 Standard Specification for Utility Segmental Concrete Paving Slabs and CSA A231.1 Precast Concrete Paving Slabs While there are no ASTM and CSA product standards yet for for concrete planks (also called linear units), this techical bulletin covers minimum recommended product characteristics, as well as best practices for at-grade construction. As further research into the structural design for paving slab and plank pavement systems is completed the recommendations in this Tech Spec will be updated. Roof applications for paving slabs are covered in ICPI Tech Spec 14–Segmental Concrete Paving Units for Roof Decks

Product Characteristics

Paving slabs —ASTM C1782 defines slabs as having an exposed face area greater than 101 in.^{2} (0.065 m^2) and a length divided by thickness (aspect ratio) greater than four. The minimum thickness is 1.2 in. (30 mm), and maximum length and width dimensions are 48 in. (1220 mm). Units require a minimum flexural strength of 725 psi (5 MPa) with no individual unit less than 650 psi (4.5 MPa). Units must meet dimensional tolerances for length, width, thickness and warpage, as well as a freeze-thaw durability requirements. Tighter tolerances for many sand-set and bitumen-set applications are noted in Table 1 in the section on Construction Guidelines.

In Canada, CSA A231.1 Precast Concrete Paving Slabs defines the dimensional envelope with a face area greater than 139.5 in.^{2} (0.09 m^2) and a length divided by thickness of greater than four. The minimum thickness is 1.2 in. (30 mm), and the maximum length and width dimensions are 39.3 in. (1000 mm). Units must have a minimum flexural strength of 725 (5 MPa) with no individual unit less than 650 psi (4.5 MPa). Units must meet dimensional tolerances for length, width, thickness and warpage, as well as a freeze-thaw durability requirements.

Planks —While there are no product standards for planks, they are generally defined as follows:

- Face area less than or equal to 288 in.^{2} (0.185 m^2)
- Length divided by thickness equal to or greater than 4
- Length divided by width equal to or greater than 4
- Minimum thickness = 2.375 in. (60 mm)
- Minimum length = 11.75 in. (298 mm)
- Maximum length = 48 in. (1220 mm)
- Minimum width = 3 in. (75 mm)
- Maximum width = 6 in. (153 mm)

Dimensional tolerances are provided in Table 1 under the Construction Guidelines section.

Flexural strength for planks can be determined using bending test apparatus in ASTM C1782 or CSA A231.1. At the time of delivery to the job site, the recommended minimum average flexural strength is 725 psi (5 MPa) with no individual unit below 650 psi (4.5 MPa). Freeze-thaw durability can be tested using methods referenced in ASTM C1782 or CSA A231.1.

Loading Limits Of Interlocking Concrete Pavements Compared To Paving Slabs and Planks

Paving slabs and planks are designed to be subject to much lower vehicular traffic than interlocking concrete pavers (or simply concrete pavers). Structural design guidance being developed by ICPI notes a maximum lifetime exposure of 30,000 18,000 lb (80 kN) equivalent single axle loads (ESALs). In contrast, ICPI Tech Spec 4–Structural Design of Interlocking Concrete Pavements and ASCE 58-16 Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways provides base and subbase thickness design tables for lifetime ESALs up to 10 million. The ICPI and ASCE structural design methods are not applicable to paving slabs and planks.

Paving slabs and planks can be produced using dry cast, wet cast, hydraulically pressed manufacturing processes. For applications on aggregate bases, the units generally will be installed according to subgrade, base, bedding sand materials and construction methods described in ICPI Tech Spec 2–Construction of Interlocking Concrete Pavements. Applications on compacted aggregate bases and bedding sand are for pedestrian or light automobile traffic with limited trucks. For additional vehicular traffic loads, slabs and planks should generally be installed on bedding sand over a concrete or asphalt base. For additional durability under vehicular traffic, paving slabs can be construed on a concrete base using the methods in ICPI Tech Spec 20–Construction of Bituminous-Sand Set Interlocking Concrete Pavement.

Construction Guidelines for Paving Slabs and Planks

Subgrade compaction and geotextiles —Per recommendations in Tech Spec 2, the soil subgrade should be compacted to at least 98% of standard Proctor density as specified in ASTM D698 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3)). Separation geotextile is recommended to be placed on the compacted soil subgrade and sides of the excavation. A 12 in. (300 mm) strip of geotextile can be used under the bedding sand and turned up at the edge restraint to prevent bedding sand loss. The separation fabric should be selected per AASHTO M-288 Geotextile Specification for Highway Applications.

Aggregate bases —These should conform to provincial, state, or local road agency specifications for bases used under asphalt. If there are no agency specifications, use ASTM D2940 Standard Specification for Graded Aggregate Material For Bases or Subbases for Highways or Airports for aggregate materials. Installed base surface tolerances should be ± 1/4 in. (6 mm) over a 10 ft (3 m) straightedge. This tolerance is tighter than the ± 3/8 in. (10 mm) over a 10 ft (3 m) straightedge for interlocking concrete pavements. The reason for the tighter base surface tolerance for slabs is to provide a more uniform support and help prevent vertical movement due to lack of interlock among the paving units. Bases should slope a minimum of 1.5% for drainage. The installed density should be at least 98% of standard Proctor density per ASTM D698. Figure 1 illustrates a typical cross section using an aggregate base.

Asphalt bases —These should conform to provincial, state or local road agency specfications. Asphalt bases can

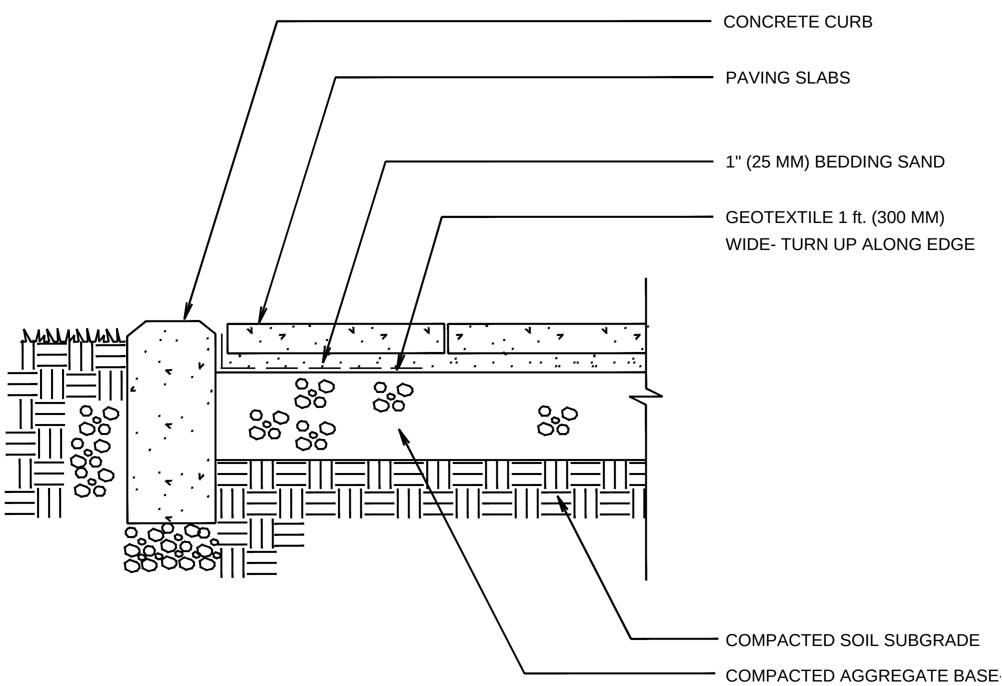

Figure 1. Typical paving slab assembly using an aggregate base

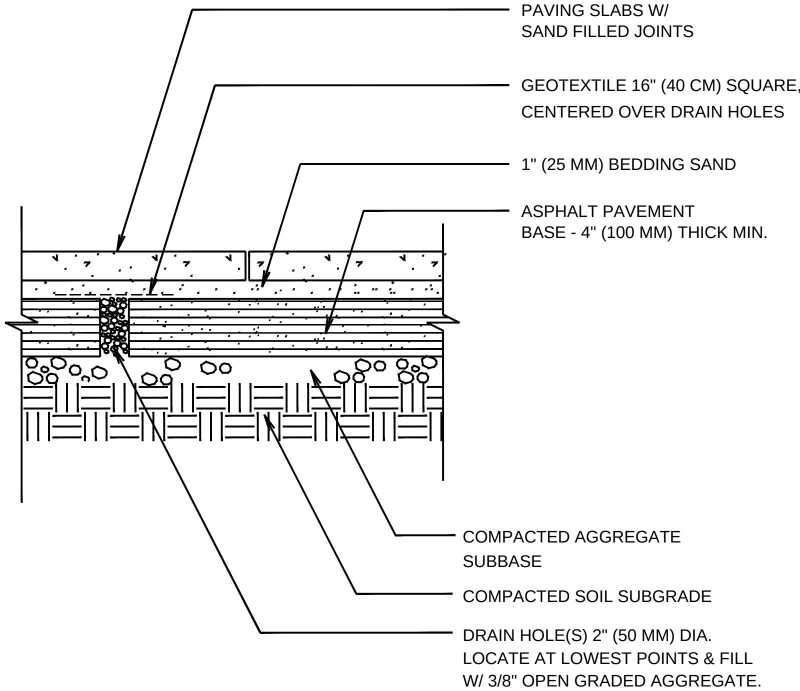

Figure 2. A typical cross section with an asphalt base and sand-set paving slabs

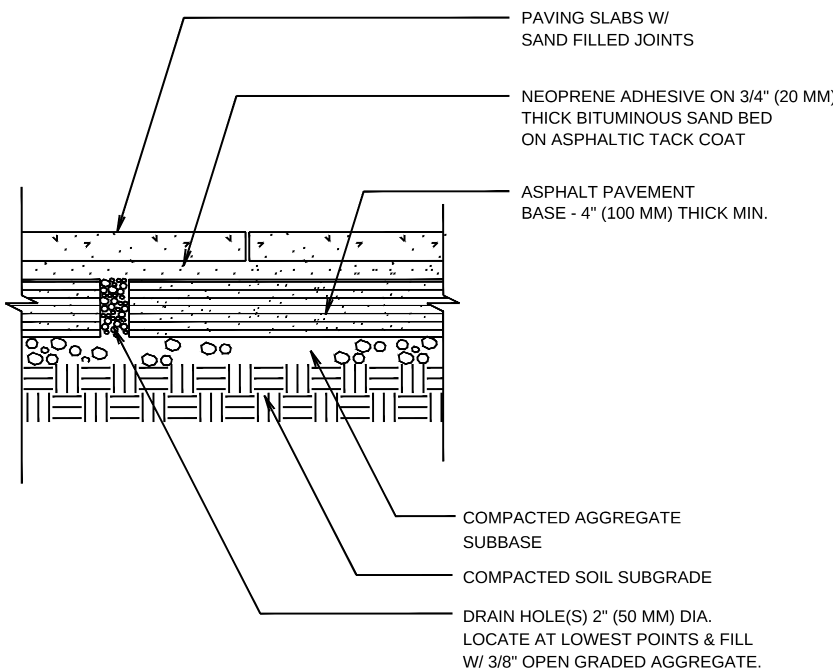

Figure 3. A typical cross section with an asphalt base and bitumen-set paving slabs

accommodate sand and bitumen-sand bedding materials. As noted for aggregate bases, the installed surface tolerance should be ± $^{1}/_{4}$ in. (6 mm) over a 10 ft (3 m) straightedge. Bases should slope a minimum of 1.5% for drainage.

Figures 2 and 3 illustrate sand-set and bitumen-set paving slab applications on an asphalt base. Typically 2 in. (50 mm) diameter holes through the asphalt base, filled with washed angular $^{3}/_{8}$ in. (9 mm) gravel, and covered

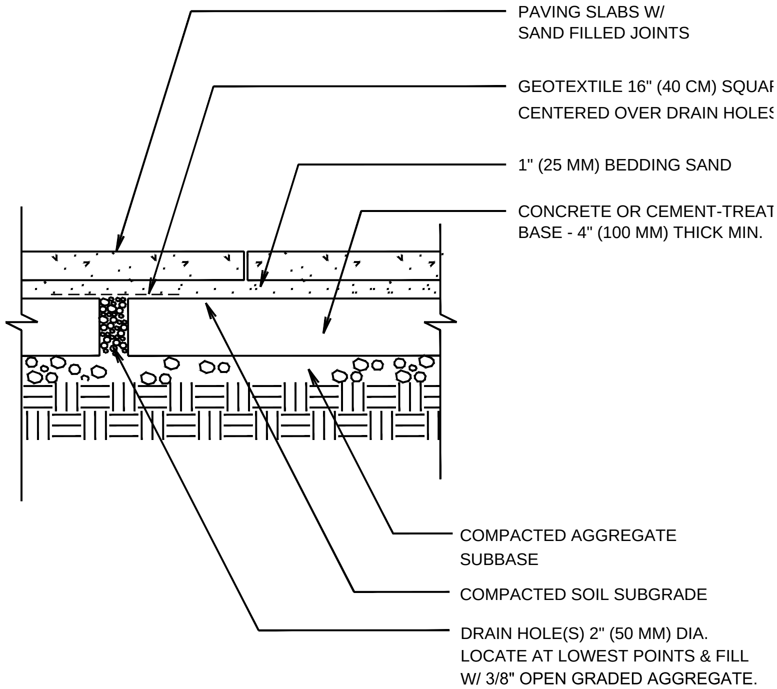

Figure 4. Typical cross section of sand-set paving slabs on a concrete base

with geotextile, to prevent loss of bedding sand, provide drainage of the bedding layer. Alternate bedding drainage systems should be considered in locations where infiltration into the subgrade is not encouraged.

Concrete bases —These should be made with minimum 3,000 psi (20 MPa) concrete per ASTM C39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens The minimum concrete base thickness should be 4 in. (100 mm). Using at least #3 rebar placed at 24 in. centers will help prevent the concrete base from displacing when it cracks. Weep holes are recommended at the lowest elevations. These should be 2 in. (50 mm) in diameter, filled with washed angular $^3/_8$ in. (9 mm) gravel, and covered with geotextile to prevent loss of bedding sand. Alternate bedding drainage systems should be considered in locations where infiltration into the subgrade is not encouraged. The surface tolerances of the concrete base should be ±¼ in. (6 mm) over a 10 ft (3 m) straightedge. Figure 4 shows a typical cross section.

Bedding sand materials and pre-compaction – Bedding sand should be 1 in. (25 mm) compacted thickness. This material should be washed concrete sand conforming to the gradations in ASTM C33 or CSA A23.2A. The percent passing the 0.075 or 0.080 mm sieves in these specifications should be no greater than 1%. Screenings or stone dust should not be used because they do not drain water. Cement-stabilized sand should not be used due to lack of

Figure 5. Precompacting the bedding sand

FIgure 6. Installing planks on uncompacted bedding sand.

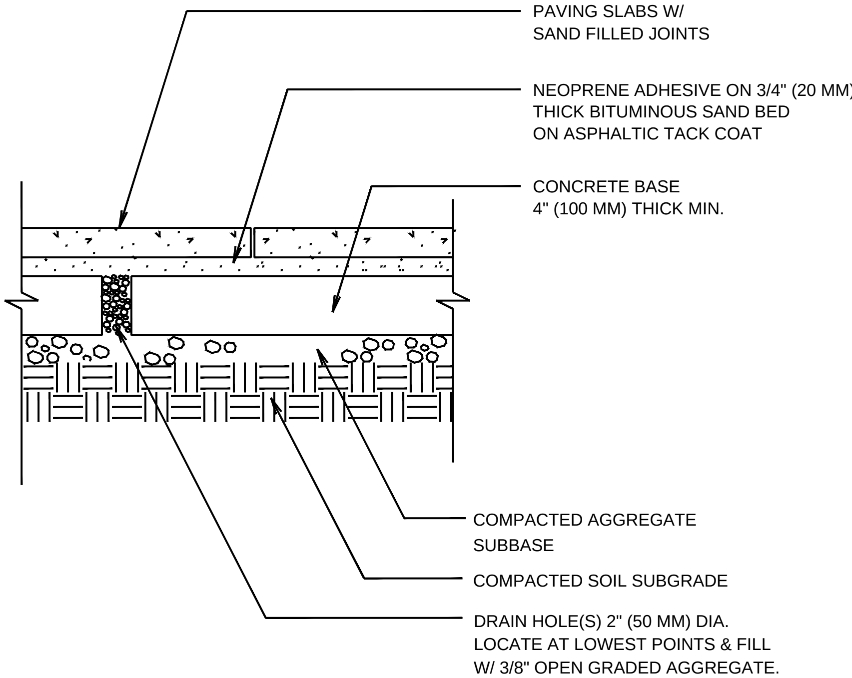

Figure 7. Typical cross section of bitumen-set paving slabs on a concrete base

drainage and potential variability of cement content and resulting stiffness in the mix.

A very smooth, even bedding sand surface is required to seat paving slabs. For paving slab applicatons, some contractors prefer to pre-compact screeded bedding sand with a plate compactor as shown in Figure 5. If pre-compaction is done, care must be taken to leave no indentations in the bedding sand surface from the plate compactor. See Figure 5. These can be removed by screeding the surface to create a thin layer (6 – 10 mm) of uncompacted sand (also known as fluffing).

The entire bedding layer should not be used to compensate for variations in the base surface beyond the specified tolerances. Paving slabs do not interlock and therefore do not spread loads to their neighbors via joint sand. Given this condition, there is no requirement to force bedding sand into the bottom of the joints when compacting the units on uncompacted bedding sand, as is done with interlocking concrete pavers. For planks 18 in. (450mm) and longer or 4 in. (100 mm) and narrower pre-compaction of the bedding sand is recommended to minimize breakage. Shorter or wider planks can be installed on uncompacted bedding sand. See Figure 6.

Bitumen-set applications —These require a concrete base or asphalt base with a surface tolerance of ± ¼ in. (6 mm) over a 10 ft (3 m) straightedge. ICPI's Tech Spec 20–Construction of Bituminous-Sand Set Interlocking Concrete Pavement provides a detailed description of the materials and construction procedures for both. Pedestrian applications can have bases constructed from either concrete or asphalt, whereas vehicular applications should only use concrete bases.

Slabs and planks may be installed with this method, and the paving units must conform to a height tolerance of +/- 1/16 in. (1.5 mm) which will require additional processing by the manufacturer. Concrete curbs, grade beams, cut stone or metal angle edge restraints are required. Pedestrian applications do not require a tack coat of emulsified asphalt on base materials, but it is required for vehicular applications. A ¾ in. (15mm) layer of

Figure 8. Sidewalk application illustrating the neoprene adhesive on an asphalt bedding layer under paving slabs

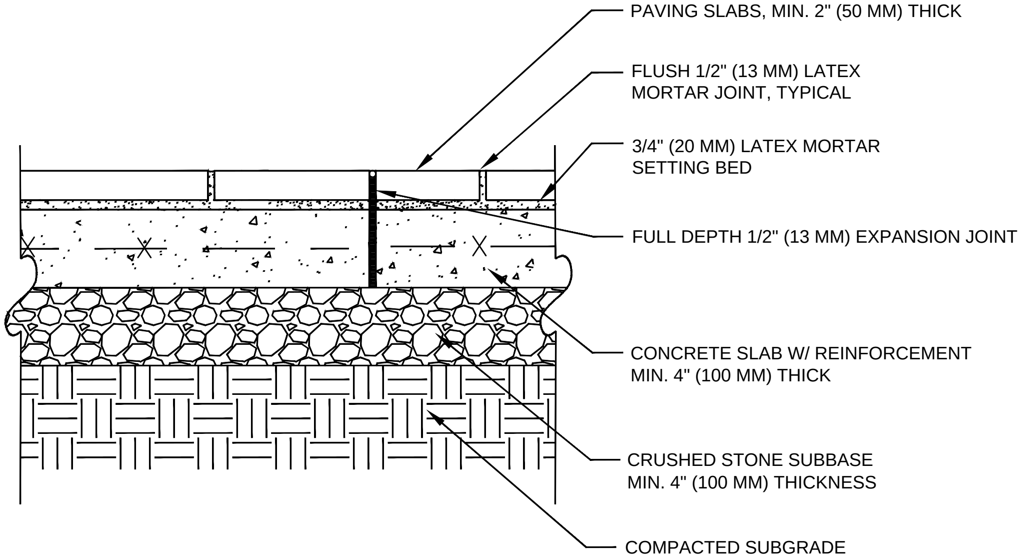

Figure 9. Typical mortar set slab application

heated sand-asphalt mix is then applied and compacted while cooling. This setting bed material may be specified from provincial, state or local road agencies as the sand-asphalt surface mix (topping layer) is typical to most asphalt roads. Figure 6 illustrates a typical cross section. While the setting bed asphalt layer is cooling, a roller or plate compactor is used to consolidate and flatten the surface. The paving units may then be placed in the specified pattern. For additional strength, a neoprene-asphalt mastic can be troweled or squeegeed onto the consolidated asphalt setting bed surface per manufacturer's instructions. This material generally takes an hour or two to "break". Then the paving slabs or planks can be placed. See Figure 7. This adhered process will not allow for paving units to be removed without damaging the setting bed and requiring additional repair.

Washed concrete sand is swept into joints and a roller compactor is applied to pavement surface to consolidate the jointing sand in place. The edge restraints will prevent horizontal creep or movement effectively locking the paving units in place. A liquid joint sealant may be applied to help with joint sand loss or a stabilized joint sand also may be used.

Mortar bedding materials —Mortar is not commonly used with paving slabs and planks due to its increased expense compared to other assemblies, potential marring units with it during placement, and overall lack of construction speed. If specified, Type M mortar should

Figure 10. Single hand scissor clamp for lifting small and thin paving slabs

Figure 11. Double hand clamp for lifting larger paving slabs


Figure 12. Self-contained vacuum lifter with boom


Figure 13. Large vacuum head lifts an oversize paving slab

conform to ASTM C270 Standard Specification for Mortar for Unit Masonry The appendix to this specification cautions on the use of mortar in pavement applications. Also, mortar conforming to ANSI A118.4–Latex Portland Cement Mortar, A118.7–Polymer Modified Cement Grouts or A118.8–Modified Epoxy Emulsion Mortar/Grout. Mortar bedding can be used in pedestrian applications in non-freezing climates and in freezing climates if fortified with a latex or epoxy additive as mortar can be susceptible to damage and deterioration from deicers. Figure 9 shows a typical cross section.

Mortar-set paving slabs or planks are not recommended in vehicular applications in any climate. The exception to using mortar in vehicular applications is for positoning very thick (> 5 in. or >125 mm) and large (<4 ft or 1.2 m) paving slabs onto a concrete base. These size units provide significant spreading of loads, thereby reducing stress on the weaker mortar layer.

Mortar beds can be thin-set with a trowel to approximately 1/2 in. (13 mm) if the concrete base beneath is correctly constructed with close surface tolerances and proper elevations. If not, then thick-set (~1 1/2 in. or 40 mm) mortar is placed, the bottom of the paving units dampened with water prior to setting on these setting bed thicknesses, and then the units placed on the mortar. A rubber mallet is used to align each unit with adjacent ones. The joints are filled with mortar squeezed from in a caulk-type tube or from a mortar bag. The mortared joints are tooled flat so they do not hold water. Mortar accidently dabbed on a slab or plank surface should be removed immediately.

Installation equipment to lift and place paving units —Paving slabs are heavy and the larger units require at least two persons to install them. Serious injury from repetitive movements from manual installation of paving slabs can be avoided by using specialized lifting and


Figure 14. Two-person vacuum lift for paving slabs


Figure 15. Two-person vacuum lift for larger paving slabs.

Figure 16. Using vacuum equipment to install paving slabs in a residential application

placing equipment. Every effort should be made to use such equipment to avoid fatigue and injury. Most projects will have a pavement area with cut units and these may require manual installation. Therefore, worker energy should be reserved for accomplishing these manual tasks, and by using slab installation equipment across as much pavement area as possible.

Installation equipment for paving slabs ranges from manual scissor clamps, that allow one or two workers to lift and place paving slabs, to vacuum lifters.

Scissor clamps —These vary in size depending on the length and width of the unit to be moved. Single hand and double hand clamps are illustrated in Figures 10 and 11. Single hand clamps are suitiable for units up to 24 in. (600 mm) long and maximum 130 lbs (58 kg). Double hand clamps require two people to operate. These are suitable for paving slabs up to 24 x 24 in. (600 x 600 mm) weighing up to 150 lbs (68 kg). These have brackets on each end that grab the paving unit and use its weight to tighten the grip on it. Gripping may be assisted by rubber pads fixed to the brackets. The unit must be grabbed from the center to avoid twisting injury when lifted by the clamp. Fingers must be kept away from pivot points.

Vacuum equipment includes a self-contained vacuum lifter with a boom arm that rotates or swings in most any direction. These machines increase installation efficiency and

Source: Interpave UK

Figures 17 and 18. Vertically stacked paving slabs on a shipping pallet can be lifted, turned to a horizontal position and placed with a vacuum device.

Table 1. Recommended dimensional tolerances paving slabs and planks in sand-set and bitumen-set applications

Length and Width, in. [mm]	Thickness, in. [mm]	Concave or Convex Warpage in One Dimension, in.[mm]
Units up to and including 24 in. [610 mm]:		Up to and including 17.75 in. [450 mm]:
–0.04 [1.0] and +0.08 [2.0]	±0.12 [3.0]	±0.08 [2.0]
Units over 24 in. [610 mm]		Over 17.75 in. [450 mm]
–0.06 [1.5] and +0.12 [3.0]	±0.12 [3.0]	±0.12 [3.0]

are especially suited for paving large areas. See Figure 12.

For very large units, lifting devices exist that can lift and place slabs weighing as much 11,000 lbs (5,000 kg). Figure 13 illustrates such a device which uses more than one vacuum head attached to the paving slab.

Smaller devices use battery or electric powered slab lifters, or they can be attached to an existing machine that provides power for creating the vacuum. Figures 14 through 16 illustrate these devices. The device shown in Figure 14 has a lifting capacity of 330 lbs (150 kg) and Figure 15 has a capacity of 440 lbs (200 kg). Figure 16 illustrates using a slab lifter for smaller slabs.

The piece of equipment that directly attaches via vacuum force to the paving slab is called a lifting head. These come with various thicknesses of foam sealant and configurations that enable lifting of textured slab or those with detectable warnings. Equipment manufacturers can recommend lifting heads for various paving slab surfaces. The sealants wear out, compromise suction, and must be replaced. In addition, most vacuum machines have air filters that must be replaced regularly to maintain a high vacuum force.

Mechanical turning of vertically stacked paving slabs - When shipped to a job site, most paving slabs are stacked vertically on their edges. There are attachments that can grab vertically stacked slabs on a pallet and rotate them to a horizontal position, ready for installation. See Figures 17 and 18.

Placing and compacting paving slabs —As with any segmental pavement, string lines should be pulled for mortared applications or chalk lines snapped onto bedding material set perpendicular to a baseline. These provide lines to guide placement. Joints are typically $^1/_8$ to $^3/_{16}$ in. (3 to 5 mm) wide unless specifically recommended by the manufacturer or designer. Manufacturers may need to grind or "gauge" slabs or planks to achieve the dimensional tolerances shown in Table 1. These result in efficient installation and tight, aligned joints specified in most applications.

Once in place, the slabs or plank surface is cleaned if needed. The units are compacted with minimum 5,000 lbf (22 kN) plate compactor with a roller attachment. See Figure 19. At least two passes should be made, with the second pass perpendicular from the first. Any cracked units should be removed and replaced, and then compacted in place.

Jointing sand —Jointing sand should conform to the gradations in C144 Standard Specification for Aggregate for Masonry Mortar or CSA A179 Mortar and Grout for Unit Masonry. This sand is placed into the joints and the pavement surface cleaned prior to compacting again to prevent surface scratches. At least two passes should be made with a roller attachment on the plate compactor. The second pass is perpendicular from the first. Compaction can follow directly behind spreading sand into the joints.

Joint sand stabilizers can be used to achieve early stabilization and reduce water ingress. Manufacturers instructions should be strictly followed. ICPI Tech Spec 5–Cleaning, Sealing and Joint Sand Stabilization of Interlocking Concrete Pavement provides additional guidance.

Sealers —Sealers can be applied to paving slabs and planks to protect them from stains and enhance their color. Tech Spec 5 provides general guidance on sealer types with advantages and disadvantages of each. If efflorescence appears on the surface, cleaners specifically

Figure 19. Compacting paving slabs with a roller attachment on a plate compactor

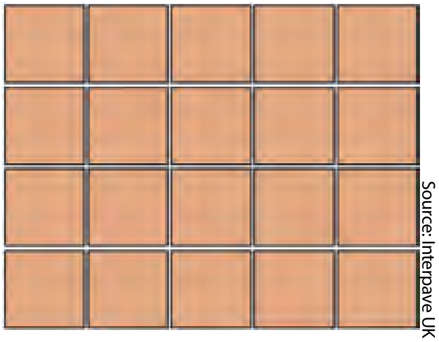

Figure 20. Stack bond

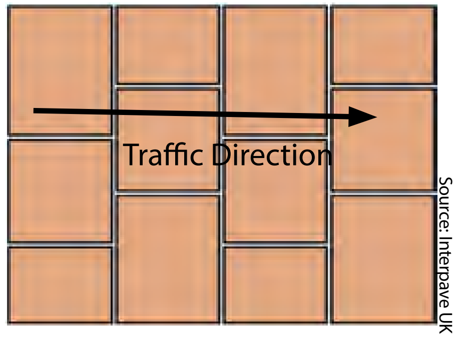

Figure 21. Transverse Running Bond

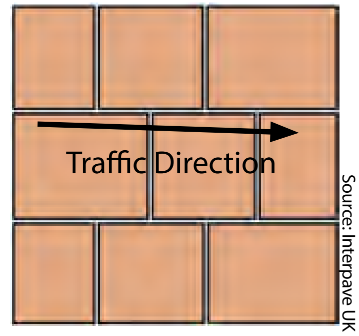

Figure 22. Longitudinal Running Bond

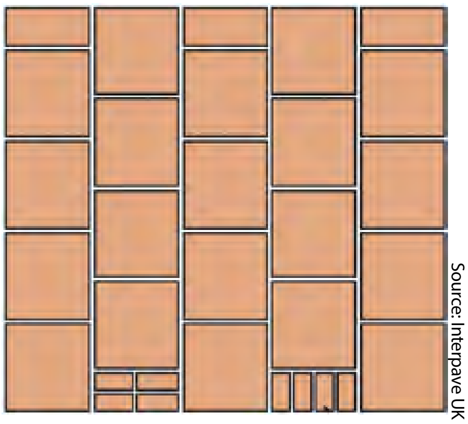

Figure 23. Running bond edges filled with concrete paver sailor or soldier courses

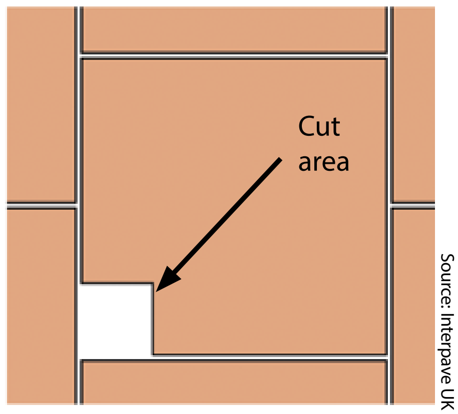

Figure 24. Cut areas less than 25% of the slab area generally do not require additional cuts on the paving slab to reduce the risk of cracking.

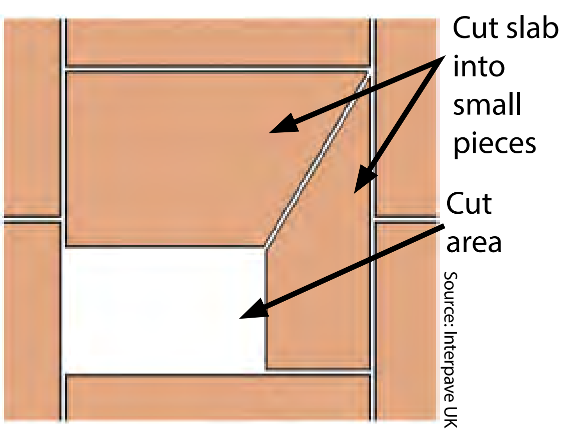

Figure 25. Cut areas 25% or greater of the slab area often require additional cuts to reduce the risk of cracking.

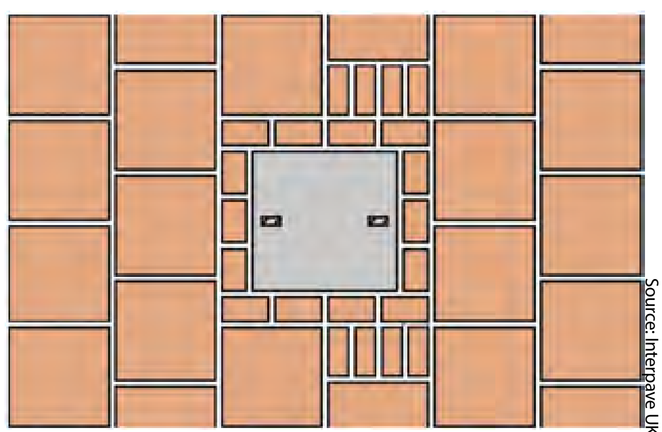

Figure 26. Using concrete pavers to fill around a utility cover

formulated for concrete paving units can be applied to remove it prior to applying sealers. However, it is best to wait through a wet or winter season prior to applying a sealer. This allows time for the efflorescence to work its way out of the concrete. Tech Spec 5 provides additional information on managing efflorescence.

Constructions Details

Stack Bond and Running Bond — For square slabs and rectangular slabs, units are placed in stack or running bond. Stack bond is shown in Figure 20. Running bond can be placed longitudinal, i.e., the longer dimension in the traffic direction, or transverse, i.e., the shorter dimen-

Figure 27. Example of a utility cover that does not fit neatly into the paving pattern.

Figure 28. Another example of cutting pavers to accommodate a utility cover set at an acute angle to the paving slab pattern

Figure 29. Filling the outside of a utility cover with mortar-set stone paving units

sion in the direction of traffic. These are shown in Figures 21 and 20. If subject to vehicular traffic, a running bond pattern is recommended using square units as they will be less prone to damage.

Figure 23 illustrates filling cut areas with saw cut paving slabs or smaller concrete pavers. The area that receives the concrete pavers as a sailor course or soldier course should be of such dimensions to accept either without cutting.

Cutting Details —When a section of a paving slab must be cut and the cut area is less than 25% of the total slab area, there is no need to include additional cuts to reduce the risk of a cracked unit. Figure 24 illustrates this.

If more than 25% of a paving slab must be cut and removed, consideration must be given to installing additional cuts to reduce the risk of cracking under loads. Figuure 24 illustrates this treatment.

Detailing Around Utilities —Provided that they are squared with the paving pattern, placing paving slabs around square or rectangular access covers is fairly straightforward. When slabs are cut to fit a running bond pattern, the cut areas can be filled with a cut slab or with smaller concrete pavers as shown in Figure 26.

In most cases, the utility cover and the paving pattern will not align with the paving slab module or with the paving pattern. Figures 27 and 28 illustrate how covers are detailed in these situations. Round utility covers should be encased in a square concrete collar sized to fit the paving slab module if possible. Another, more elegant option is filling in the outside radius of the cover with smaller stone units as shown on Figure 29. The stones are mortared into the concrete collar around the cover.

Curb Ramp Details —Curb ramps and driveway entrances can be detailed one of two ways shown in Figures 30 and 31. Figure 30 shows a sidewalk that does not dip into the driveway apron and Figure 31 shows one that does.

Edge Restraints —These should follow guidance provided in Table 2 of Tech Spec 3–Edge Restraints for Interlocking Concrete PavementsThis Tech Spec provides a summary of the types and recommended applications.

Maintenance —Extra paving slabs or planks should be ordered for future maintenance should a paving unit become unduly stained or crack and require replacement. An advantage of segmental paving is that it can be removed and reinstated after base or underground utility repairs. Tech Spec 6–Reinstatement of Interlocking Concrete Pavements provides specific steps on removing and reinstating paving units.

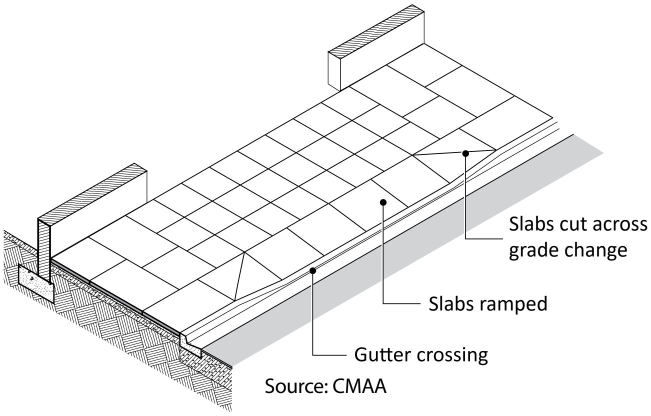

Figure 30. Driveway entrance with a ramped apron

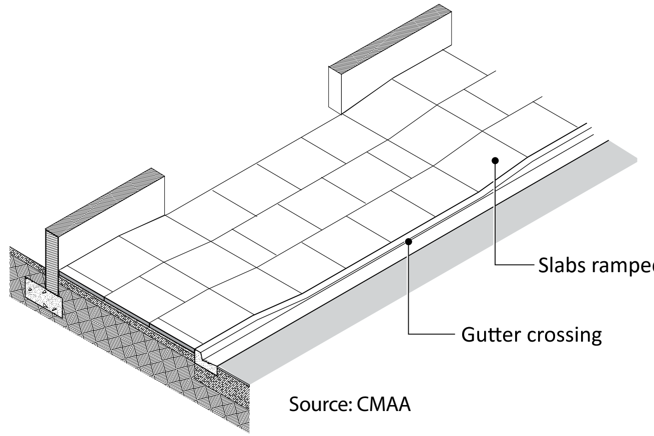

Figure 31. Driveway entrance with a depressed sidewalk surface.

Use of ICPI Certified Installers —ICPI offers training and experience certification of segmental concrete pavement installers. This training includes taking a two-day course, passing the exam and providing evidence of at least 10,000 sf (1,000 m^2) of installation experience. Continuing education requirements must be met as well, eight hours over two years.

A step further for contractors is receiving the Commercial Specialist Designation. This includes taking a course, passing the exam and providing evidence of a minimum of 50,000 sf (5,000 m^2) of paving units installed in commercial applications. This area may include paving slabs and planks. Specifiers are encouraged to include this ICPI designation in commercial project specifications and also specify that the contractor submit proof of slab or plank installation experience as appropriate to the project.

Slab and plank requirements for permeable applications —Paving slabs can be used in permeable applications. Slabs 16 x 16 in. (400 x 400 mm) and larger should be limited to pedestrian uses only and their minimum thickness should be 3.125 in. (80 mm). Using 16 x 16 in. or larger units in vehicular applications risks tipping and cracking. Slabs smaller than 16 x 16 in. when used in vehicular applications should be at least 3.125 in. (80 mm) thick.

Planks for permeable applications longer than 12 in. (300mm) are recommended for pedestrian only uses and their minimum thickness should be 3.125 in (80 mm).

Detailed construction guidelines for permeable subbases, base, bedding/jointing aggregates and edge restraints can be found in ICPI Tech 18–Construction of Permeable Interlocking Concrete Pavement Systems. These construction guidelines apply to slabs and planks designed for permeable applications. These units have wider joints (typically filled with No. 8 or 89 stone) than non-permeable applications in order to receive stormwater runoff. Note: Compaction of slabs and planks for permeable applications should be done with roller attachment on the plate compactor as previously described.

References

Concrete Masonry Association of Australia (CMAA), PA05 Concrete Flag Pavements – Design and Construction Guide, Australia, 2014 (www.cmaa.com.au)

Interpave UK, Concrete Flag Paving: Guide to the Properties, Design, Handling, Construction, Reinstatement and Maintenance of Concrete Flag Pavements, Edition 4, United Kingdom, 2010 (www.paving.org.uk)

Interlocking Concrete Pavement Institute®

13750 Sunrise Valley Drive
Herndon, VA 20171

In Canada:
P.O. Box 1150
Uxbridge, ON L9P 1N4
Canada

Tel: 703.657.6900
Fax: 703.657.6901
E-mail: icpi@icpi.org
www.icpi.org

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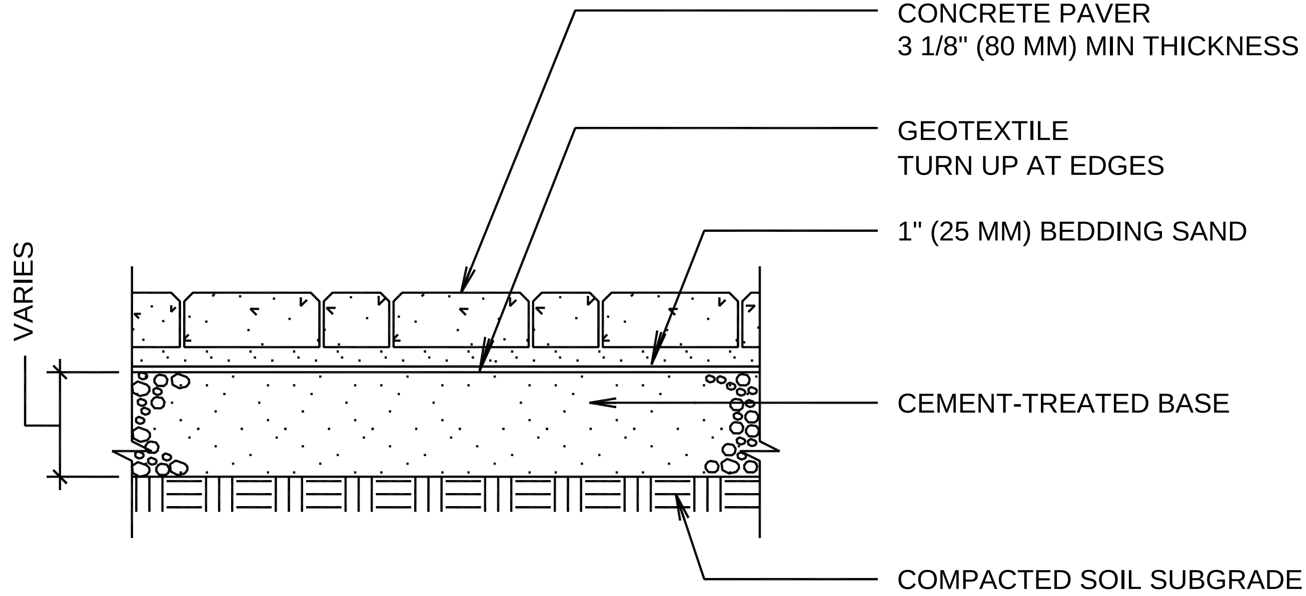
TECHNICAL DRAWINGS



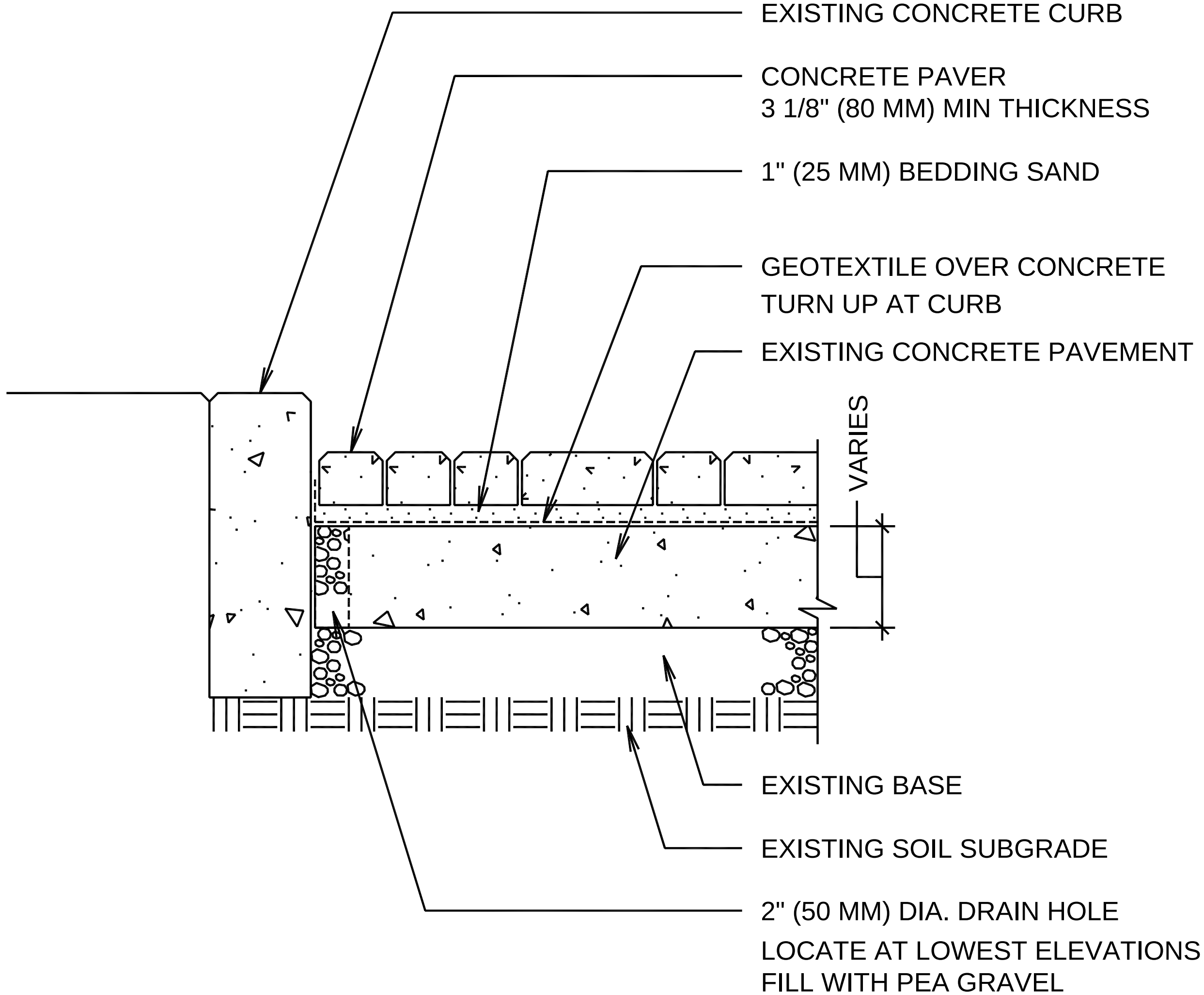
NOTES:

1. BASE, SUB-BASE, AND SUBGRADE THICKNESS VARY WITH LOADS, SUBGRADE STRENGTH, AND CLIMATE.
2. CONCRETE PAVERS MAY BE INLAYED ON EXISTING ASPHALT OR CONCRETE GAS STATION PAVEMENTS.
3. SEALING JOINTS OF PAVERS IS RECOMMENDED. FOR GAS STATION APPLICATIONS.
4. PROVIDE 2 IN. (50 MM) DIAMETER DRAIN HOLE(S) FILLED W/ PEA GRAVEL AT LOWEST ELEVATIONS. DRAIN TO EMERGENCY SPILL CATCHMENT.
5. PROVIDE 1 IN. (25 MM) DIAMETER HOLES THROUGH CURBS TO CATCH BASINS. BOTTOM OF HOLES TO BE EVEN WITH SURFACE OF CEMENT-TREATED BASE. COVER HOLES WITH GEOTEXTILE.

STREET/PARKING LOT/GAS STATION ON CEMENT TREATED BASE

DRAWING NO.	ICPI-01
SCALE	F.S.

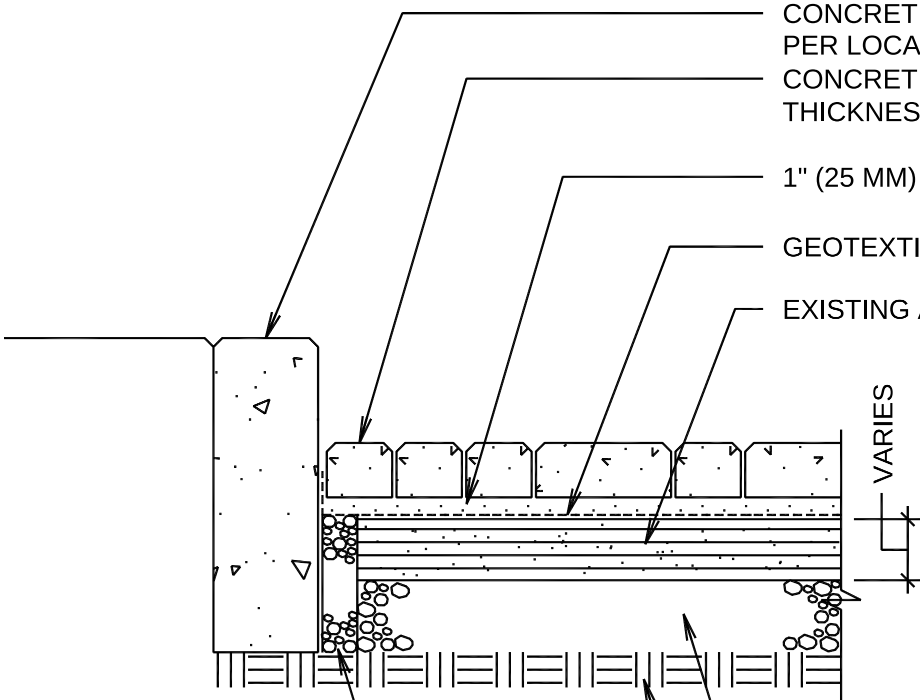
DUCON
OUTDOOR LIVING



NOTE:
PROVIDE 1 IN. (25 MM) DRAIN HOLE(S) IN CATCH BASINS.
BOTTOM OF HOLES TO BE EVEN WITH SURFACE OF EXISTING
CONCRETE PAVING. COVER HOLES WITH GEOTEXTILE.

STREET / PARKING LOT
OVERLAY ON EXISTING CONCRETE PAVEMENT

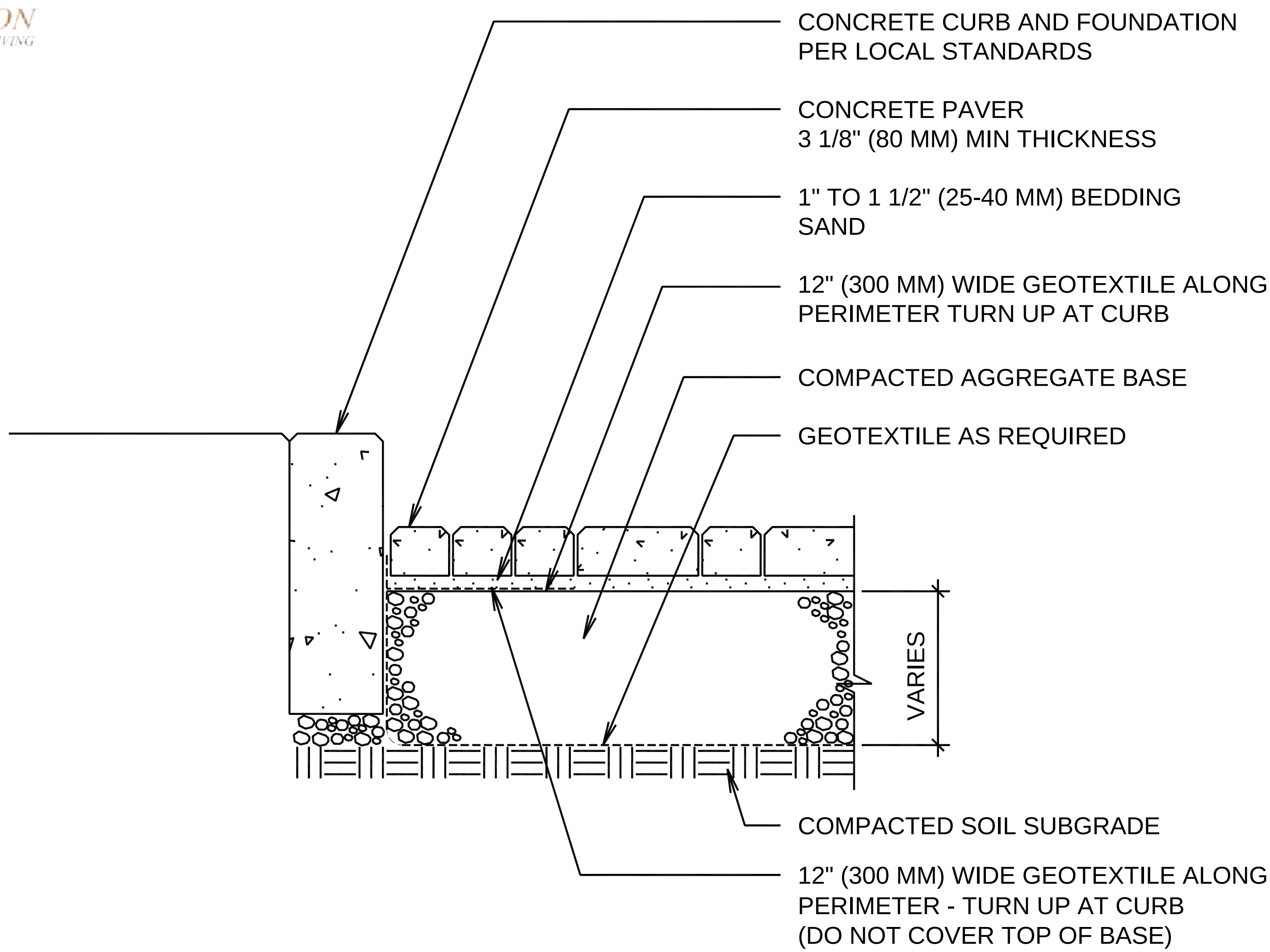
DRAWING NO.	ICPI-02
SCALE	F.S.



1. DRAIN BEDDING SAND OF EXCESS MOISTURE THROUGH PAVEMENT AT LOWEST POINTS AS SHOWN OR AT CATCH BASIN(S).
2. PROVIDE 1 IN. (25 MM) DRAIN HOLES IN CATCH BASINS. BOTTOM OF HOLES TO BE EVEN WITH SURFACE OF EXISTING PAVEMENT. COVER HOLES WITH GEOTEXTILE.
3. DO NOT PROVIDE DRAIN HOLES TO SUBGRADE WHEN WATER TABLE IS LESS THAN 2 FT. (0.6 M) FROM TOP OF SOIL SUBGRADE. PROVIDE DRAIN HOLES TO CATCH BASINS

STREET / PARKING LOT
OVERLAY ON EXISTING ASPHALT PAVEMENT

DRAWING NO.	ICPI-03
SCALE	F.S.

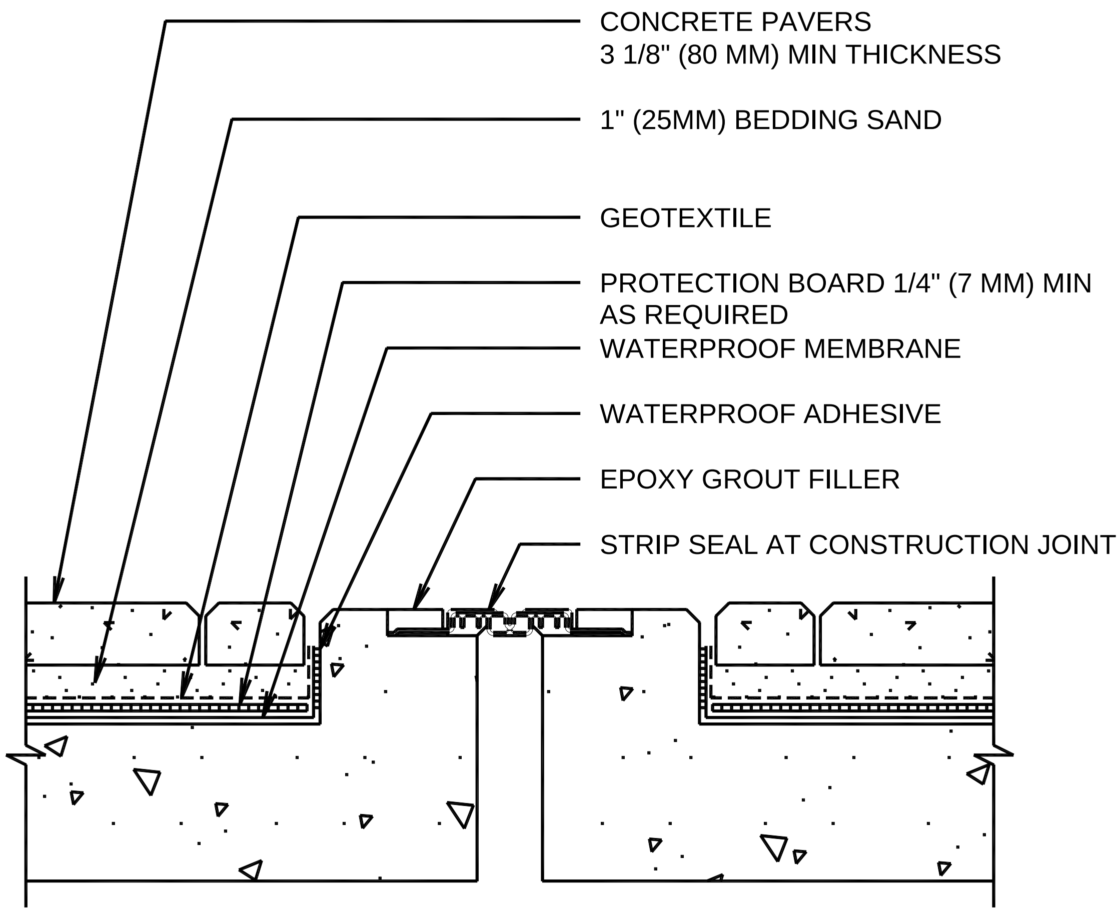


NOTES:

1. DRAIN PIPES BELOW THE BASE MAY BE NECESSARY IN SLOW DRAINING SOIL SUBGRADE.
2. BASE THICKNESS VARIES WITH TRAFFIC, CLIMATE, AND SUBGRADE CONDITIONS. COLDER CLIMATES AND WEAK SOILS MAY REQUIRE THICKER BASES. CONSULT ICPI TECH SPEC 4 TO DETERMINE BASE THICKNESS.
3. CONSULT ICPI TECH SPEC 2 FOR GUIDELINES AND SPECIFICATIONS FOR BASE MATERIALS, SUBGRADE SOIL AND BASE COMPACTION.
4. DO NOT COVER ENTIRE TOP OF AGGREGATE BASE WITH GEOTEXTILE.

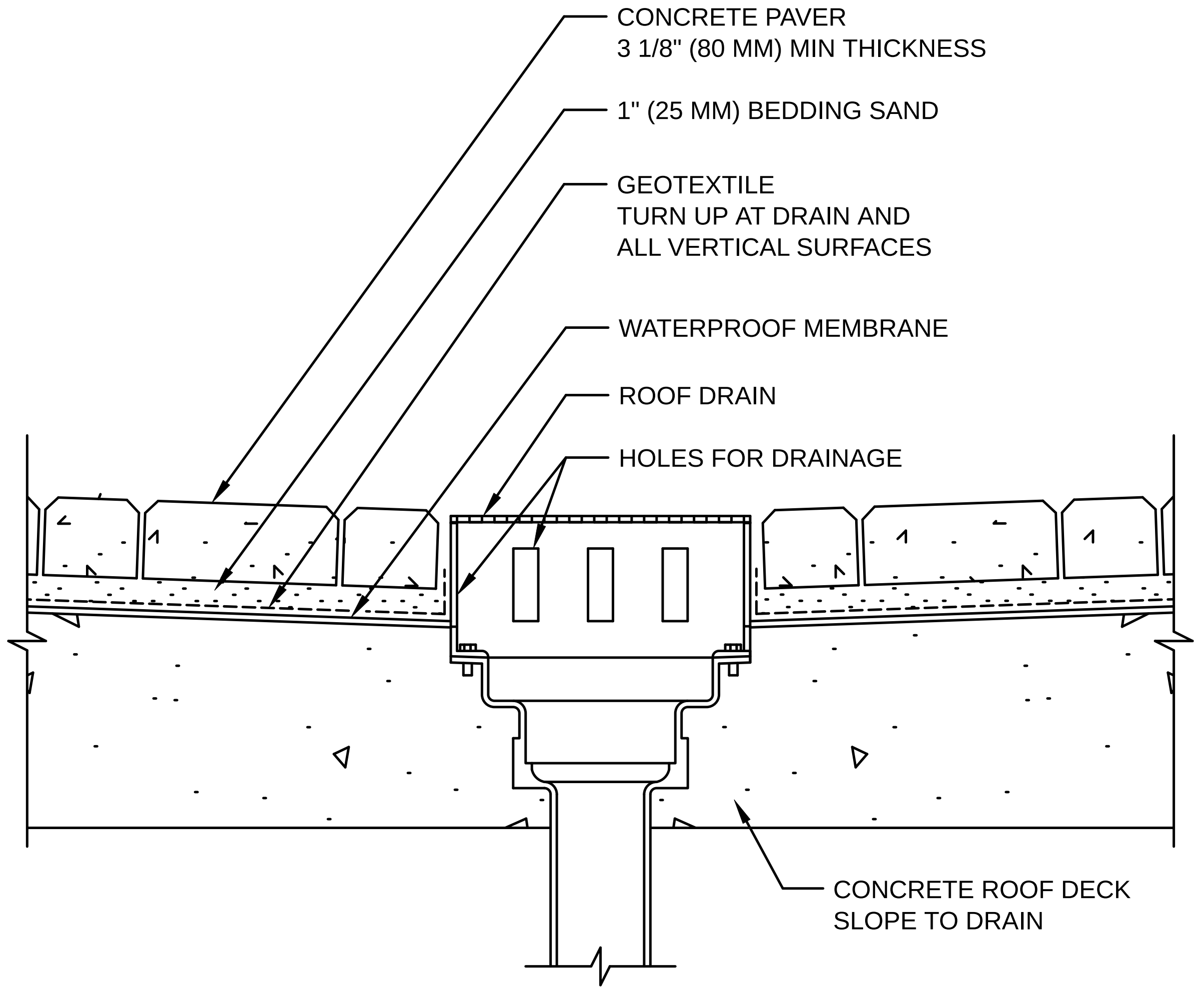
STREET / PARKING LOT ON COMPACTED AGGREGATE BASE

DRAWING NO.	ICPI-04
SCALE	F.S.



PARKING GARAGE OVER UNINHABITED SPACE - EXPANSION JOINT

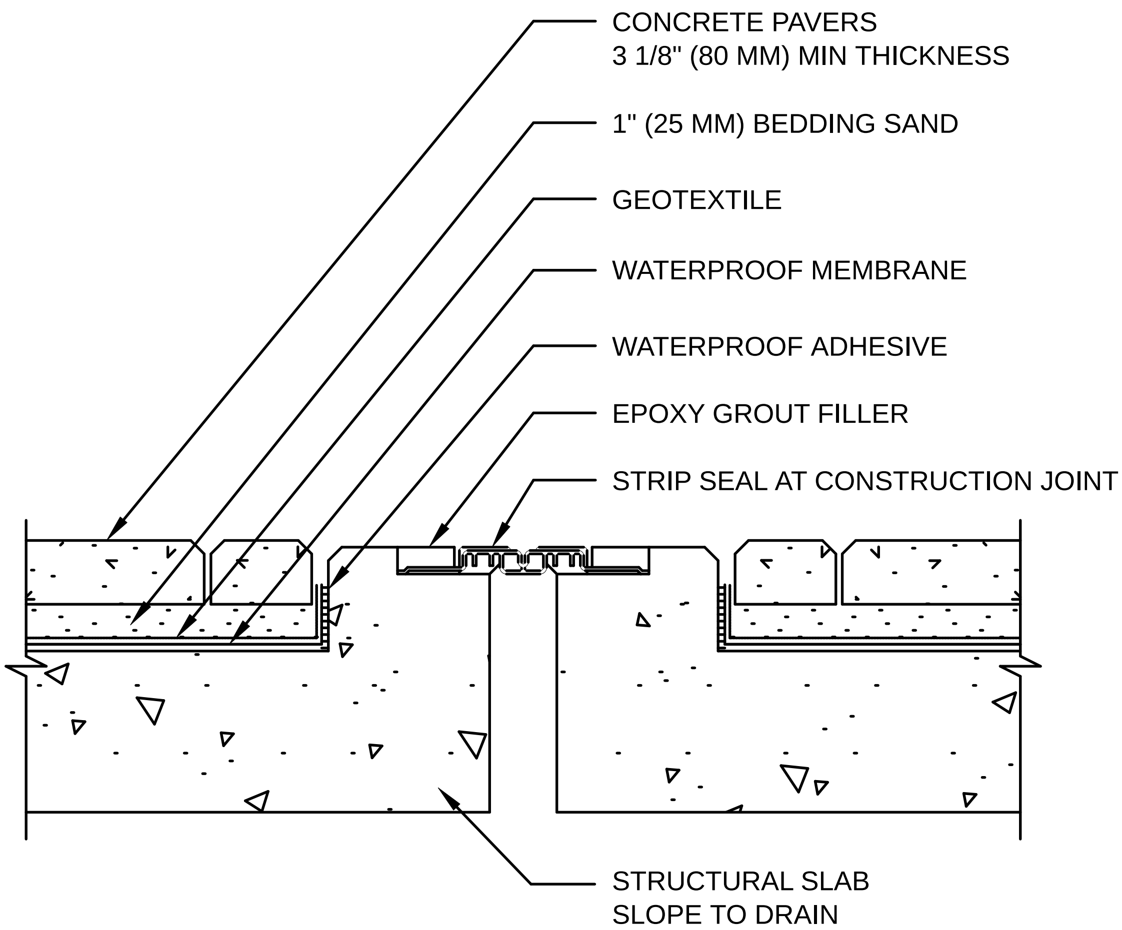
DRAWING NO.	ICPI-05
SCALE	F.S.



PARKING GARAGE DRAIN

DRAWING NO.
ICPI-06

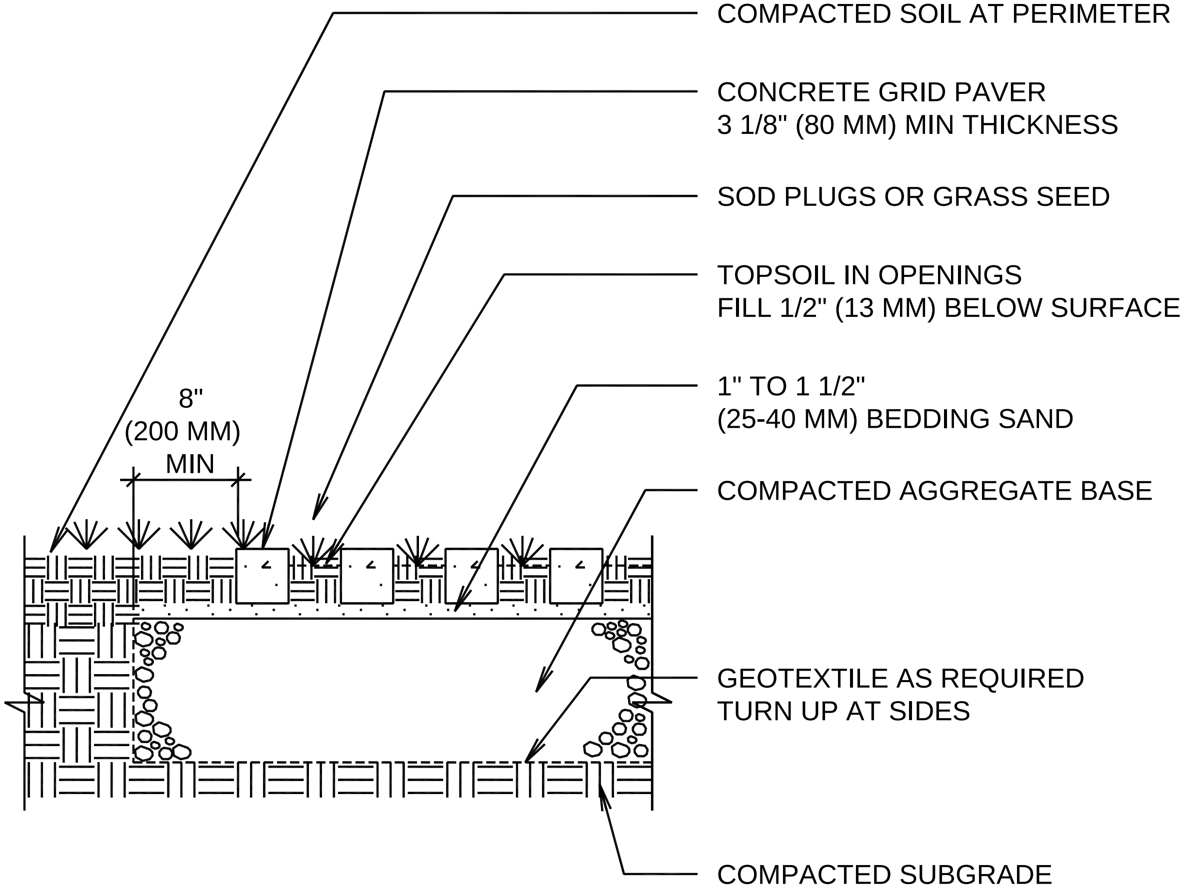
SCALE
F.S.



PARKING GARAGE OVER INHABITED SPACE - EXPANSION JOINT

DRAWING NO. ICPI-07

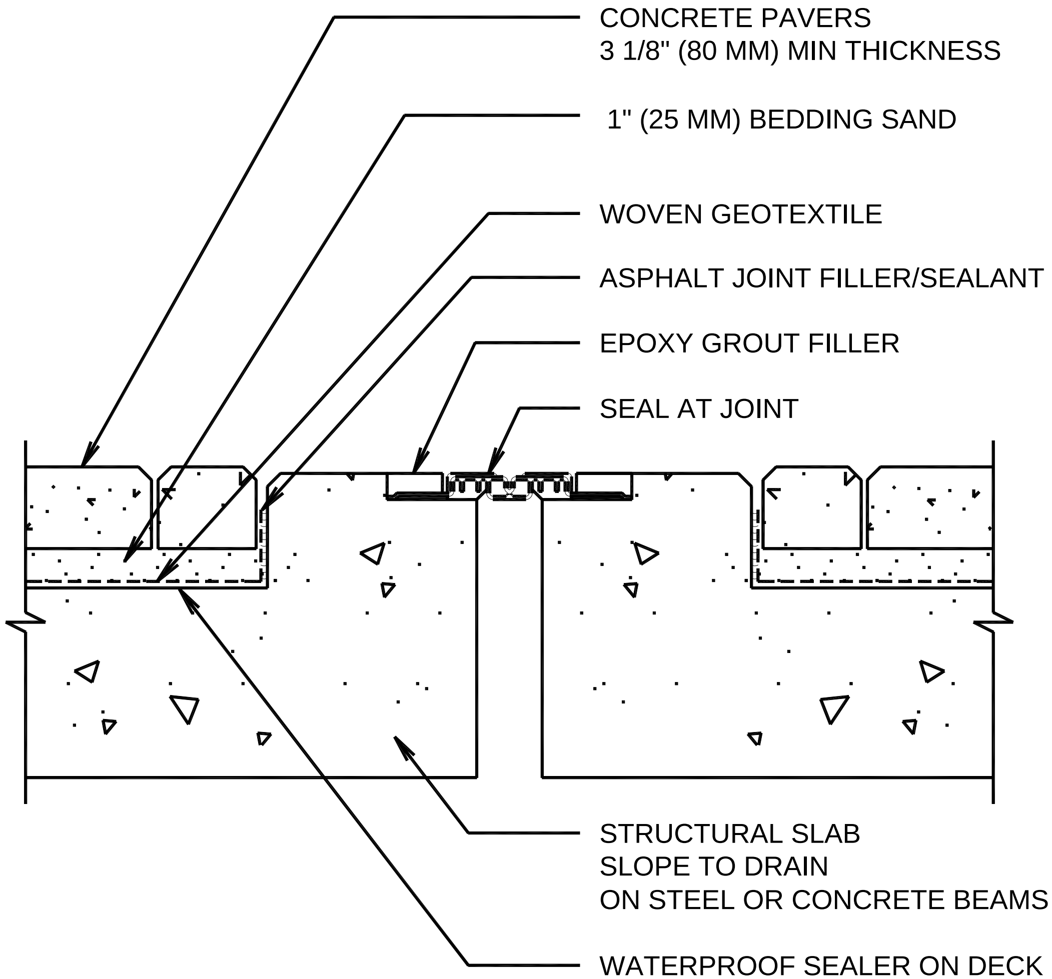
SCALE F.S.



NOTE: 1. BASE THICKNESS VARIES WITH TRAFFIC, CLIMATE, AND SUBGRADE.
2. MINIMUM BASE THICKNESS: 6" (150 MM) RESIDENTIAL DRIVEWAYS, 8" FIRELANES & PARKING LOTS.

CONCRETE GRID PAVERS-FIRELANE, DRIVEWAY & INTERMITTENT PARKING

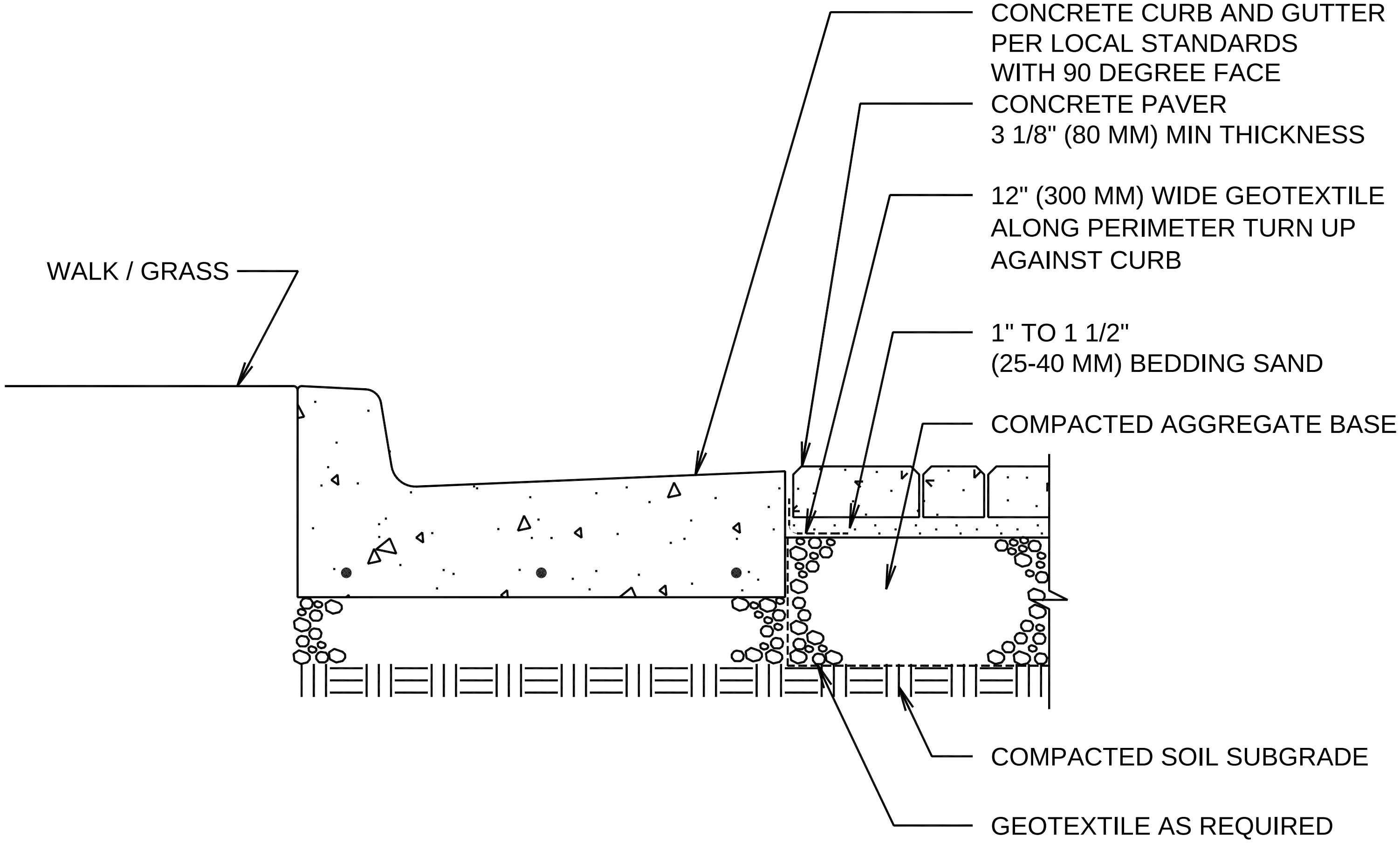
DRAWING NO.	ICPI-08
SCALE	F.S.



NOTE: PROVIDE DRAINAGE OF EXCESS MOISTURE IN BEDDING SAND AT PERIMETER OF STRUCTURAL SLAB.

BRIDGE DECK

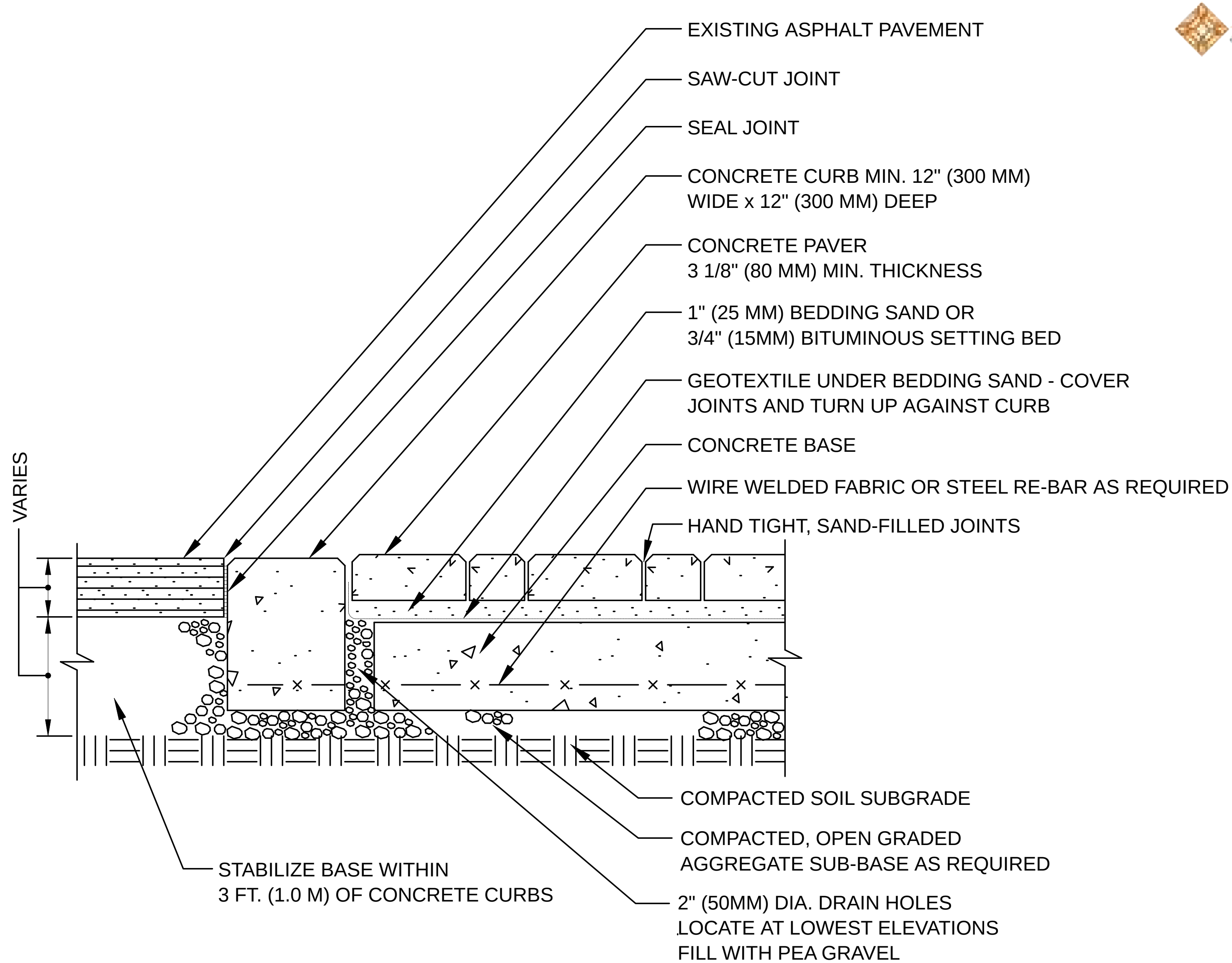
DRAWING NO.	ICPI-11
SCALE	F.S.



NOTE: DRAIN MAY BE NECESSARY IN SOIL SUBGRADE.

CONCRETE CURB AND GUTTER WITH CONCRETE PAVERS

DRAWING NO.	ICPI-10
SCALE	F.S.

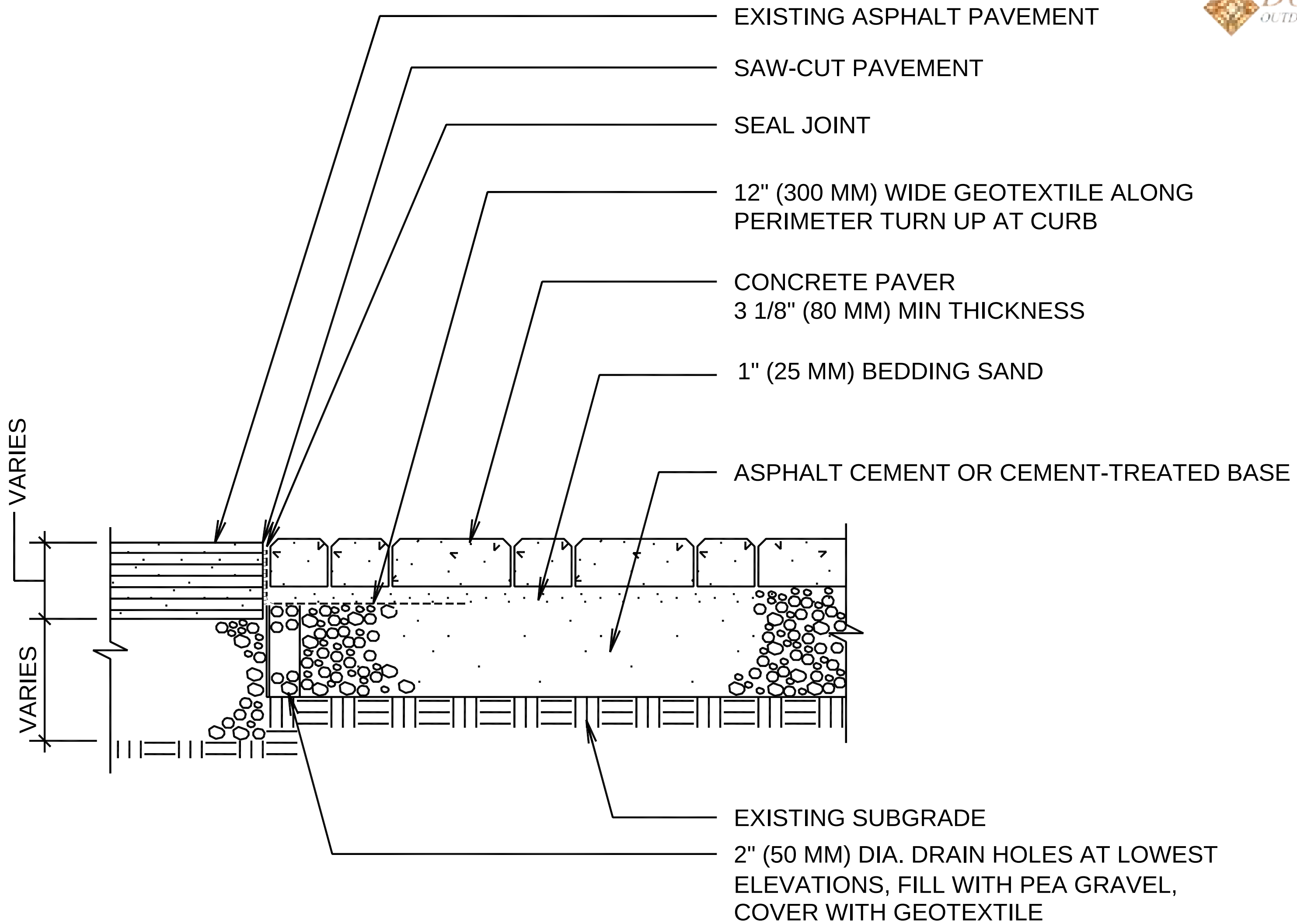


NOTE:

1. BASE THICKNESS AND REINFORCING VARIES WITH TRAFFIC, CLIMATE, AND SUBGRADE CONDITIONS.
2. CONCRETE BASE MINIMUM 2% SLOPE FROM CENTERLINE TO CURB.
3. DO NOT PROVIDE DRAIN HOLES TO SUBGRADE WHEN WATER TABLE IS LESS THAN 2 FT. (0.6 M) FROM TOP OF SOIL SUBGRADE. PROVIDE DRAIN HOLES TO CATCH BASINS.

CROSSWALK ON CONCRETE BASE

DRAWING NO.	ICPI-12
SCALE	F.S.

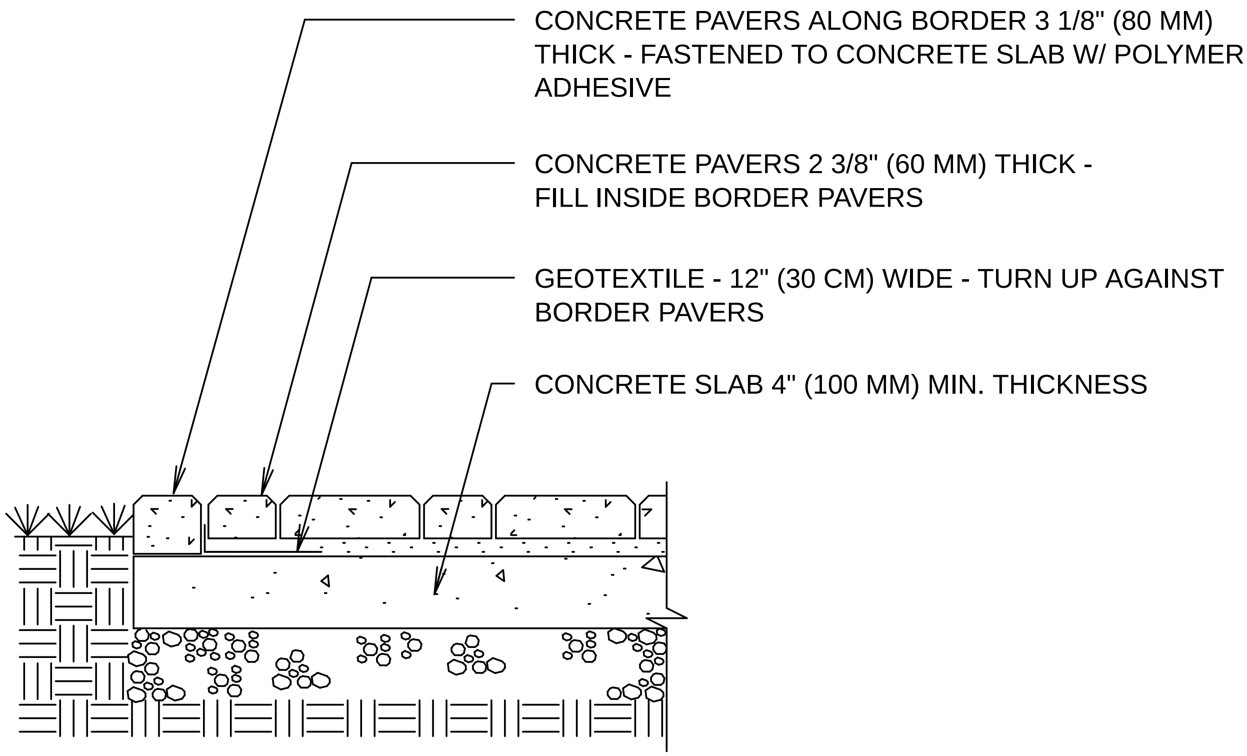


NOTES:

1. BASE THICKNESS VARIES WITH TRAFFIC, CLIMATE, AND SUBGRADE. COLDER CLIMATES AND WEAK SOIL MAY REQUIRE THICKER BASES.
2. BOTTOM ELEVATION OF EXISTING ASPHALT PAVEMENT MUST BE BELOW BEDDING SAND.
3. CONCRETE BEAMS AT ENDS OF PAVEMENT MAY BE NECESSARY IF ASPHALT IS SUBJECT TO RUTTING.
4. DO NOT PROVIDE DRAIN HOLES TO SUBGRADE WHEN WATER TABLE IS LESS THAN 2 FT. (0.6 M) FROM TOP OF SOIL SUBGRADE. PROVIDE DRAIN HOLES TO CATCH BASINS.
5. USE IN AREAS WITH CAR TRAFFIC ONLY.

CROSSWALK ON ASPHALT OR CEMENT TREATED BASE

DRAWING NO.	ICPI-13
SCALE	F.S.

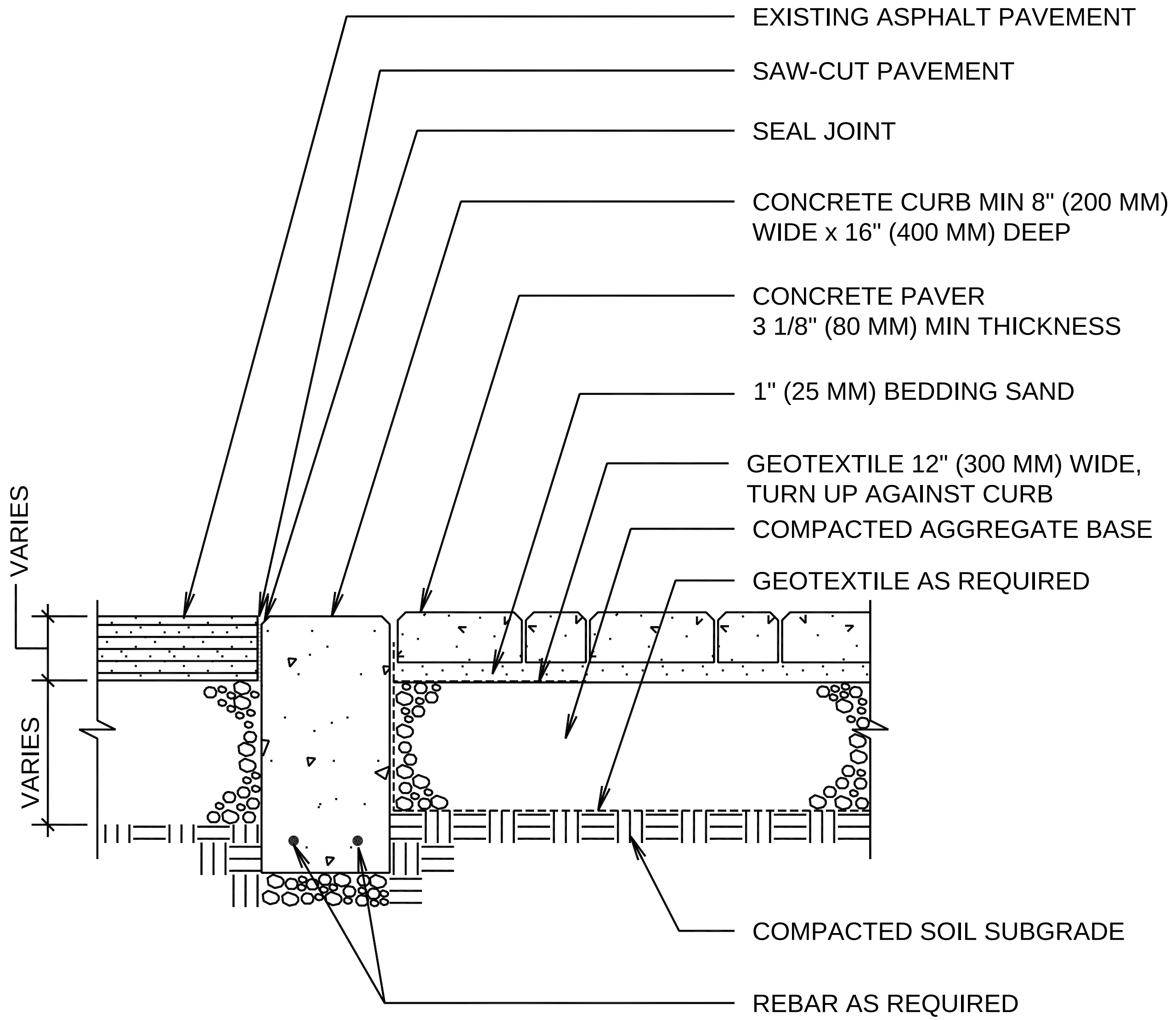


NOTES:

1. CONCRETE SLAB SHOULD BE FREE OF CRACKS AND HEAVING. COVER CRACKS WITH GEOTEXTILE.
2. CONCRETE SHOULD SLOPE AWAY FROM HOUSE.

PATIO OVERLAY ON CONCRETE SLAB

DRAWING NO.	ICPI-14
SCALE	F.S.

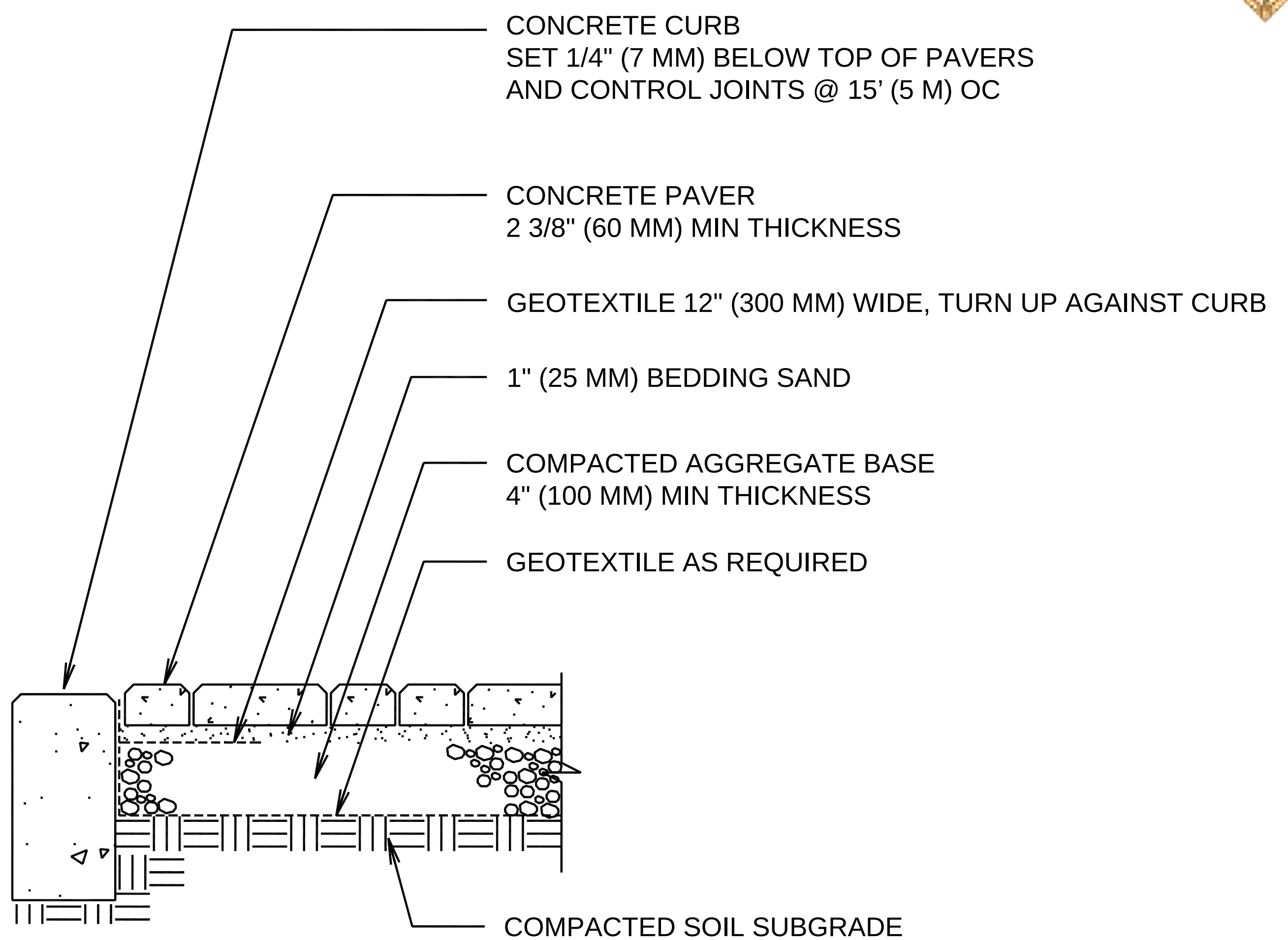


NOTE:

1. BASE THICKNESS VARIES WITH TRAFFIC, CLIMATE, AND SUBGRADE CONDITIONS.
2. CONCRETE CURBS DO NOT DEFLECT TO THE SAME DEPTH AS PAVERS OR EXISTING ASPHALT. THIS DETAIL IS NOT RECOMMENDED FOR OTHER THAN LOW VOLUME RESIDENTIAL STREETS.
3. THICKENING ASPHALT PAVEMENT ADJACENT TO CONCRETE CURB IS RECOMMENDED.

CROSSWALK ON COMPACTED AGGREGATE BASE

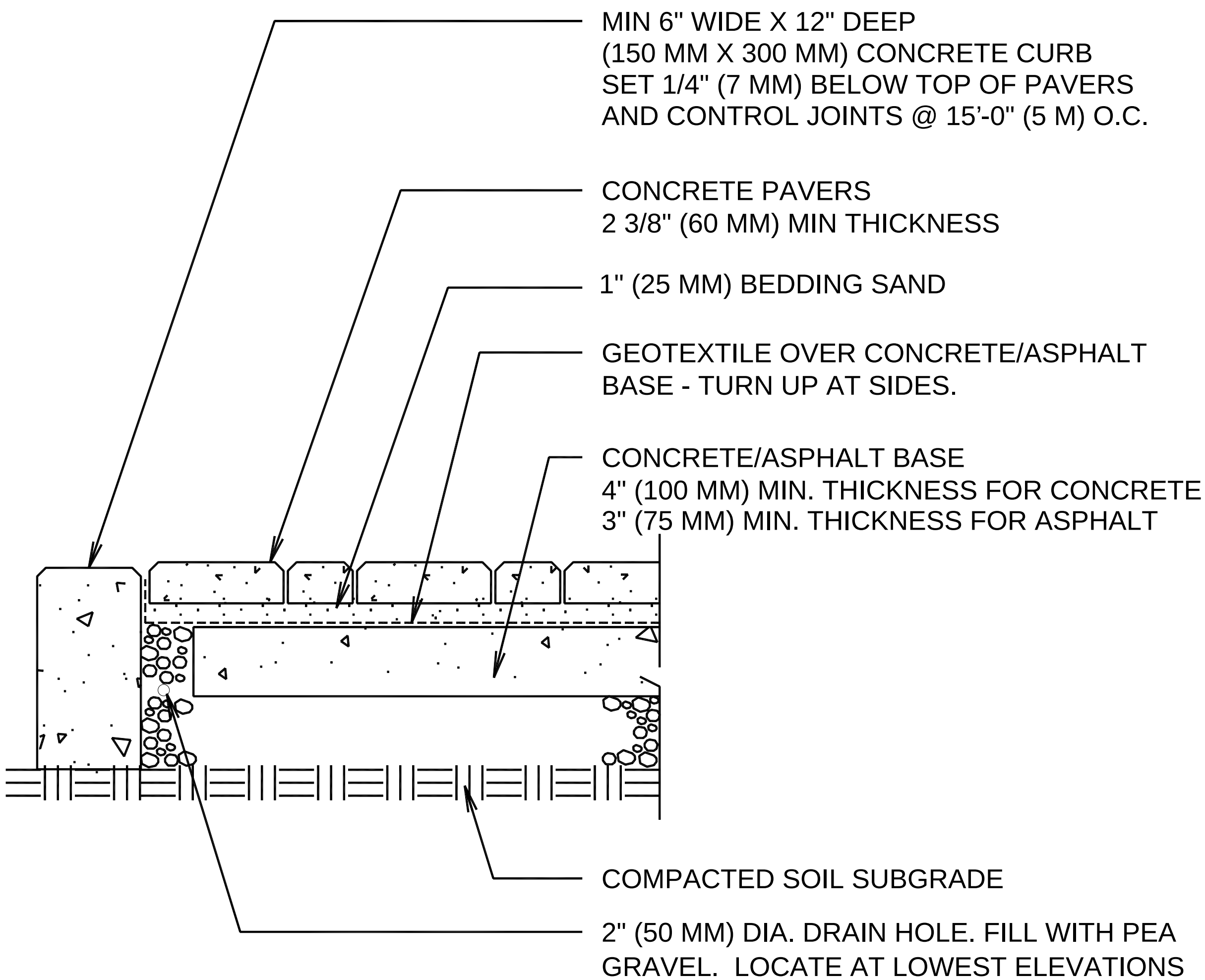
DRAWING NO.	ICPI-15
SCALE	F.S.



NOTE:

1. THICKNESS OF BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE. COLDER CLIMATES MAY REQUIRE THICKER BASES.
2. CONSULT ICPI TECH SPEC 2 FOR GUIDELINES ON SPECIFICATIONS FOR BASE MATERIALS, SUBGRADE SOIL AND BASE COMPACTION.

PATIO / SIDEWALK / PLAZA ON COMPACTED AGGREGATE BASE	DRAWING NO. ICPI-16
	SCALE F.S.

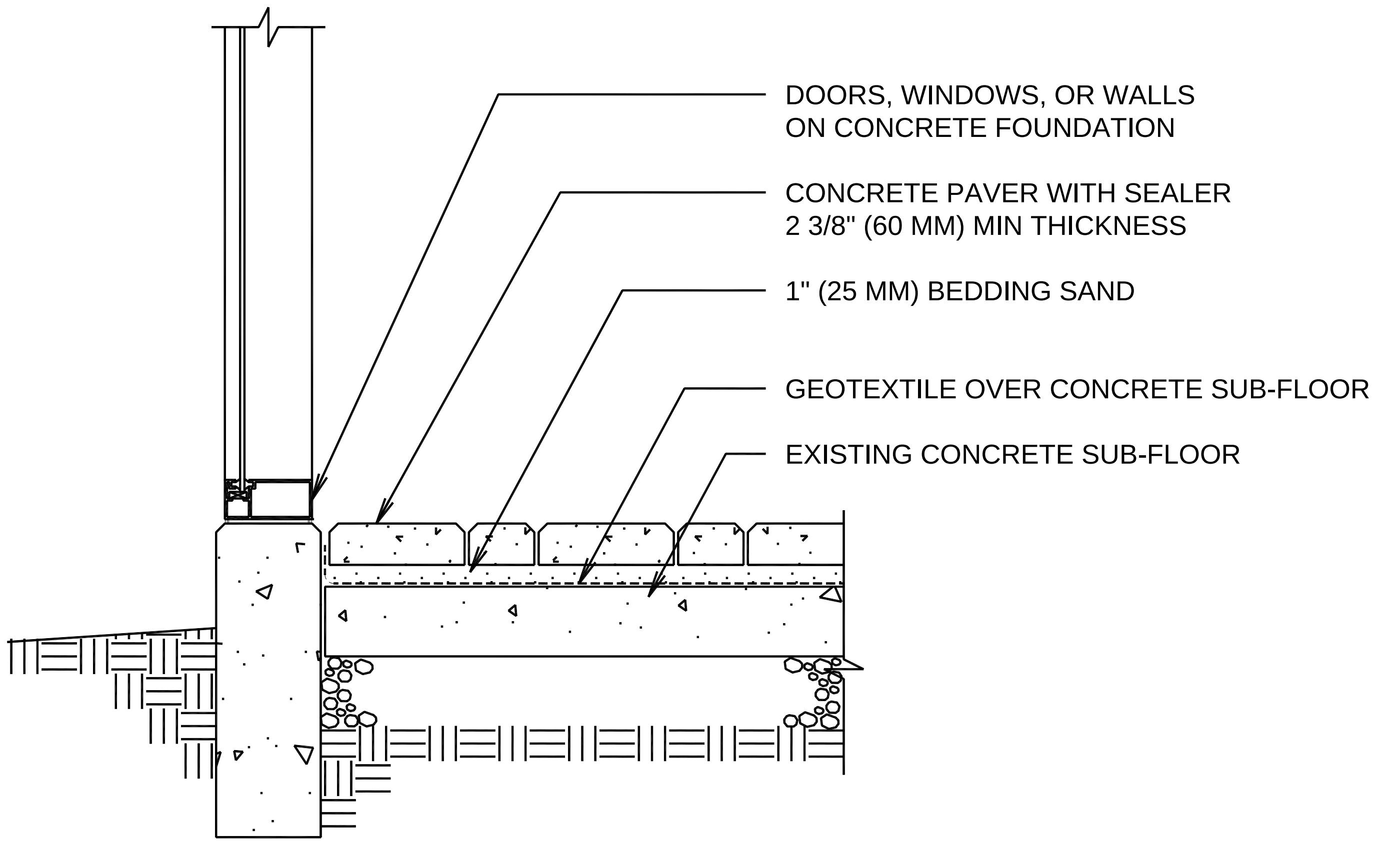


NOTES:

1. THICKNESS OF BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE. COLDER CLIMATES MAY REQUIRE THICKER BASES.
2. CONSULT ICPI TECH SPEC 2 FOR GUIDELINES ON SPECIFICATIONS FOR BASE MATERIALS, SUBGRADE SOIL AND BASE COMPACTION.

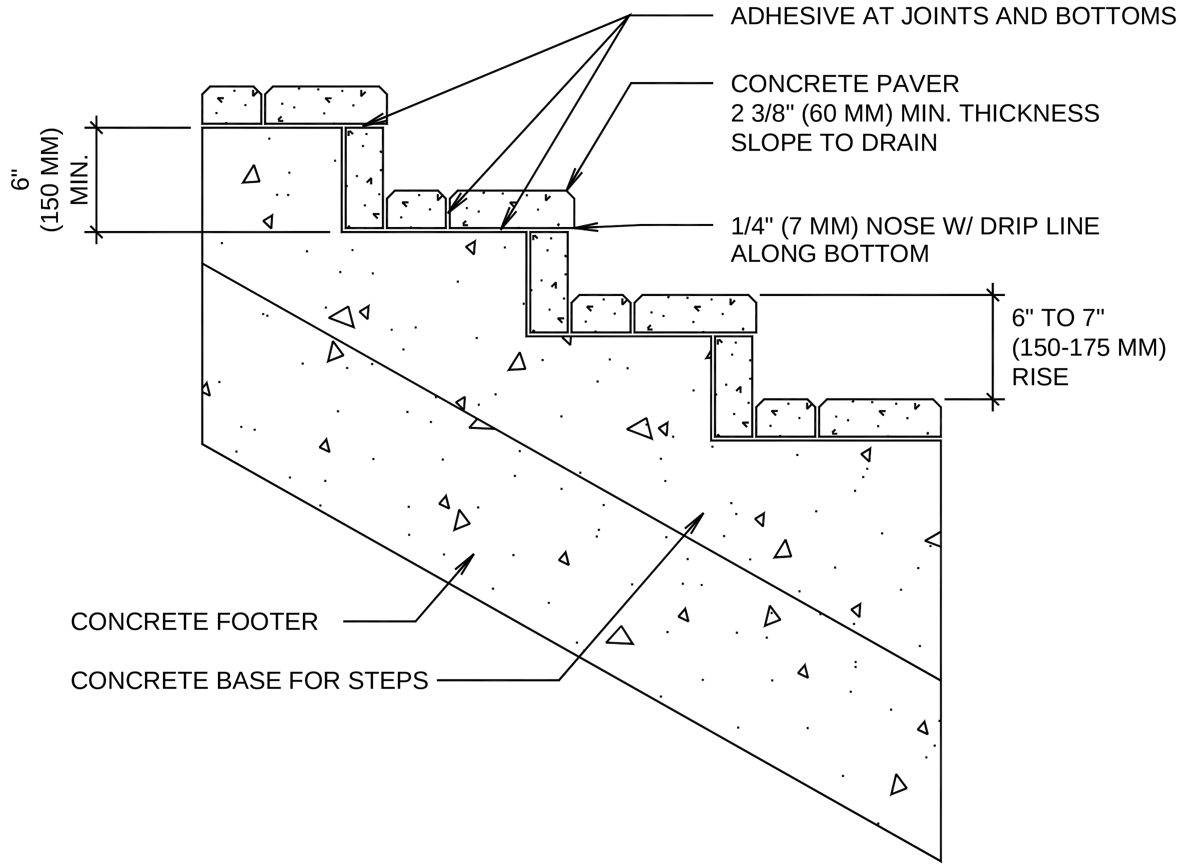
SIDEWALK/PLAZA OVERLAY ON EXISTING CONCRETE OR ASPHALT

DRAWING NO.	ICPI-17
SCALE	F.S.



INTERIOR WITH CONCRETE BASE

DRAWING NO.	ICPI-18
SCALE	F.S.

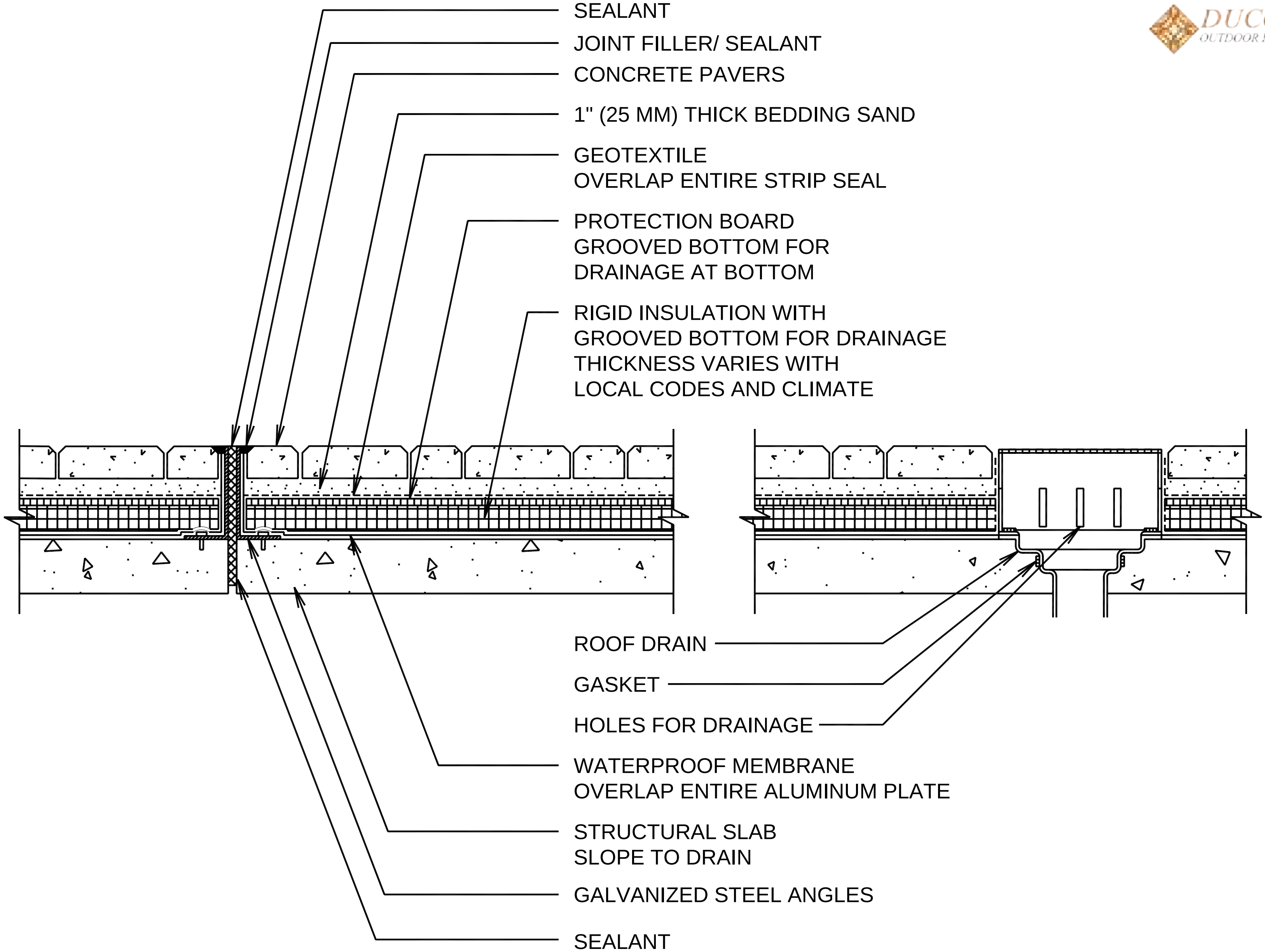


NOTES:

1. USE OF MORTAR IS NOT RECOMMENDED EXCEPT IN NON-FREEZE-THAW AREAS.
2. SAW DRIP LINES INTO BOTTOMS OF ALL STEP NOSES.

STEPS WITH CONCRETE PAVERS

DRAWING NO.	ICPI-19
SCALE	NO SCALE

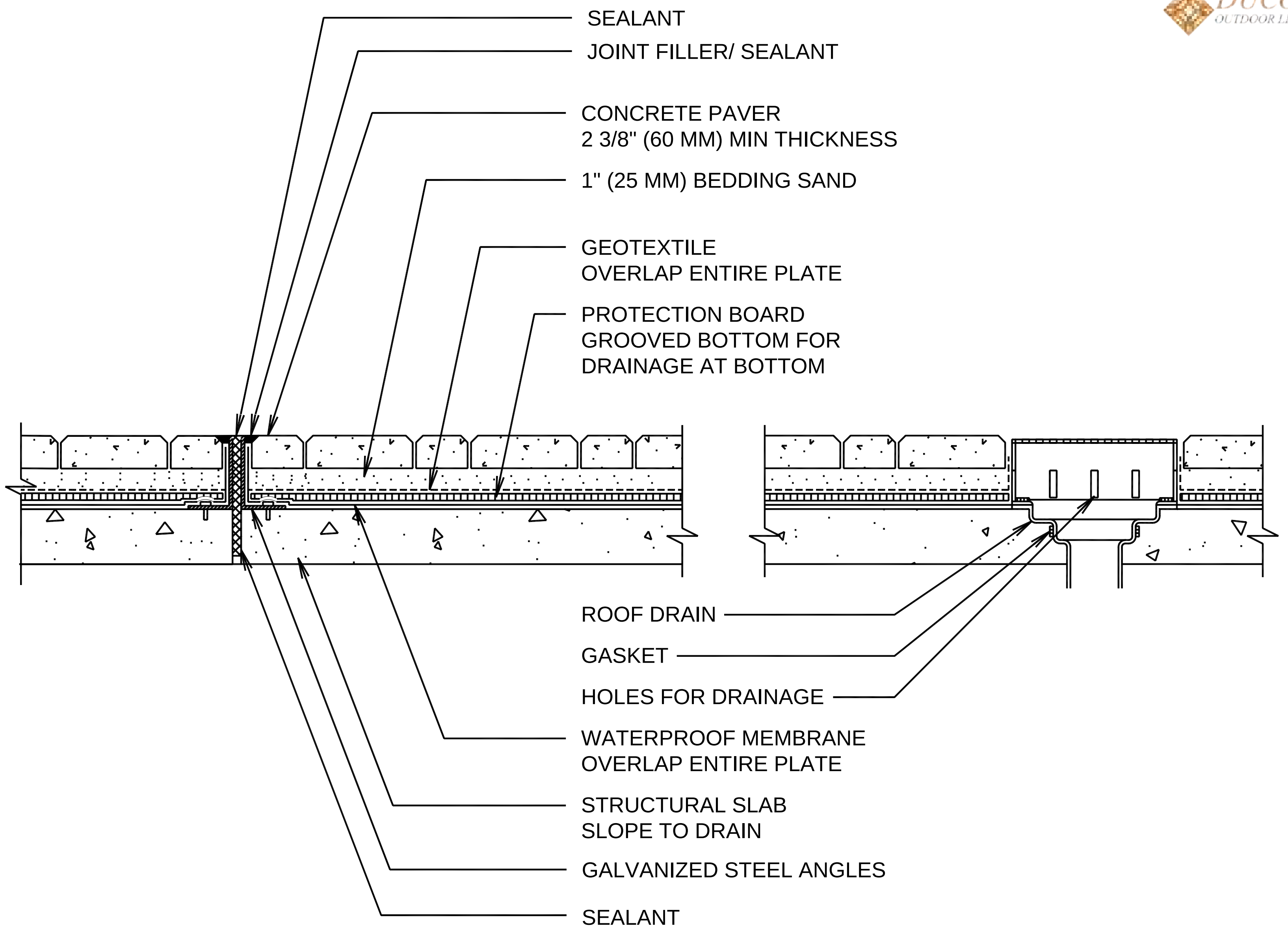


NOTES: 1. CHECK WITH LOCAL WIND CODES FOR BALLAST REQUIREMENTS.
2. PROTECTION BOARD AND INSULATION MUST WITHSTAND STATIC AND DYNAMIC LOADS.

ROOF PLAZA DECK OVER HABITABLE SPACE

DRAWING NO. ICPI-20

SCALE F.S.

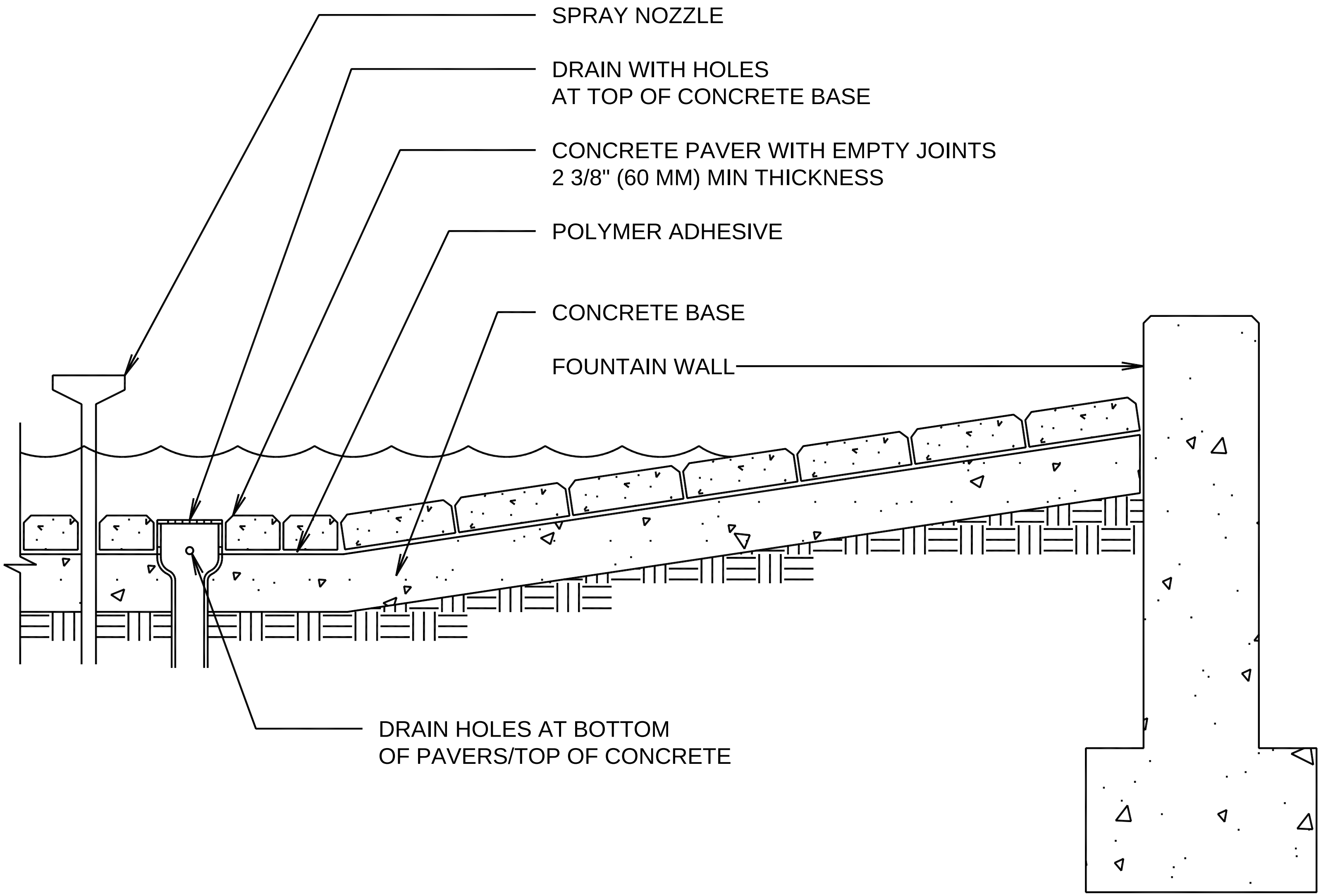


NOTE: 1. CHECK WITH LOCAL WIND CODES FOR BALLAST REQUIREMENTS.
2. PROTECTION BOARD MUST WITHSTAND STATIC AND DYNAMIC LOADS.

ROOF PLAZA DECK OVER UNINHABITED SPACE

DRAWING NO. ICPI-21

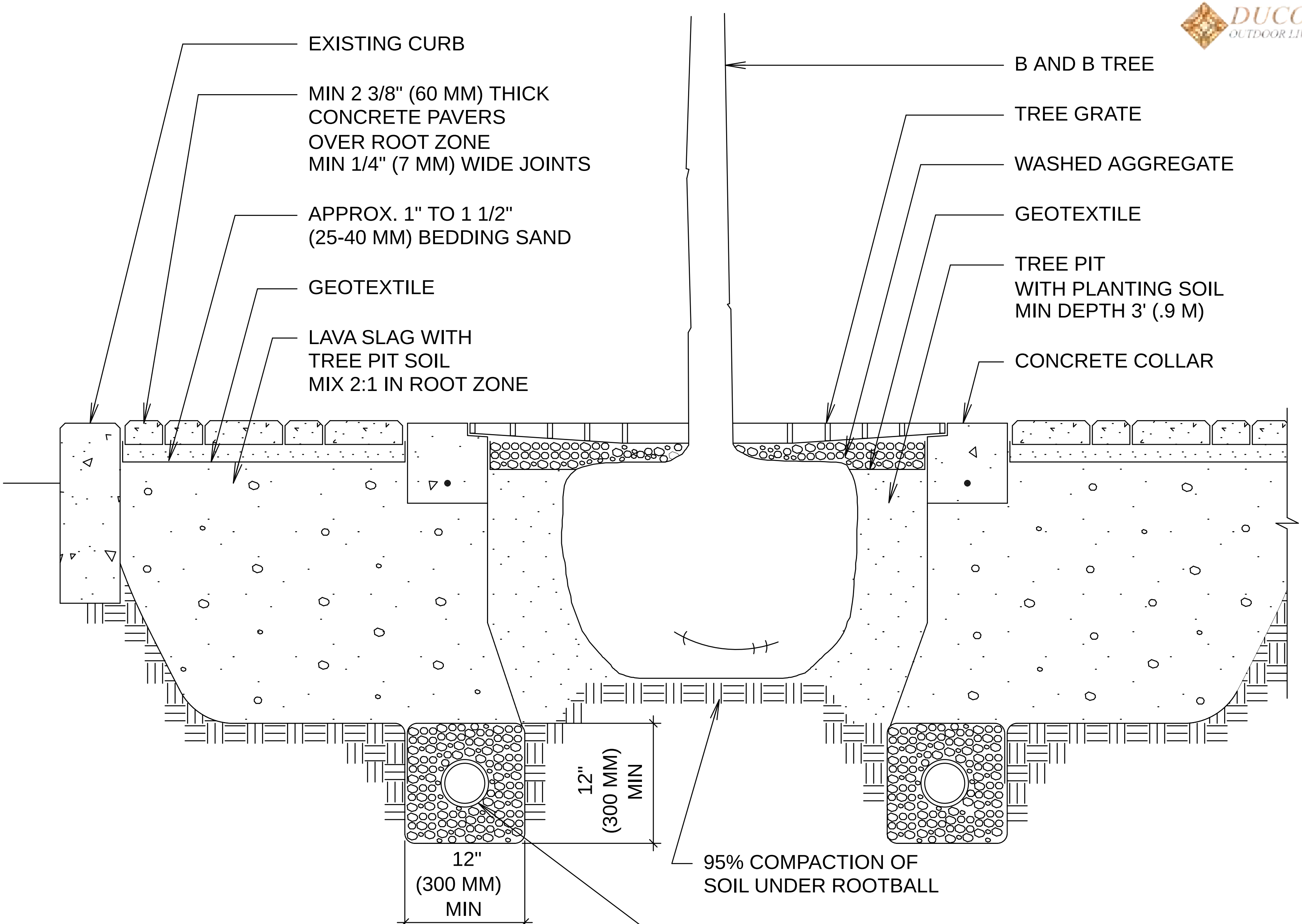
SCALE F.S.



NOTE: PAVERS CAN BE LAID WITHOUT POLYMER ADHESIVE.

FOUNTAIN

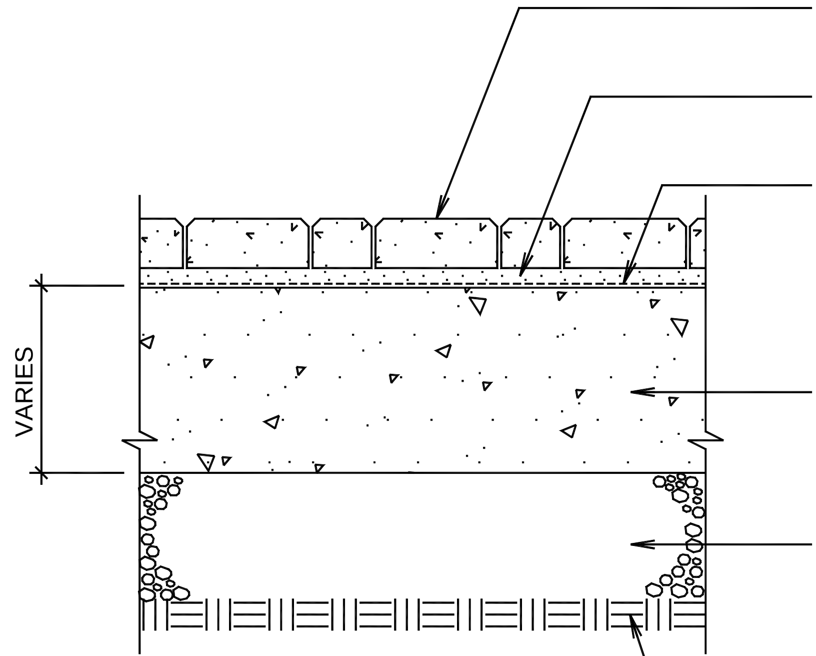
DRAWING NO.	ICPI-22
SCALE	F.S.



NOTE: ROOT BARRIER MAY BE REQUIRED INSIDE
OF CONCRETE COLLAR DEPENDING ON TREE SPECIES.
CONSULT ABORIST FOR THIS APPLICATION.

TREE PIT - NON-COMPACTED ROOT ZONE UNDER PAVERS

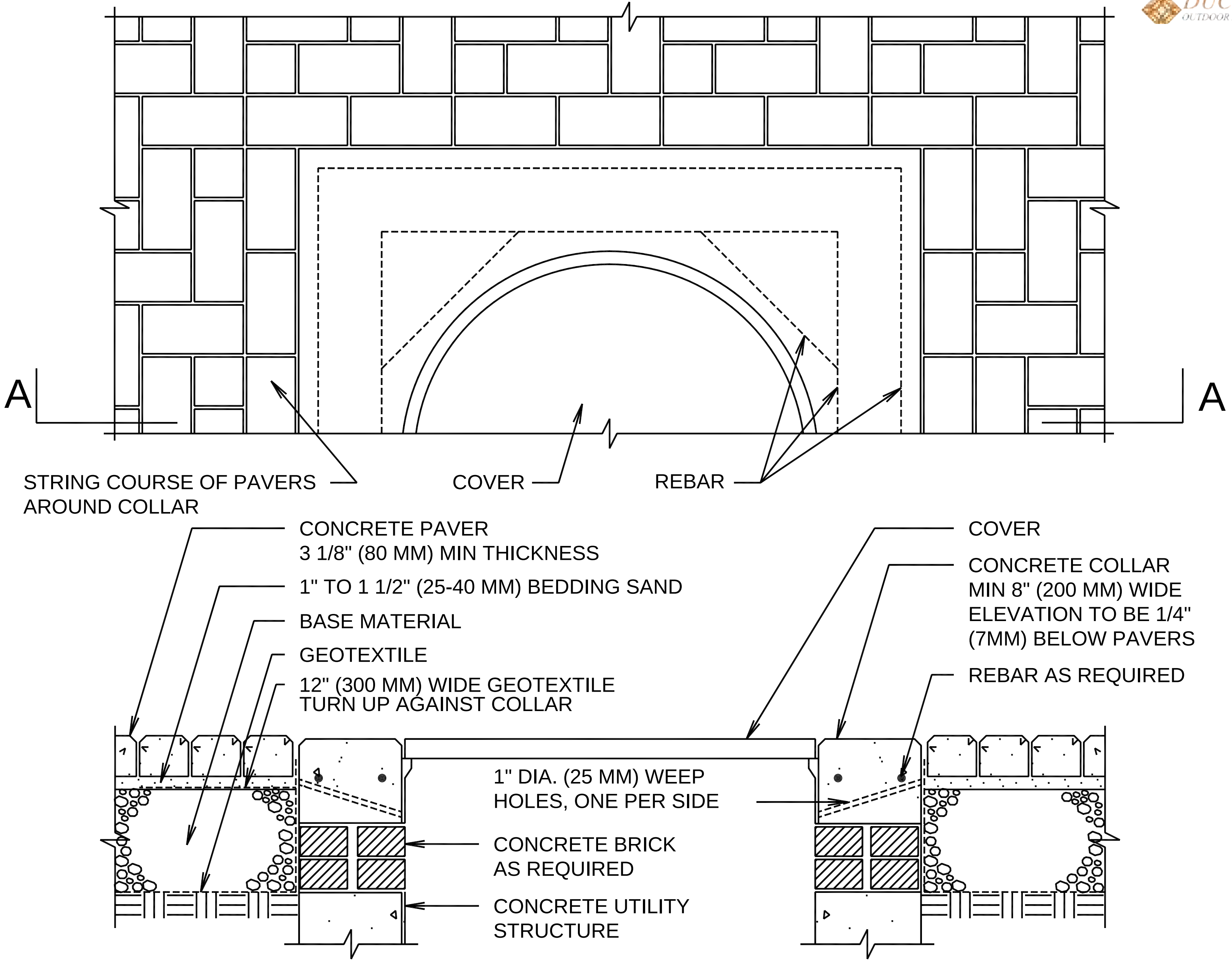
DRAWING NO.	ICPI-23
SCALE	F.S.



NOTES:

1. EXISTING ASPHALT OR CONCRETE PAVEMENT SHALL BE THOROUGHLY INSPECTED FOR AREAS IN NEED OF PATCHING OR REPLACEMENT. CONDUCT ALL REPAIRS AND FILL ALL CRACKS GREATER THAN 1/4 IN. (6 MM) WIDE PRIOR TO PLACING GEOTEXTILE, SAND, AND PAVERS.
2. PROVIDE DRAINAGE OF SAND LAYER THROUGH WEEP HOLE(S) INTO CATCH BASIN(S).

PORT / INDUSTRIAL PAVEMENT ON EXISTING ASPHALT OR CONCRETE	DRAWING NO.	ICPI-34
	SCALE	NO SCALE

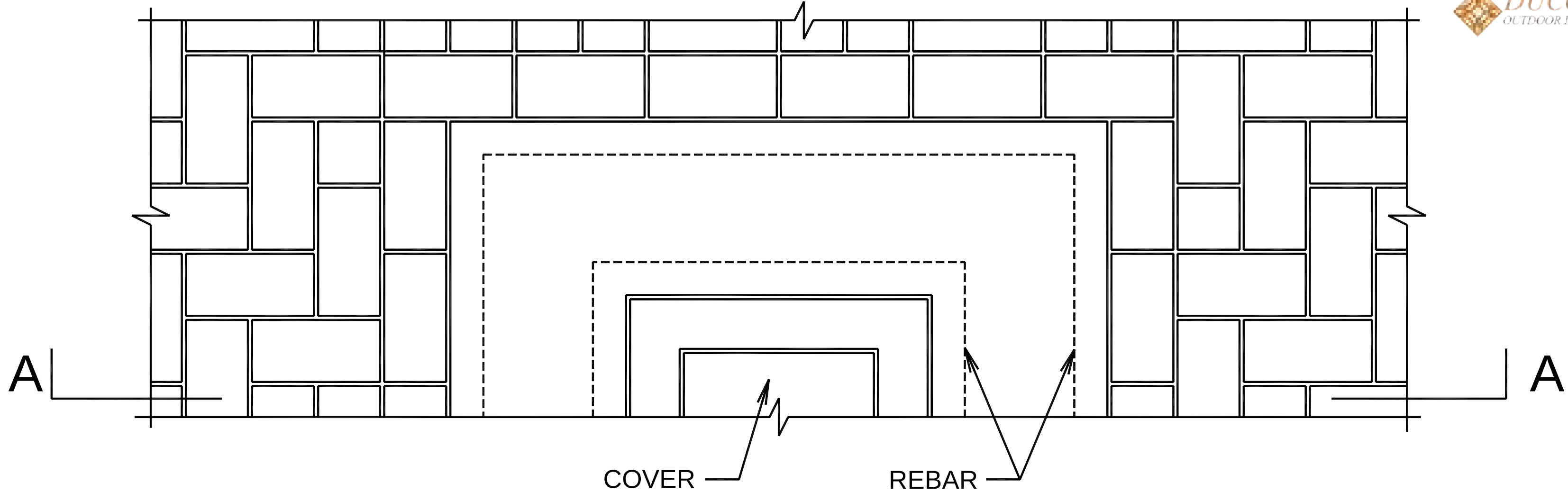


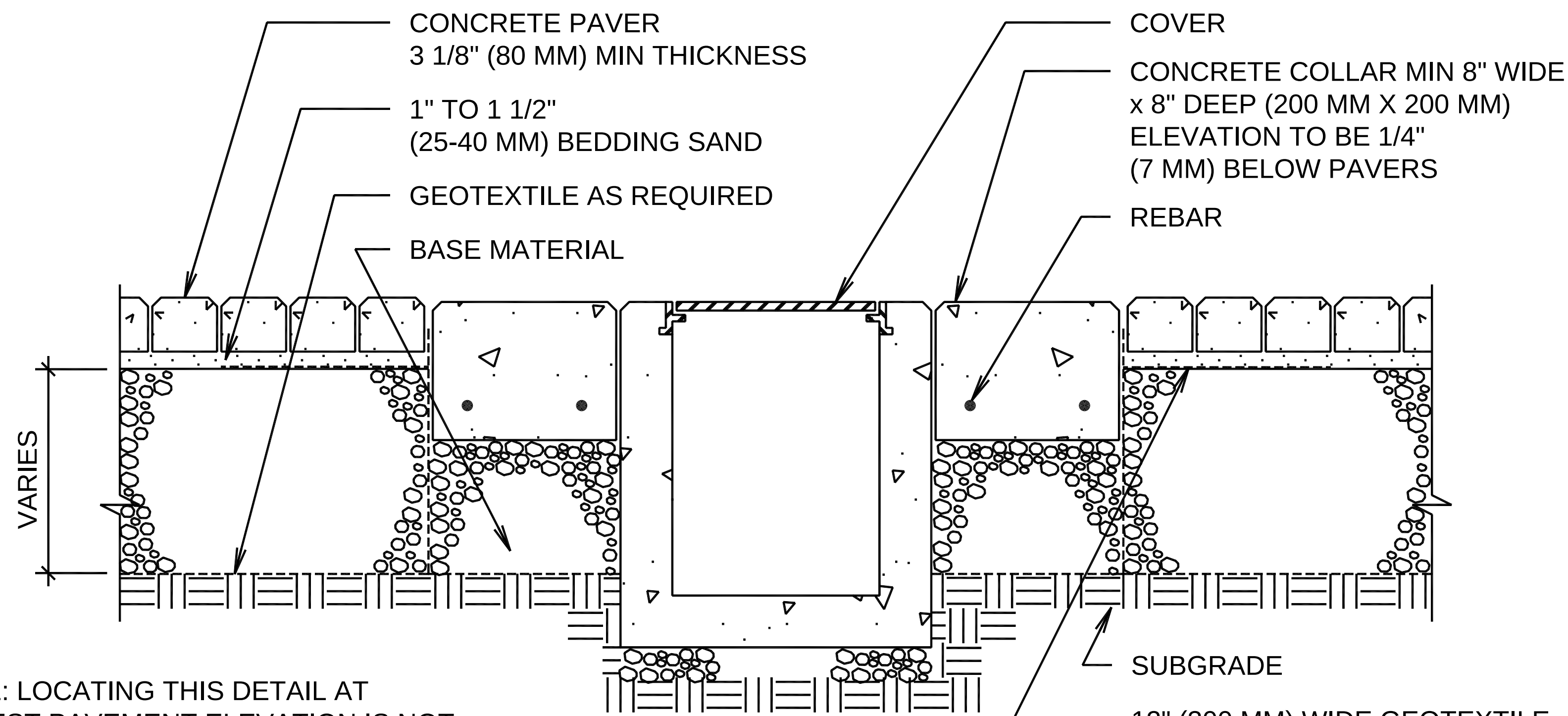
SECTION AA

UTILITY STRUCTURE
MANHOLE

DRAWING NO.	ICPI-24
SCALE	F.S.

DUCON OUTDOOR LIVING





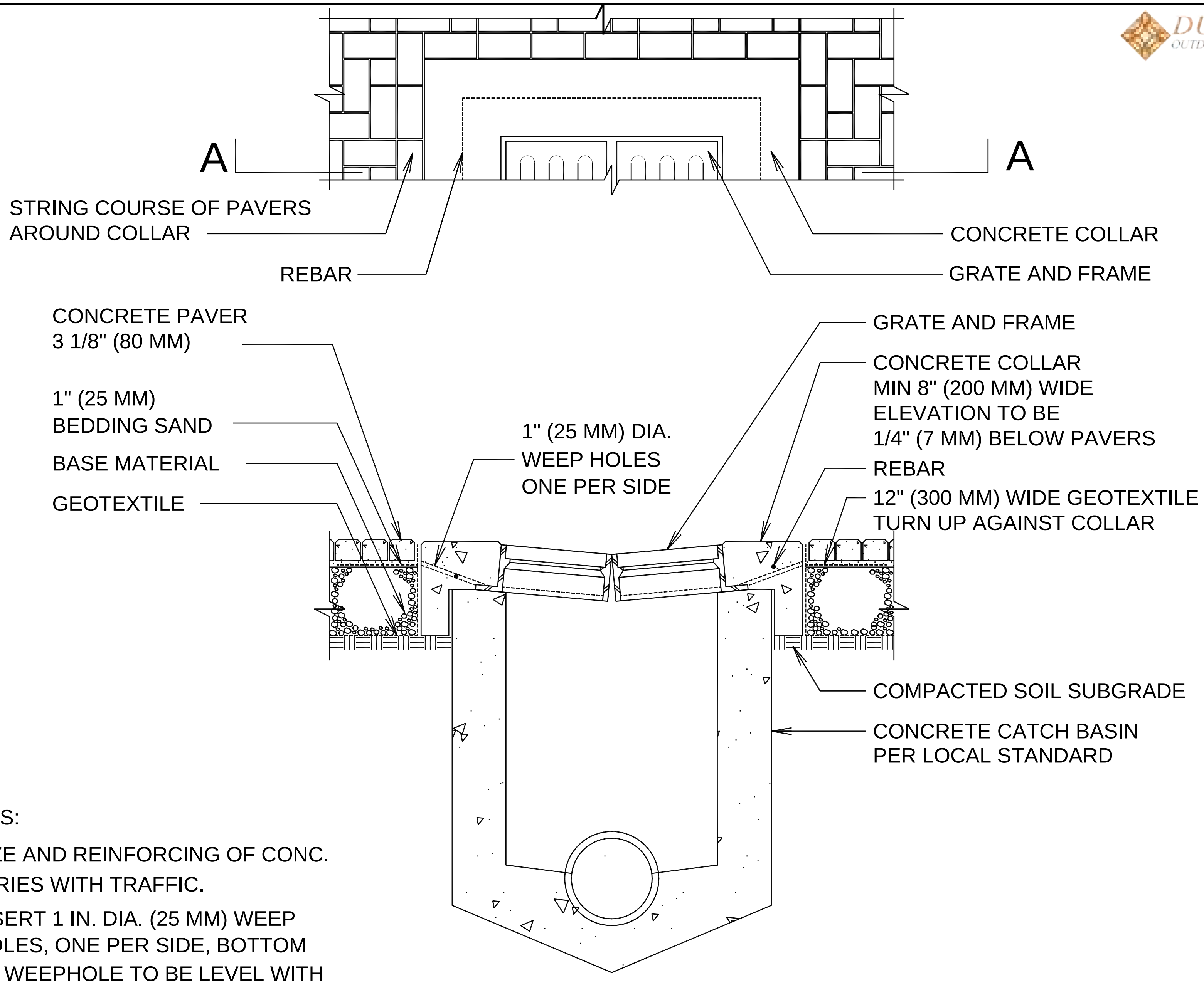
SECTION AA

NOTE: LOCATING THIS DETAIL AT LOWEST PAVEMENT ELEVATION IS NOT RECOMMENDED.

UTILITY STRUCTURE

VALVE BOX \ PULL BOX \ LAMPHOLE

DRAWING NO.	ICPI-25
SCALE	F.S.



SECTION AA

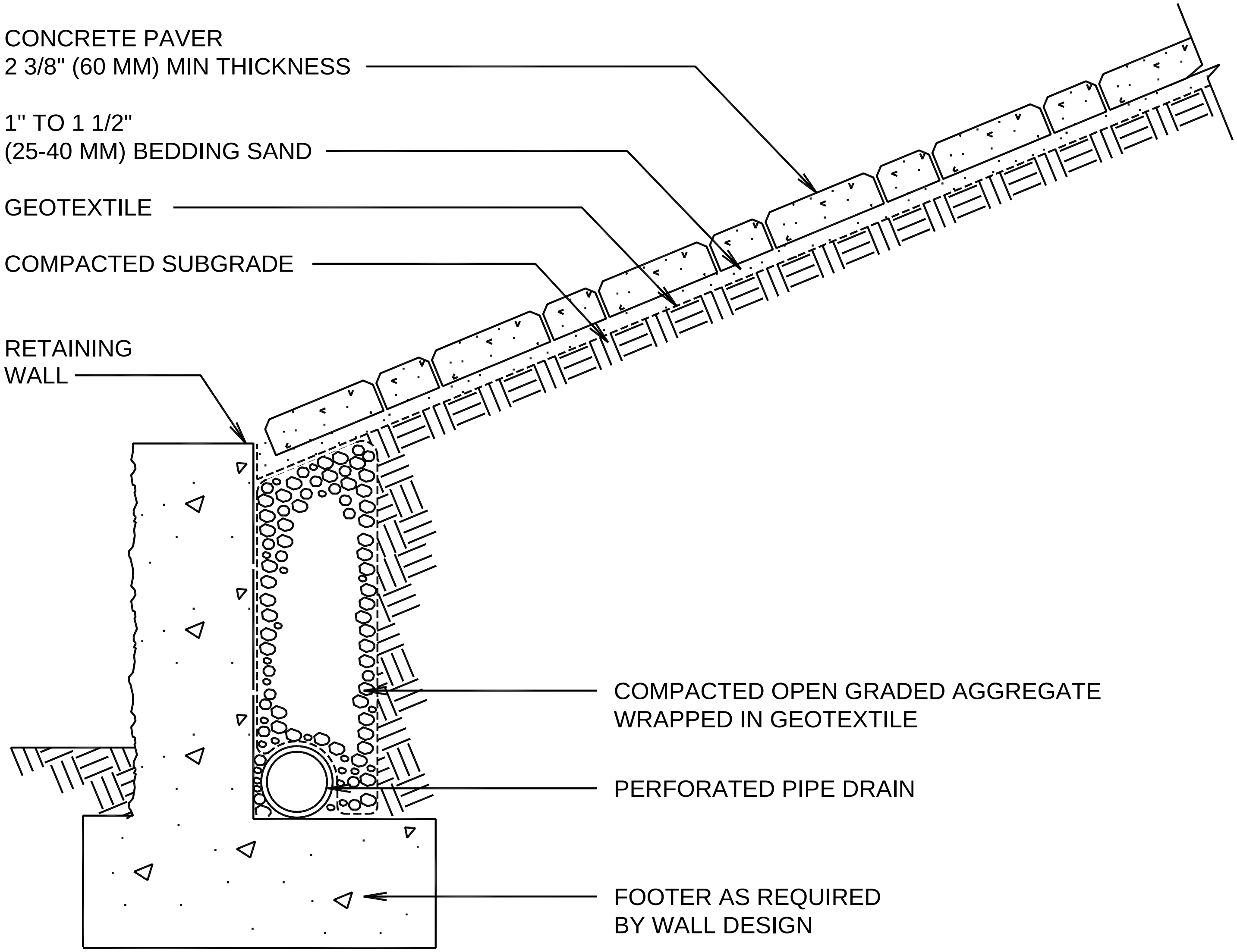
NOTES:

1. SIZE AND REINFORCING OF CONC. VARIES WITH TRAFFIC.
2. INSERT 1 IN. DIA. (25 MM) WEEP HOLES, ONE PER SIDE, BOTTOM OF WEEPHOLE TO BE LEVEL WITH SURFACE OF BASE. COVER WITH GEOTEXTILE.

CATCH BASIN

DRAWING NO. ICPI-26

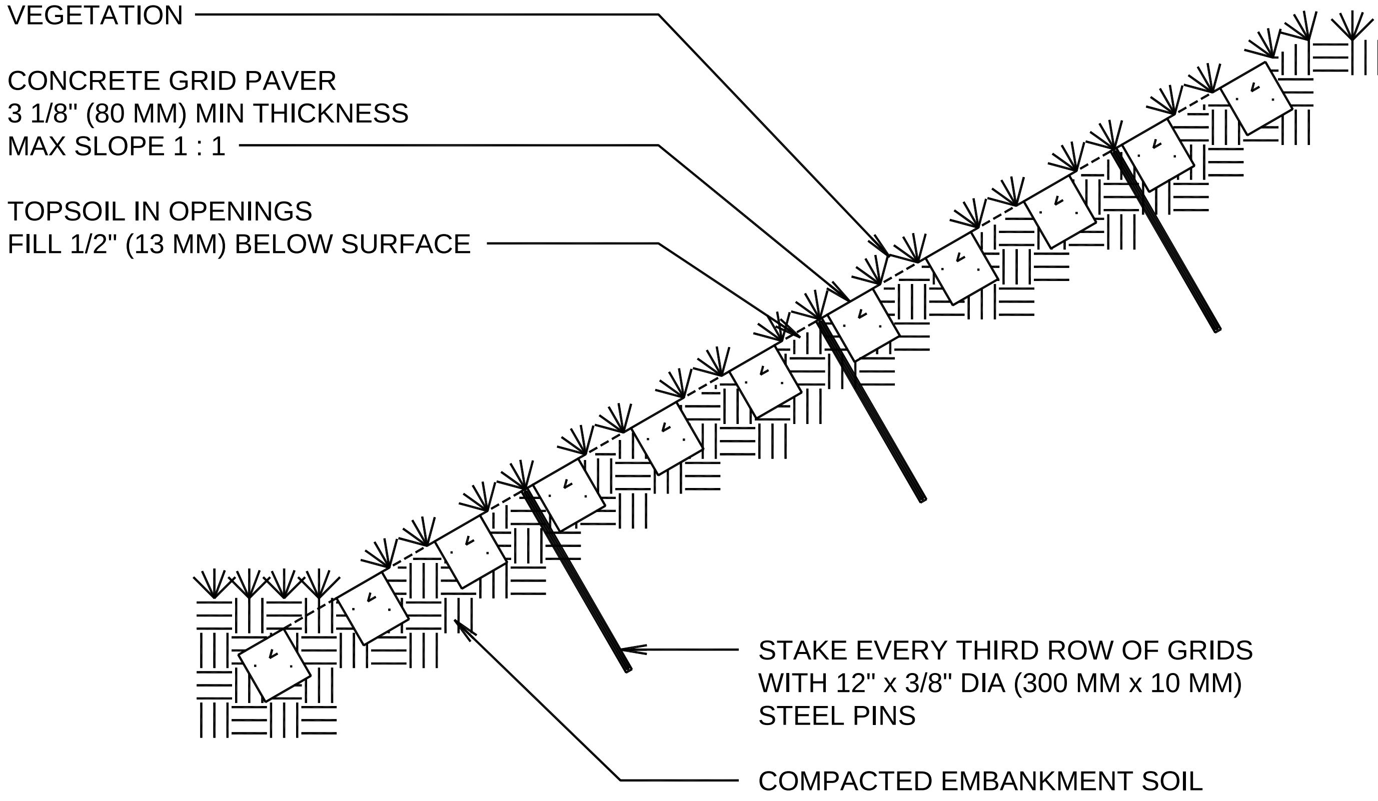
SCALE F.S.



NOTE:
1. MAXIMUM SLOPE SHOULD NOT EXCEED ANGLE OF REPOSE FOR BEDDING SAND.
2. PROVIDE EDGE RESTRAINTS ON SIDES OF INSTALLATION.
3. ENGINEERING OF THE SEGMENTAL RETAINING WALL IS REQUIRED WHEN HEIGHT EXCEEDS 4 FT. (1.0 M).

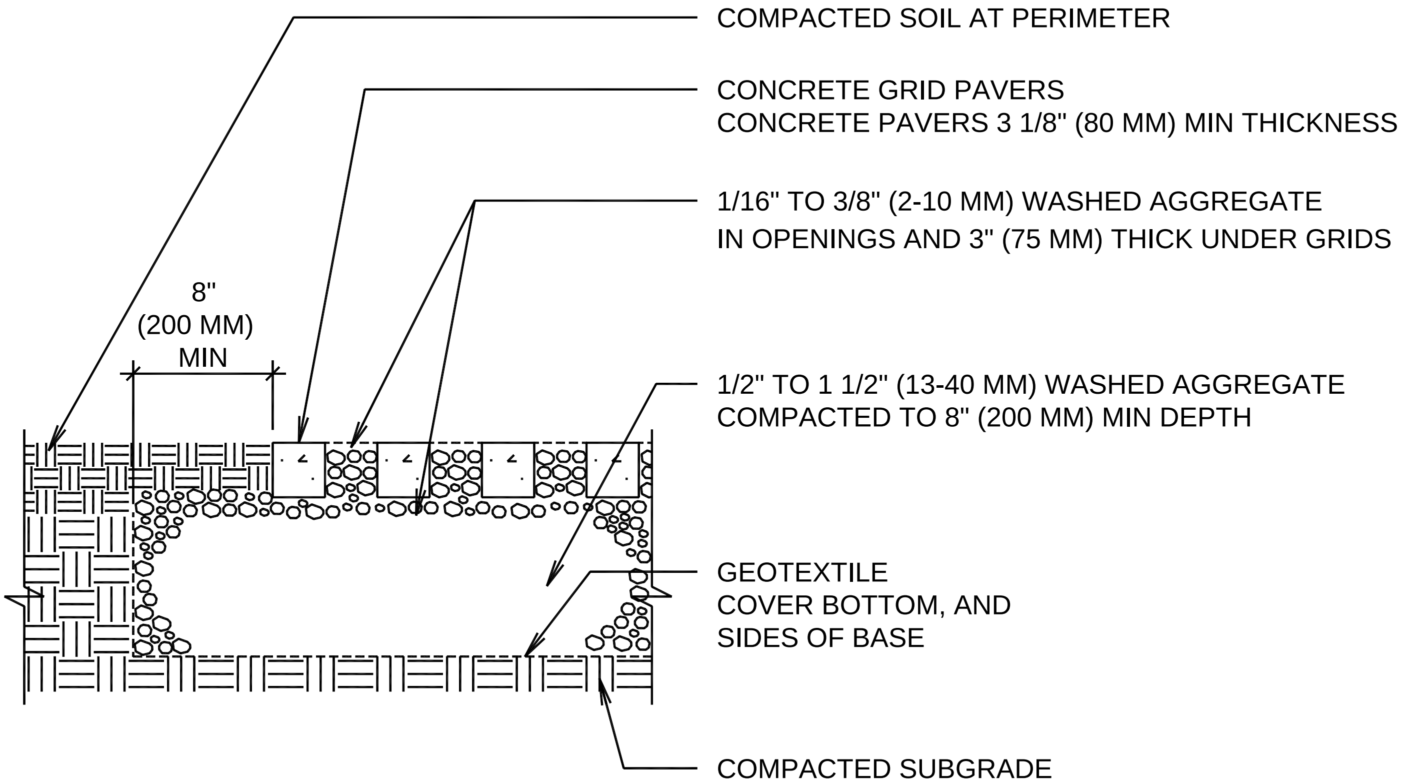
SLOPE PROTECTION
CONCRETE PAVERS

DRAWING NO.	ICPI-27
SCALE	F.S.



SLOPE PROTECTION
CONCRETE GRIDS

DRAWING NO.	ICPI-28
SCALE	F.S.

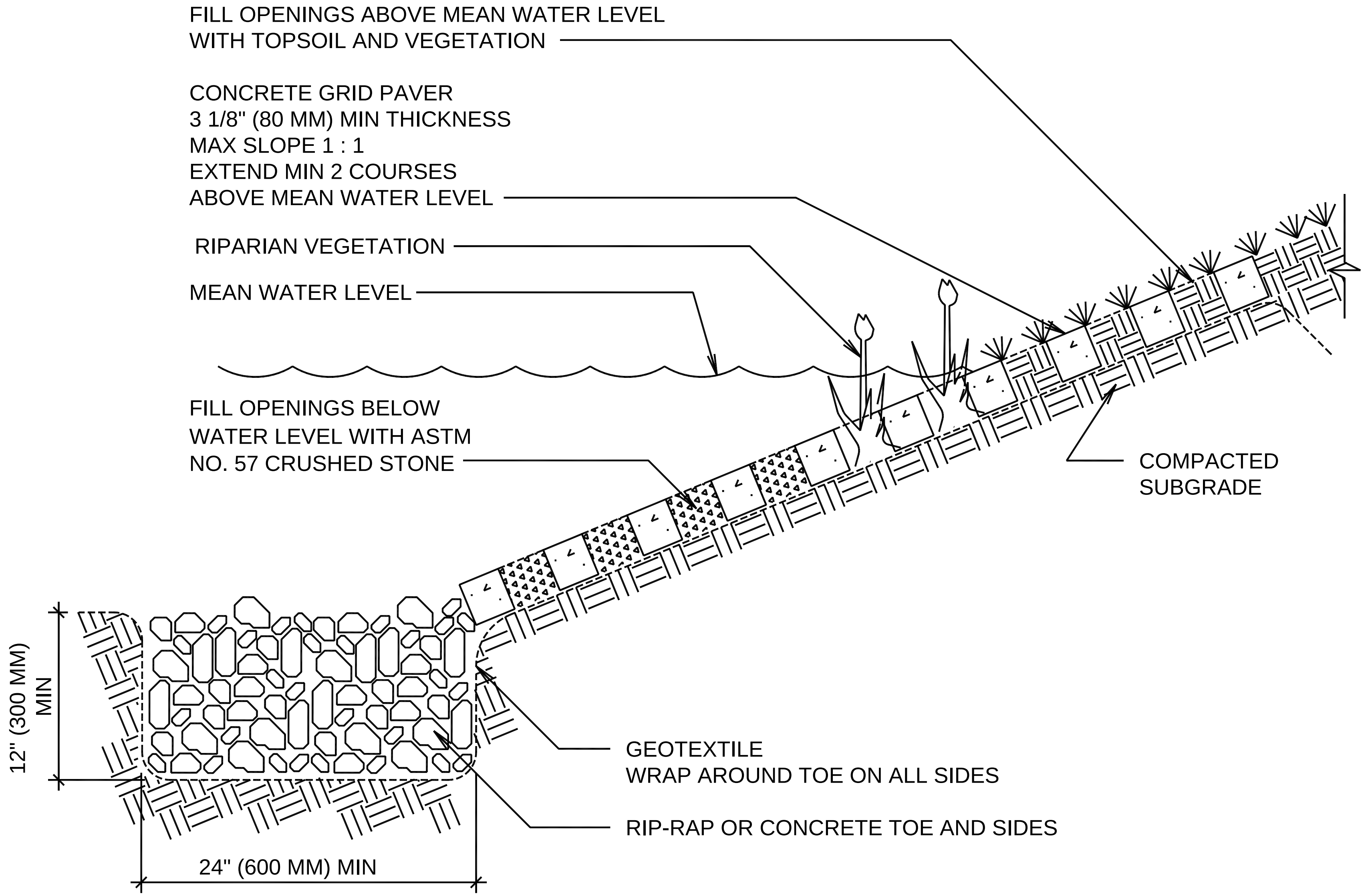


NOTES:

1. DEPTH OF OPEN GRADED BASE WILL EFFECT RUNOFF STORAGE CAPACITY
2. BEARING CAPACITY AND PERMEABILITY OF SOIL SUBGRADE SHOULD BE EVALUATED FOR SUITABILITY WITH APPLICATION, TRAFFIC & STORM WATER STORAGE CRITERIA. DRAINAGE OF SUBGRADE MAY BE REQUIRED.

CONCRETE GRID PAVERS FOR STORM WATER RUN-OFF CONTROL

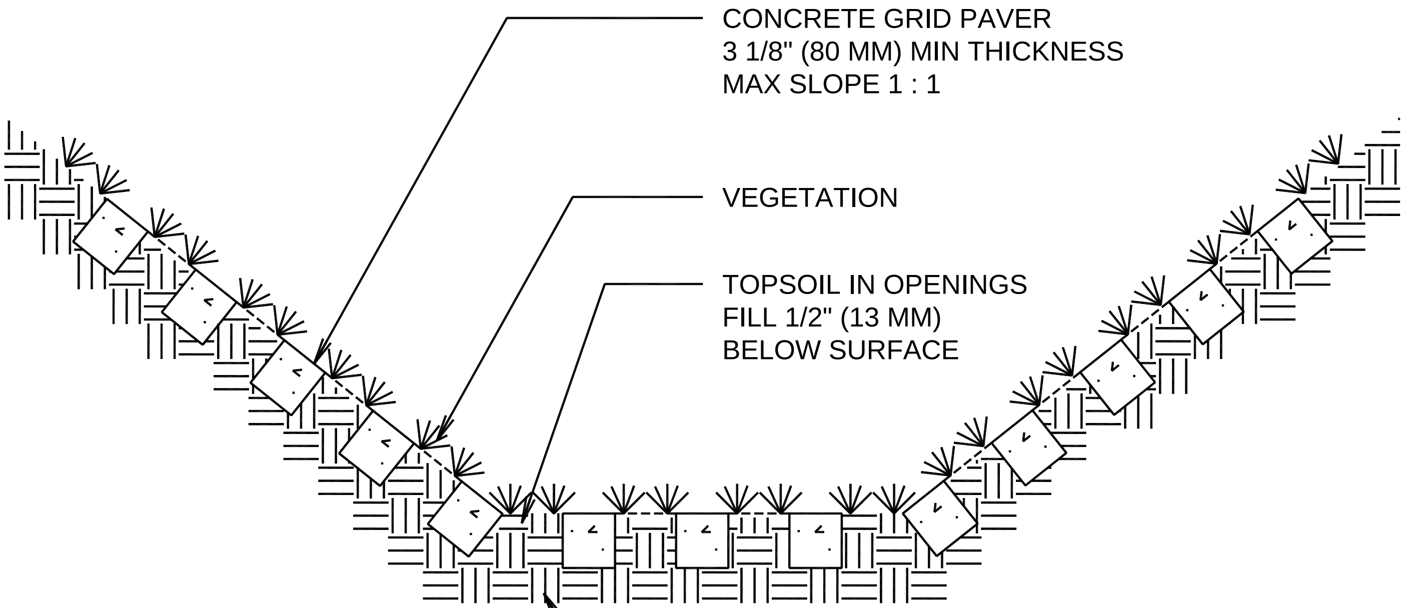
DRAWING NO.	ICPI-29
SCALE	F.S.



RIPARIAN STABILIZATION

CONCRETE GRIDS FOR STREAM BANKS AND LAKESIDES

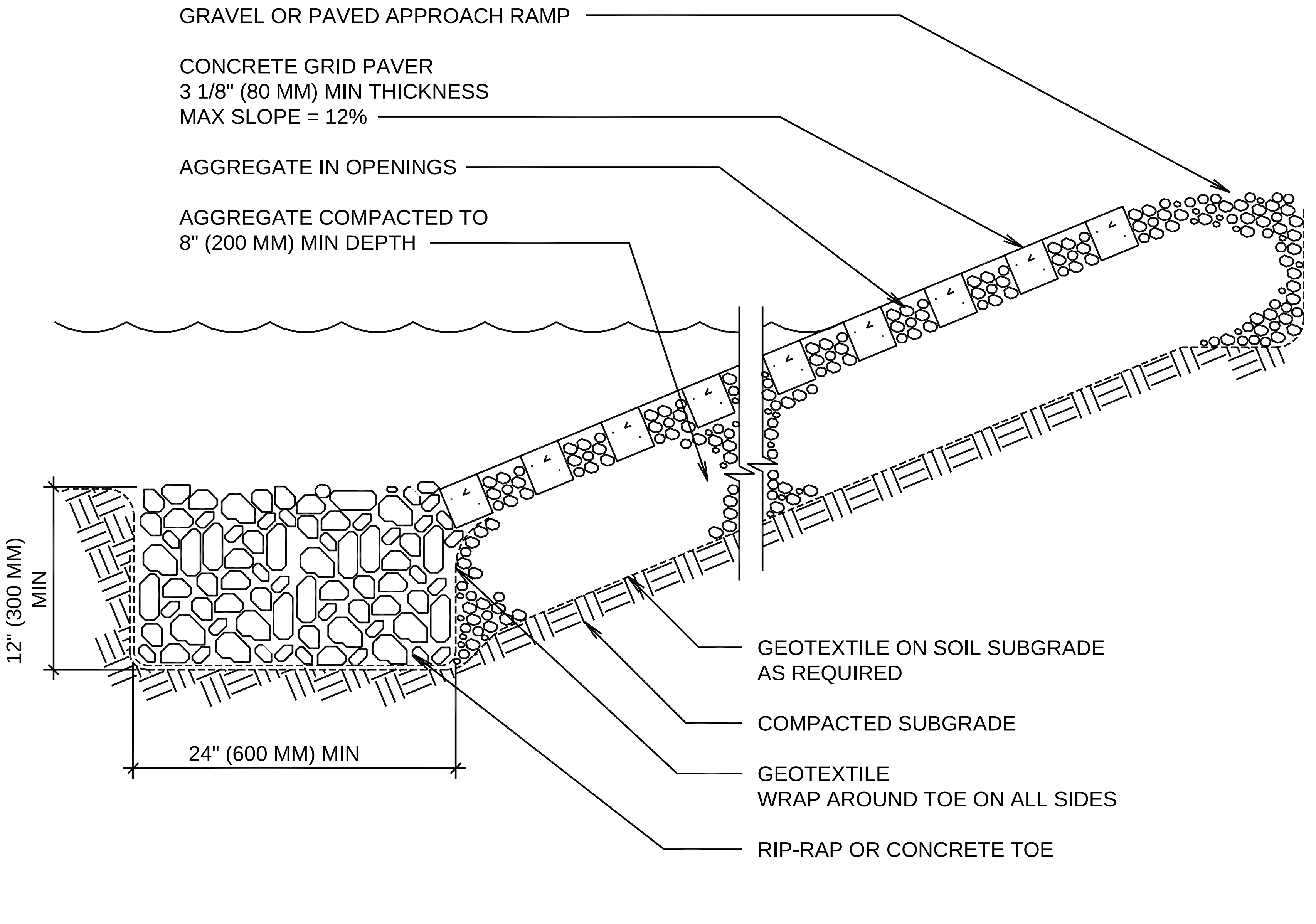
DRAWING NO.	ICPI-30
SCALE	F.S.



NOTE: AGGREGATE MAY BE USED IN OPENINGS OF GRID PAVERS.

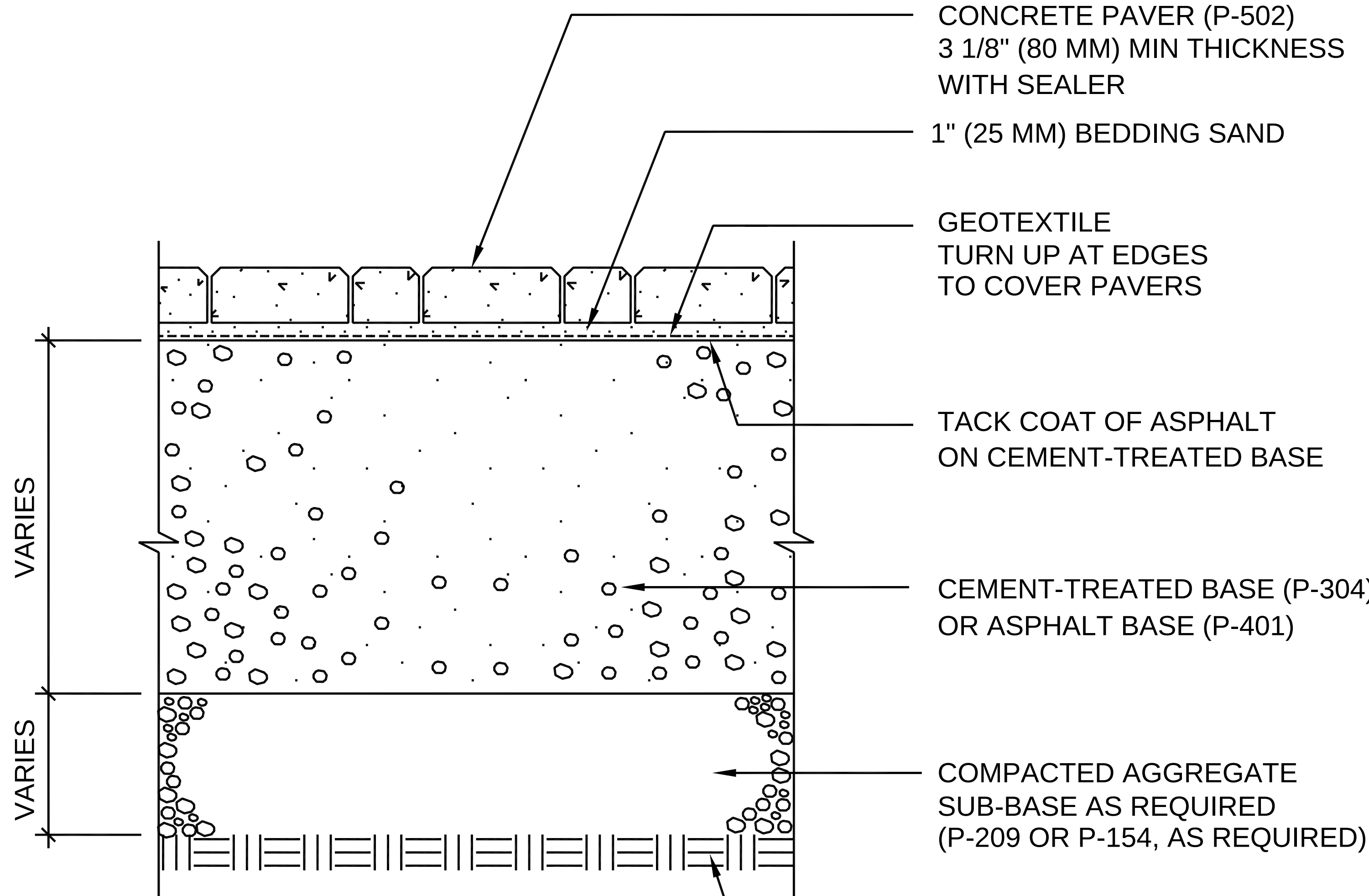
DITCH LINER FOR INTERMITTENT FLOWS - CONCRETE GRID PAVERS

DRAWING NO.	ICPI-31
SCALE	F.S.



NOTE: USE FOR NON-TIDAL FRESHWATER APPLICATIONS.

BOAT RAMP CONCRETE GRID PAVEMENT	DRAWING NO.	ICPI-32
	SCALE	F.S.

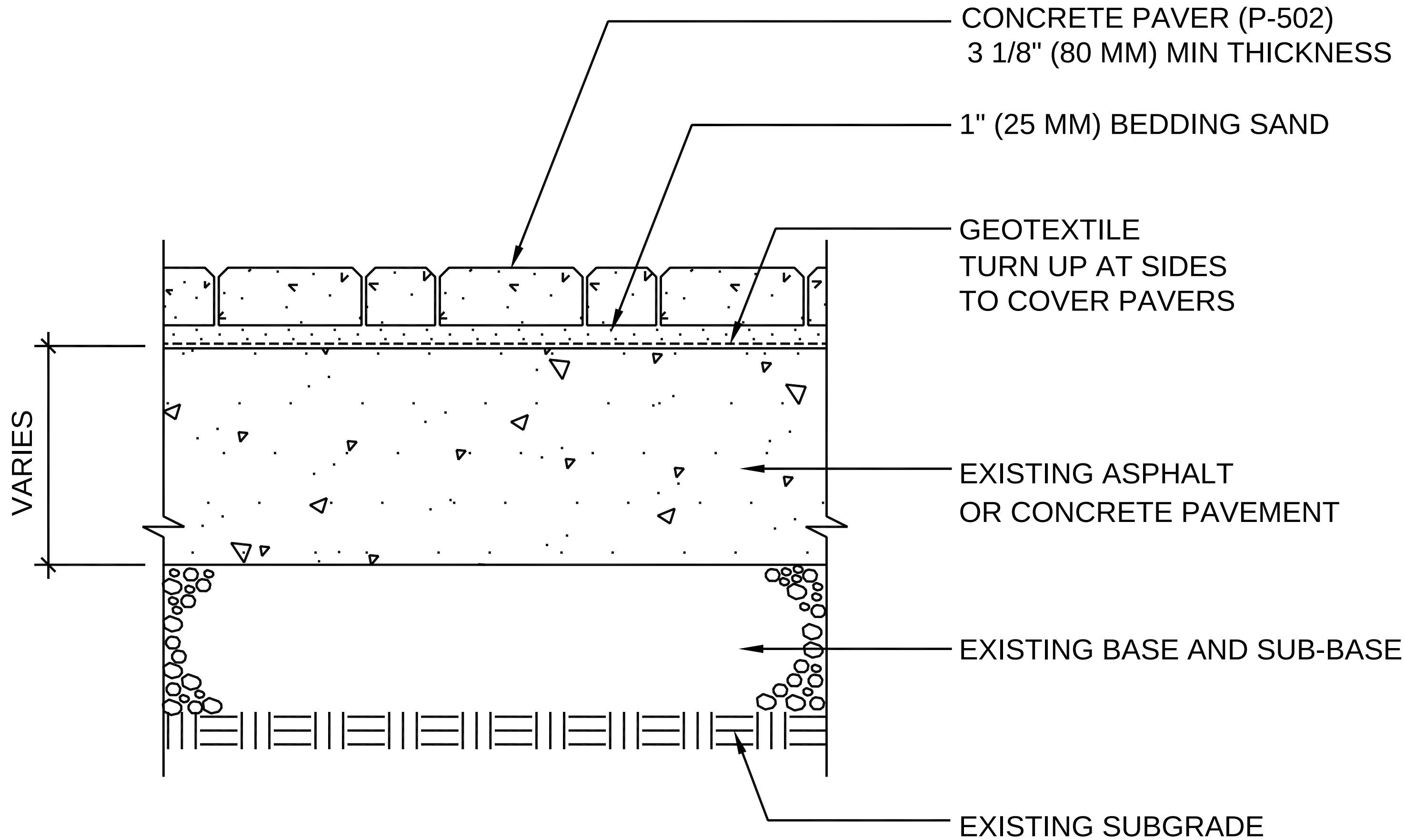


NOTE:

BASE, SUB-BASE, AND SUBGRADE THICKNESS VARY WITH LOADS, SOIL STRENGTH, AND CLIMATE.

AIRFIELD PAVEMENT WITH CEMENT TREATED OR ASPHALT BASE

DRAWING NO.	ICPI-35
SCALE	F.S.

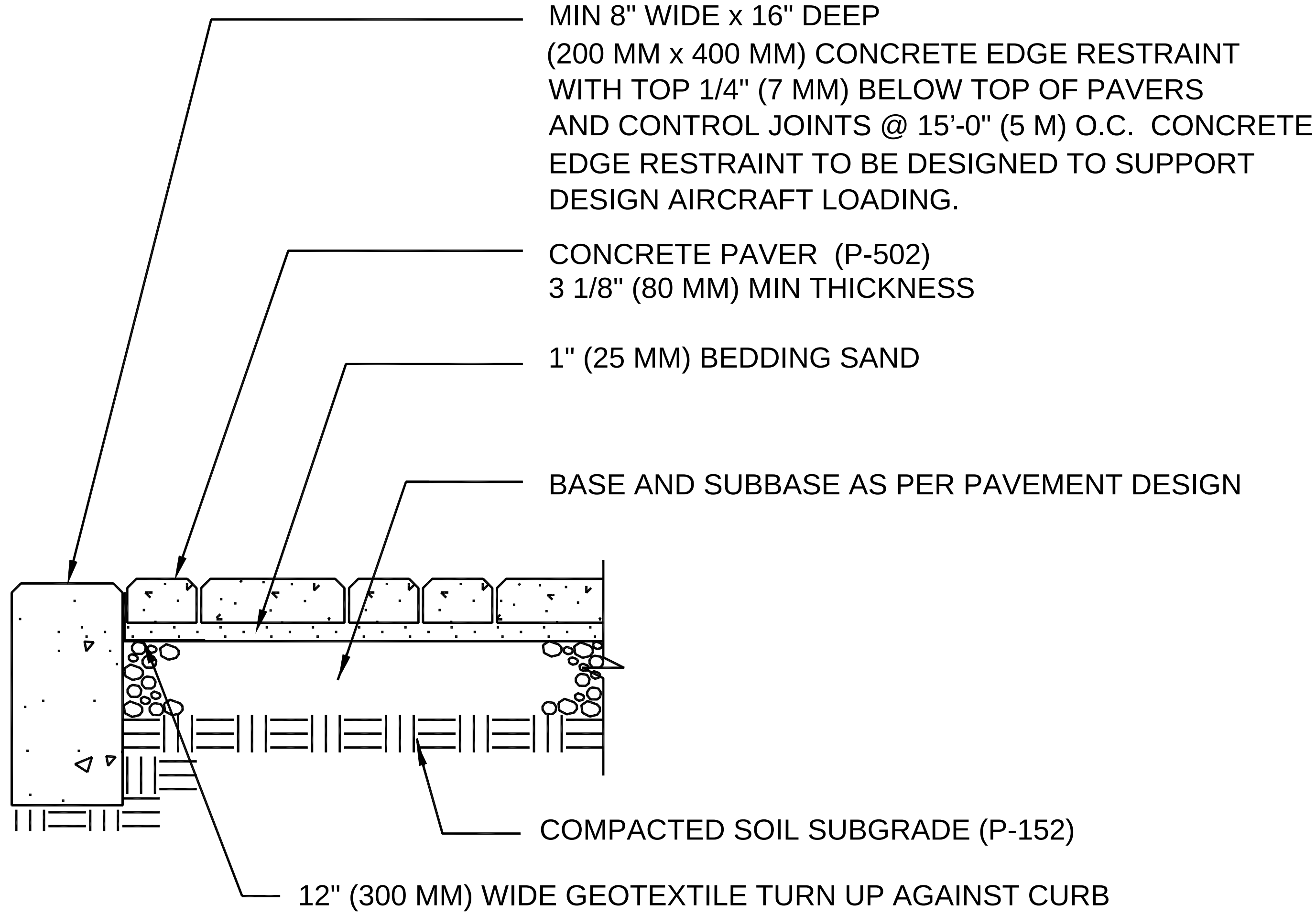


NOTE:

EXISTING ASPHALT OR CONCRETE PAVEMENT SHALL BE THOROUGHLY INSPECTED FOR AREAS IN NEED OF PATCHING OR REPLACEMENT. CONDUCT ALL REPAIRS AND FILL ALL CRACKS GREATER THAN 1/4 IN. (7 MM) WIDE PRIOR TO PLACING GEOTEXTILE, SAND, AND PAVERS.

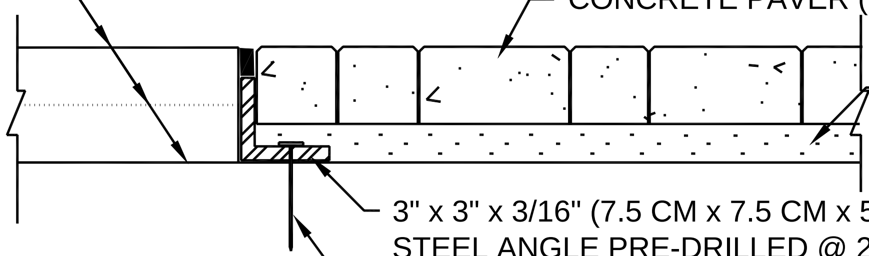
AIRFIELD PAVEMENT ON EXISTING ASPHALT OR CONCRETE

DRAWING NO.	ICPI-36
SCALE	F.S.



AIRFIELD PAVEMENT AT CONCRETE EDGE RESTRAINT

DRAWING NO.	ICPI-37
SCALE	F.S.



NOTES:

1. CONSTRUCT P-401 OVERLAY APPROX. 2 FT. (60 CM) PAST ANGLE LOCATION AND CUT BACK FOR ANGLE INSTALLATION

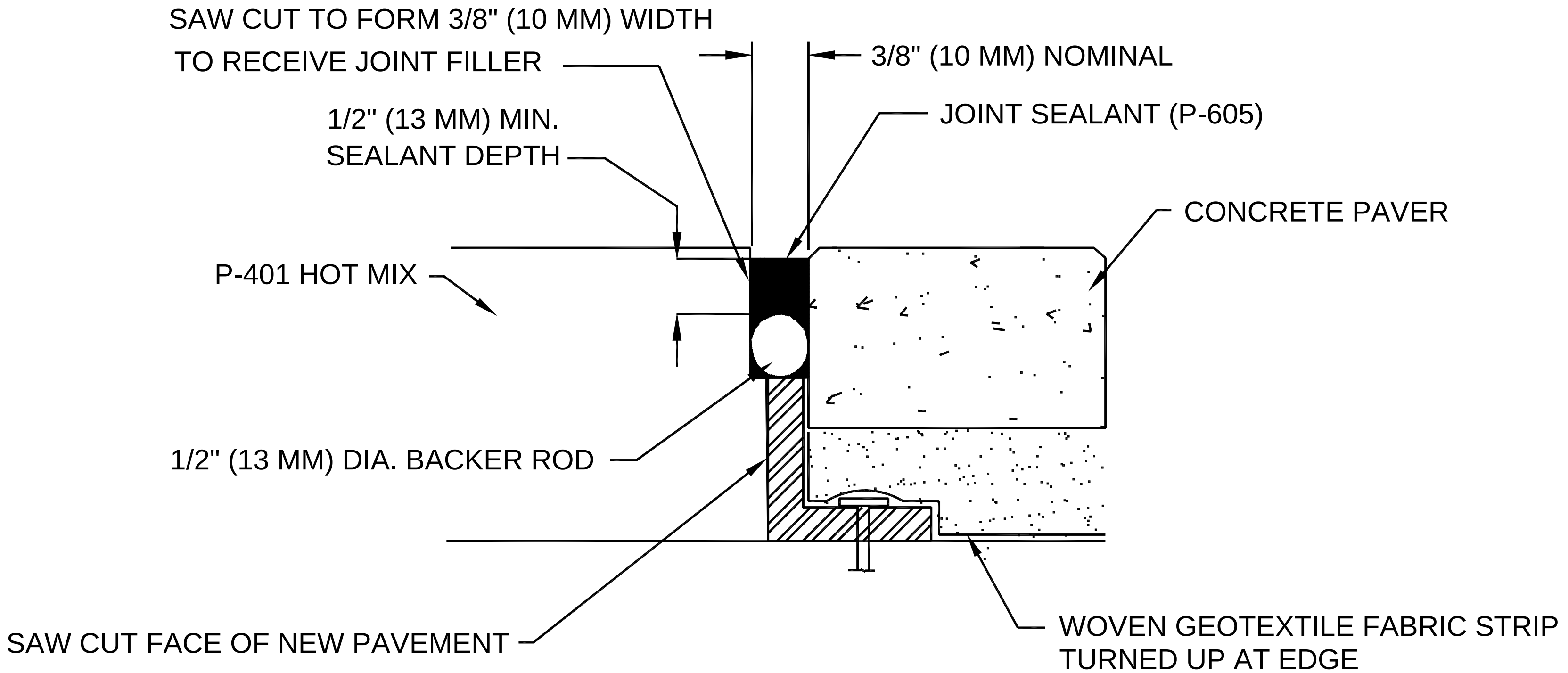
2. ADJUST ANGLE LOCATION +/- 2 IN. (5 CM) TO MINIMIZE CUTTING BLOCKS

3. ADD DRAIN HOLES AS NECESSARY AT LOWEST ELEVATIONS. COVER WITH GEOTEXTILE.

AIRFIELD PAVEMENT INLAY

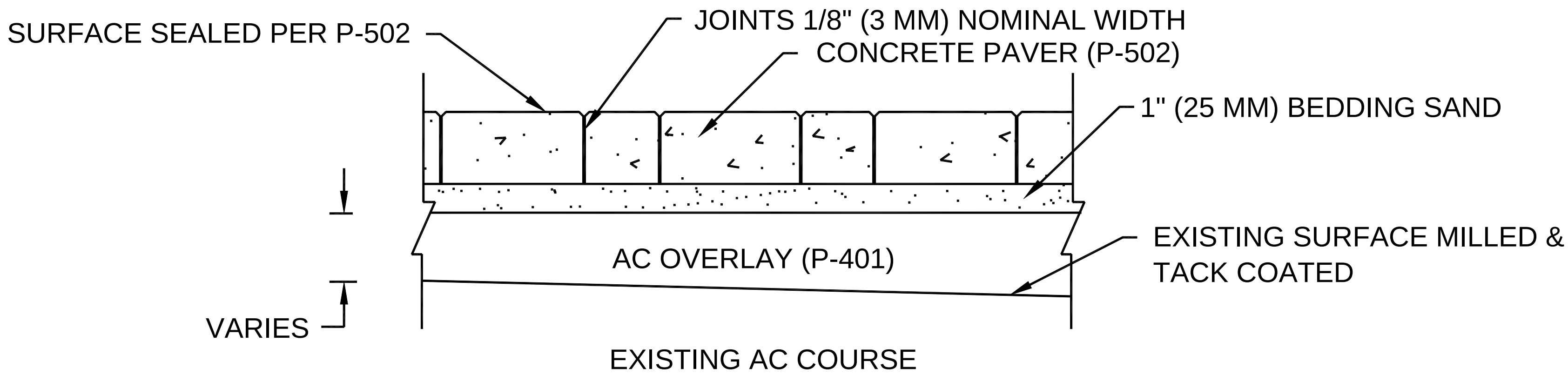
AT STEEL ANGLE EDGE RESTRAINT DETAIL

DRAWING NO.	ICPI-38
SCALE	F.S.



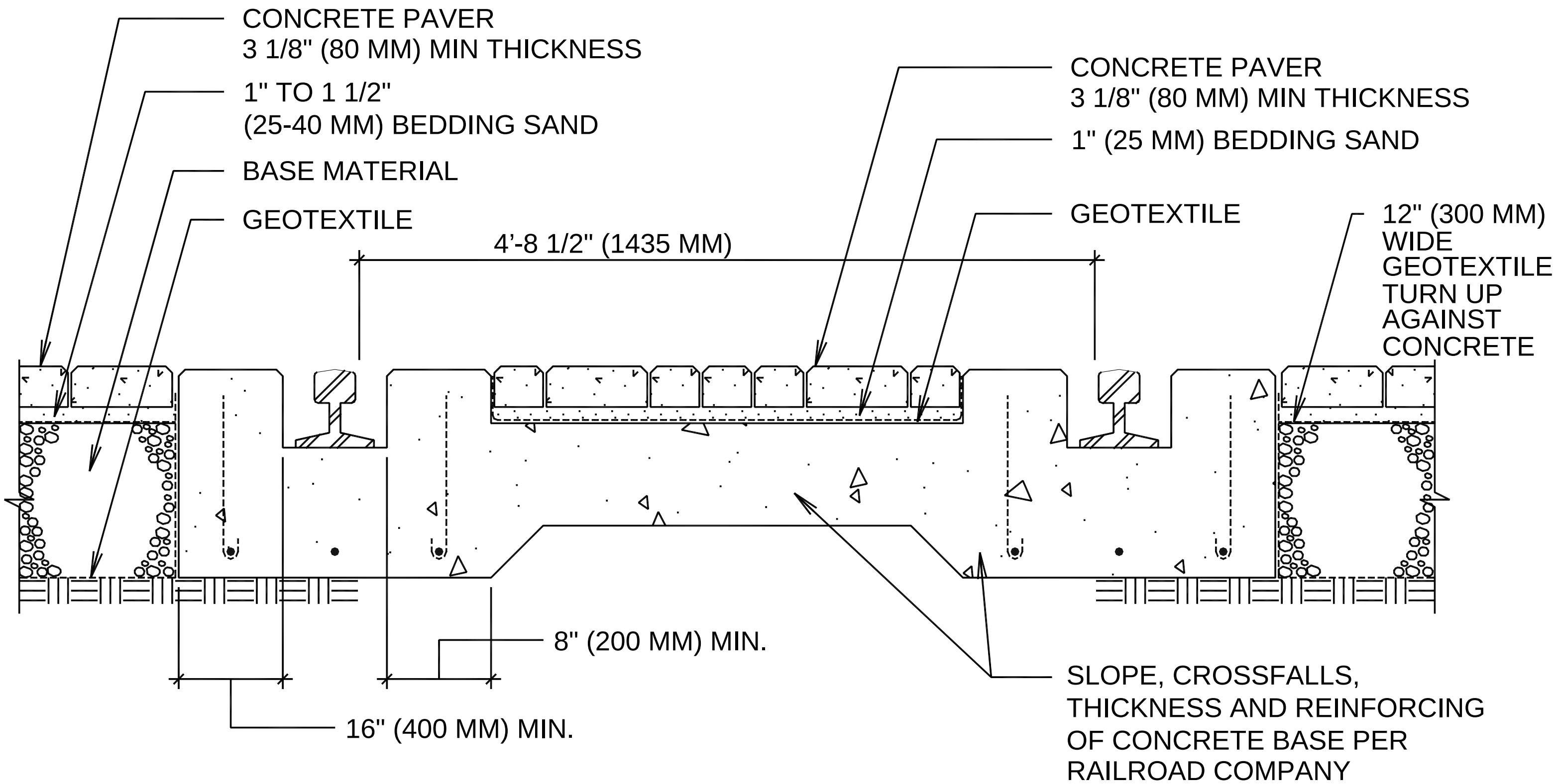
AIRFIELD PAVEMENT INLAY
IN ASPHALT AT EDGE RESTRAINT

DRAWING NO.	ICPI-39
SCALE	F.S.



AIRFIELD PAVEMENT OVERLAY
OF EXISTING FLEXIBLE PAVEMENT

DRAWING NO.	ICPI-40
SCALE	F.S.

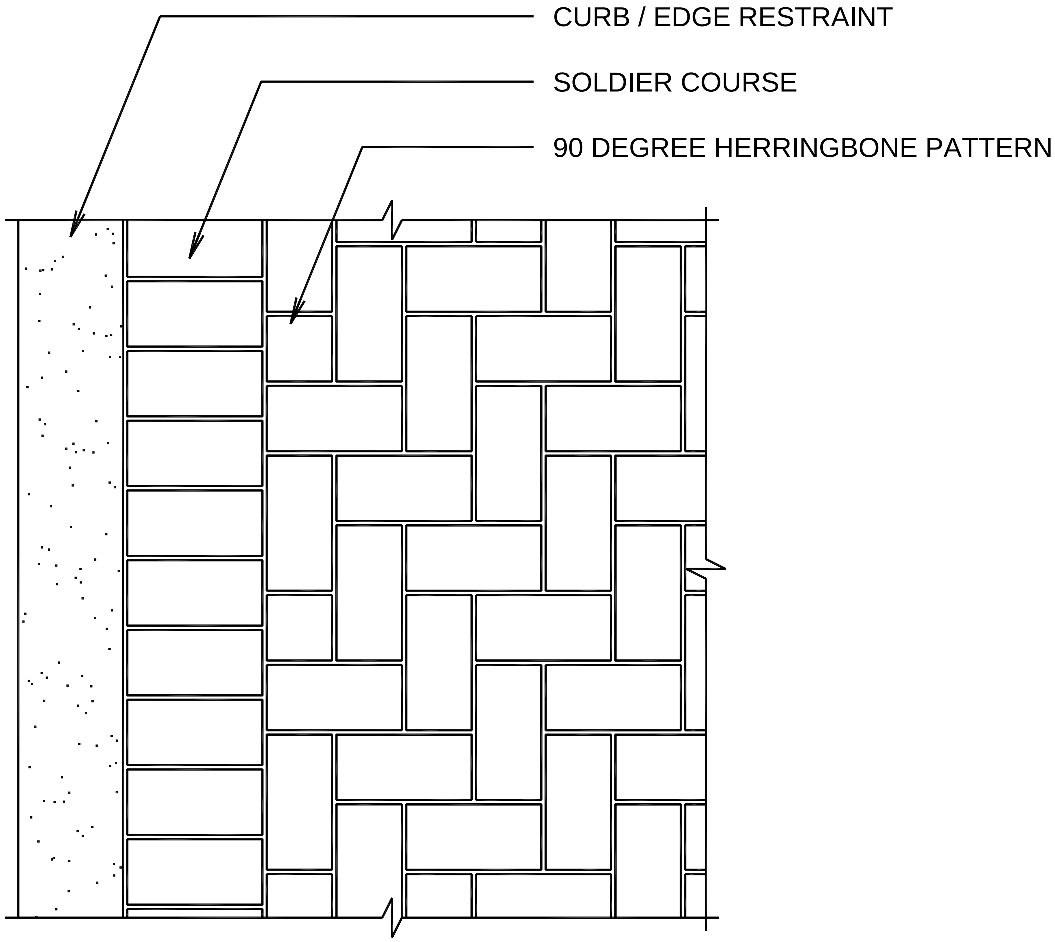


NOTE: DRAIN SAND LAYER THROUGH CONCRETE SLAB WITH PEA GRAVEL FILLED WEEP HOLE(S) OR AT CATCH BASIN(S).

RAILROAD CROSSING

DRAWING NO. ICPI-41

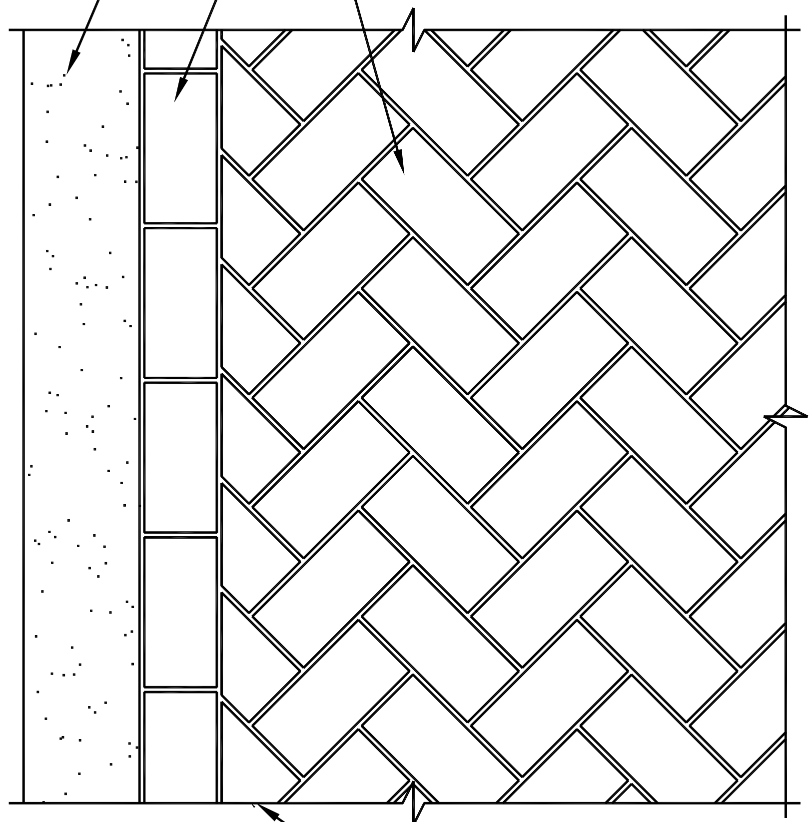
SCALE F.S.



SOLDIER COURSE EDGE WITH 90 DEGREE
HERRING BONE PATTERN

DRAWING NO. ICPI-42

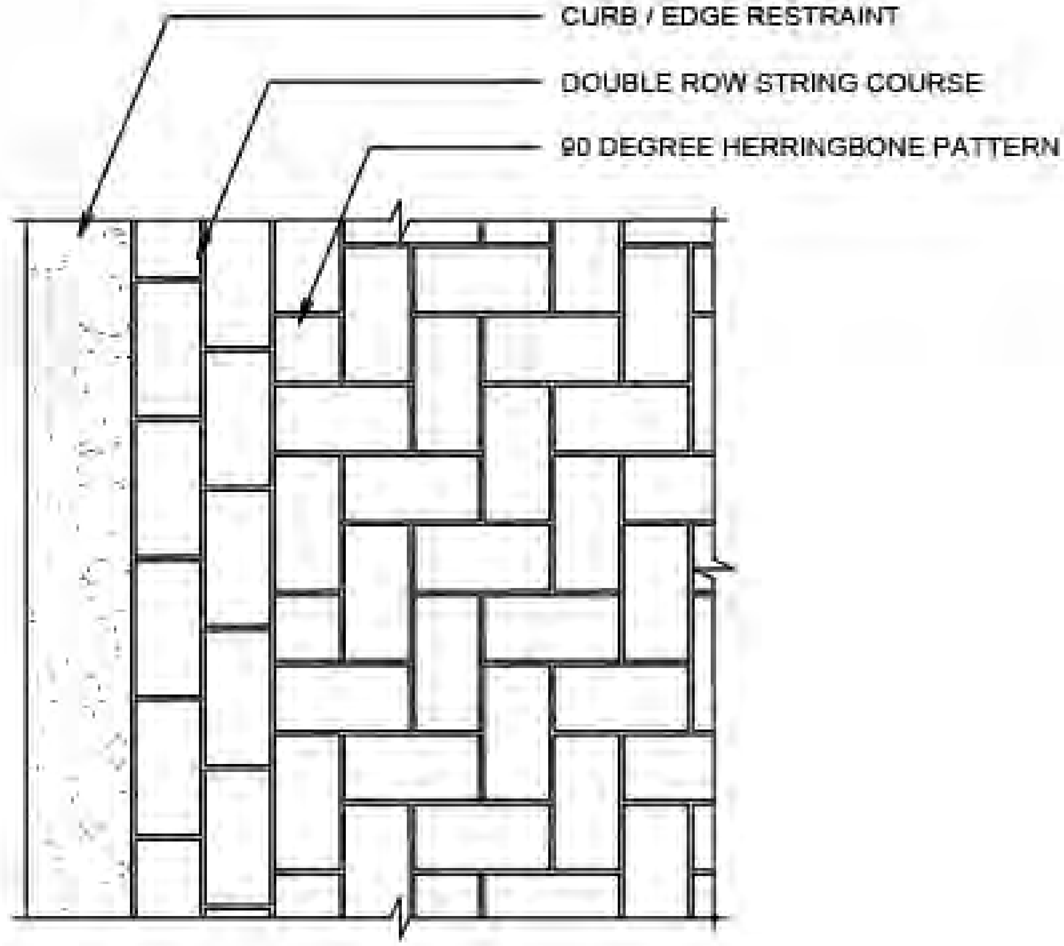
SCALE F.S.



STRING CO
45 DEGRE

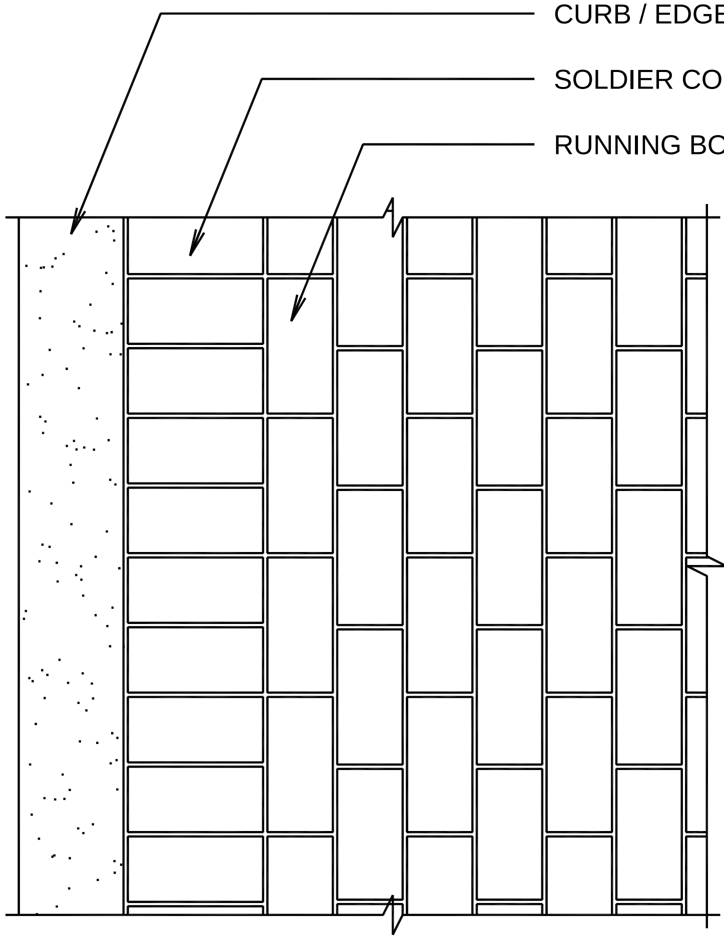
ICPI-64

NO SCALE



DOUBLE STRING SOLDIER COURSE EDGE WITH
90 DEGREE HERRING BONE PATTERN

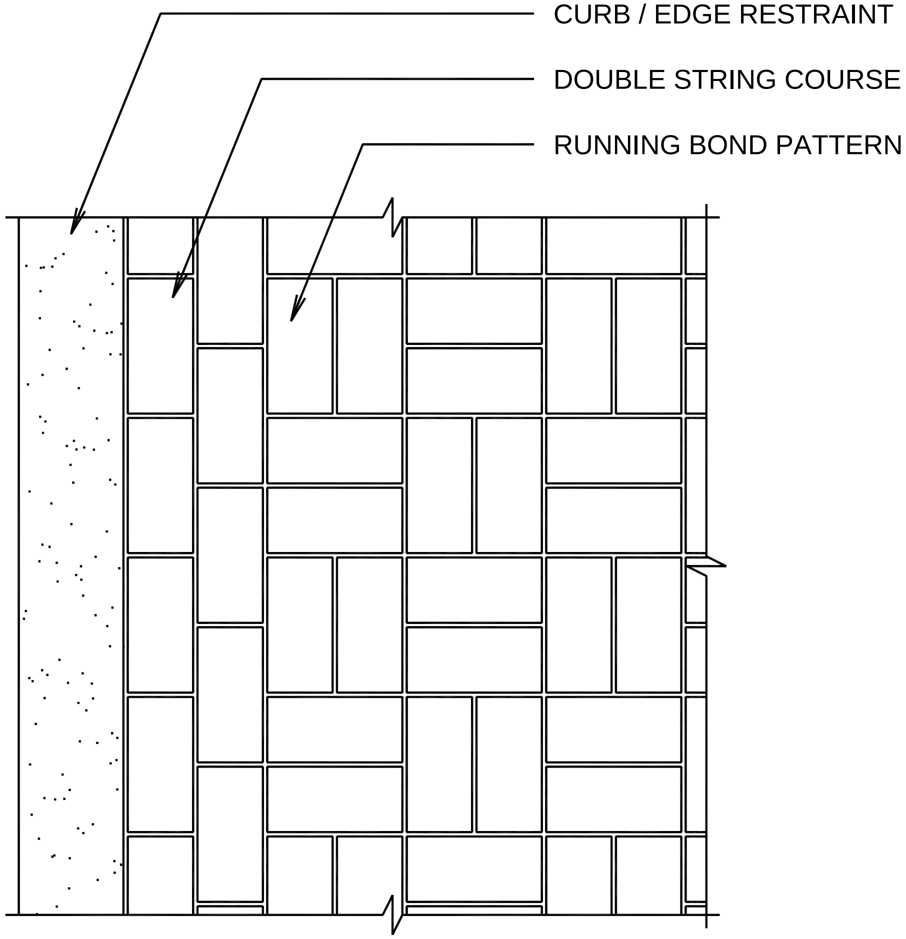
DRAWING NO.	ICPI-44
SCALE	F.S.



SOLDIER COURSE EDGE WITH RUNNING BOND PATTERN

DRAWING NO. ICPI-45

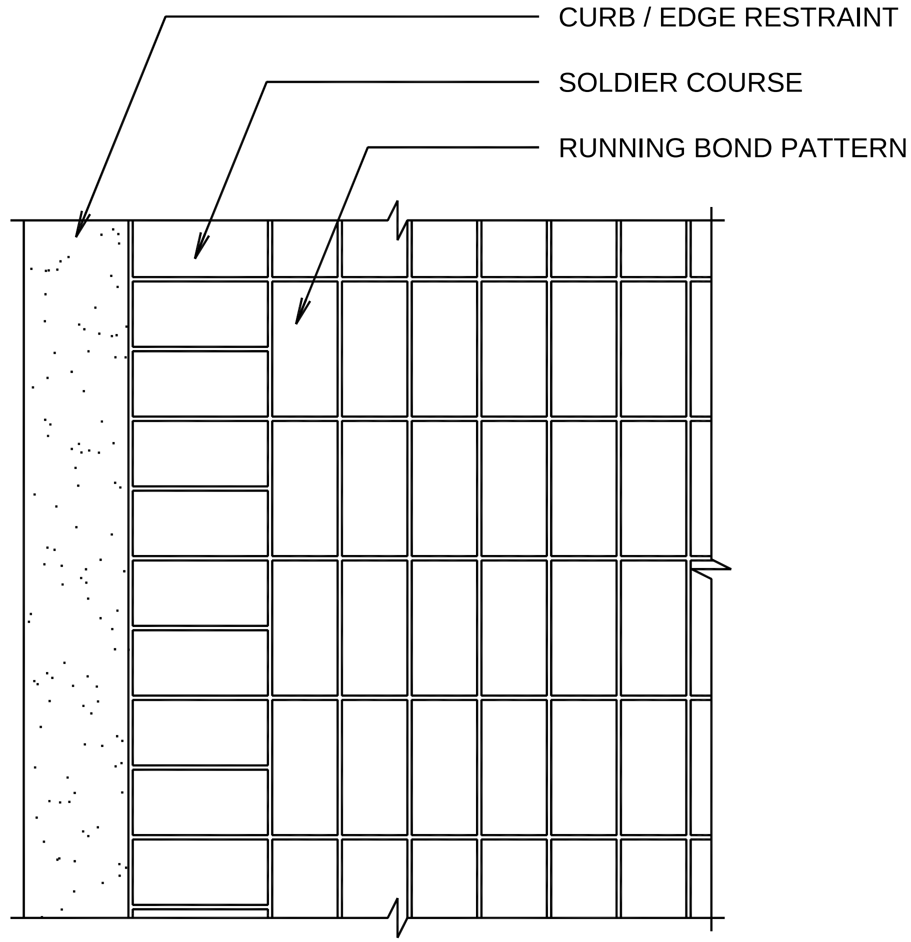
SCALE F.S.



DOUBLE STRING COURSE EDGE WITH PARQUET PATTERN

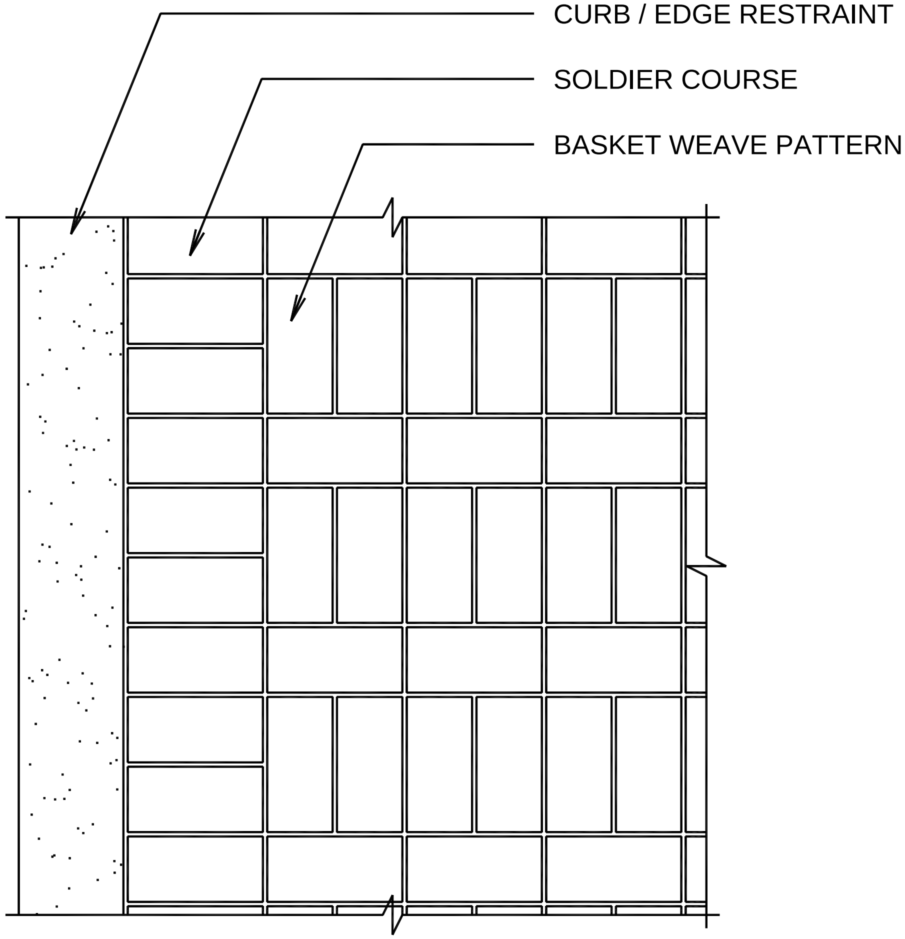
DRAWING NO. ICPI-46

SCALE F.S.



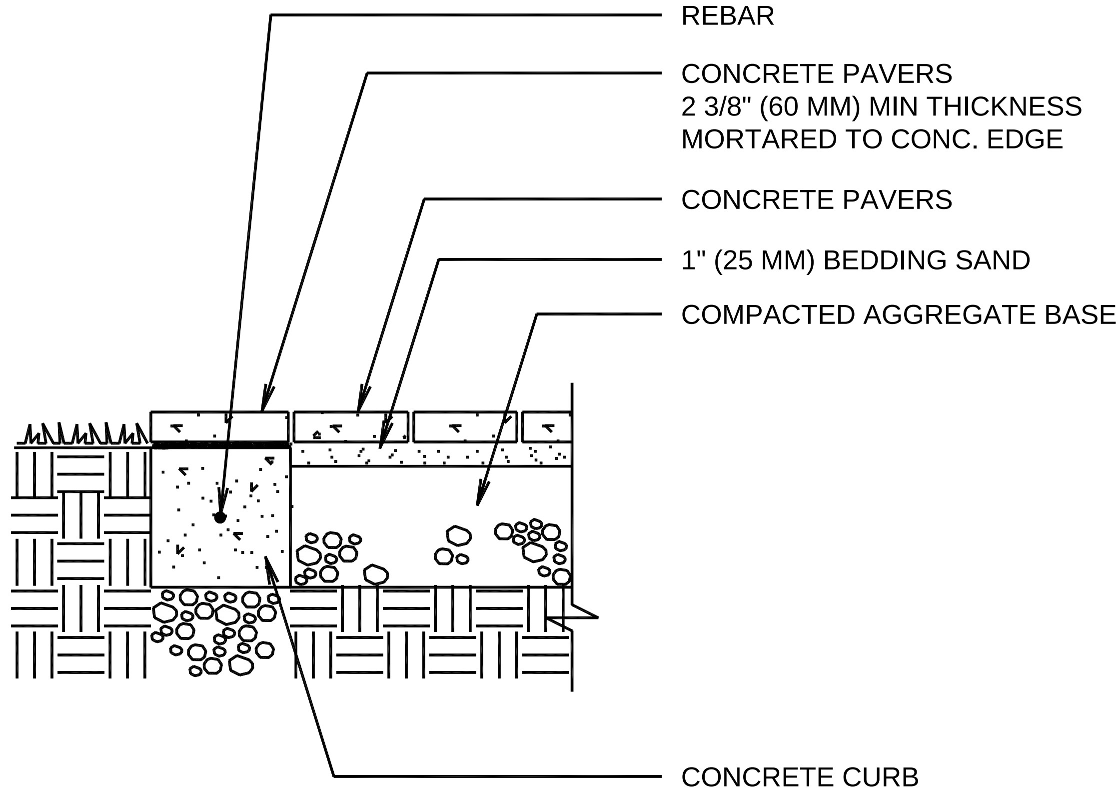
SOLDIER COURSE EDGE WITH STACK BOND PATTERN

DRAWING NO.	ICPI-47
SCALE	F.S.



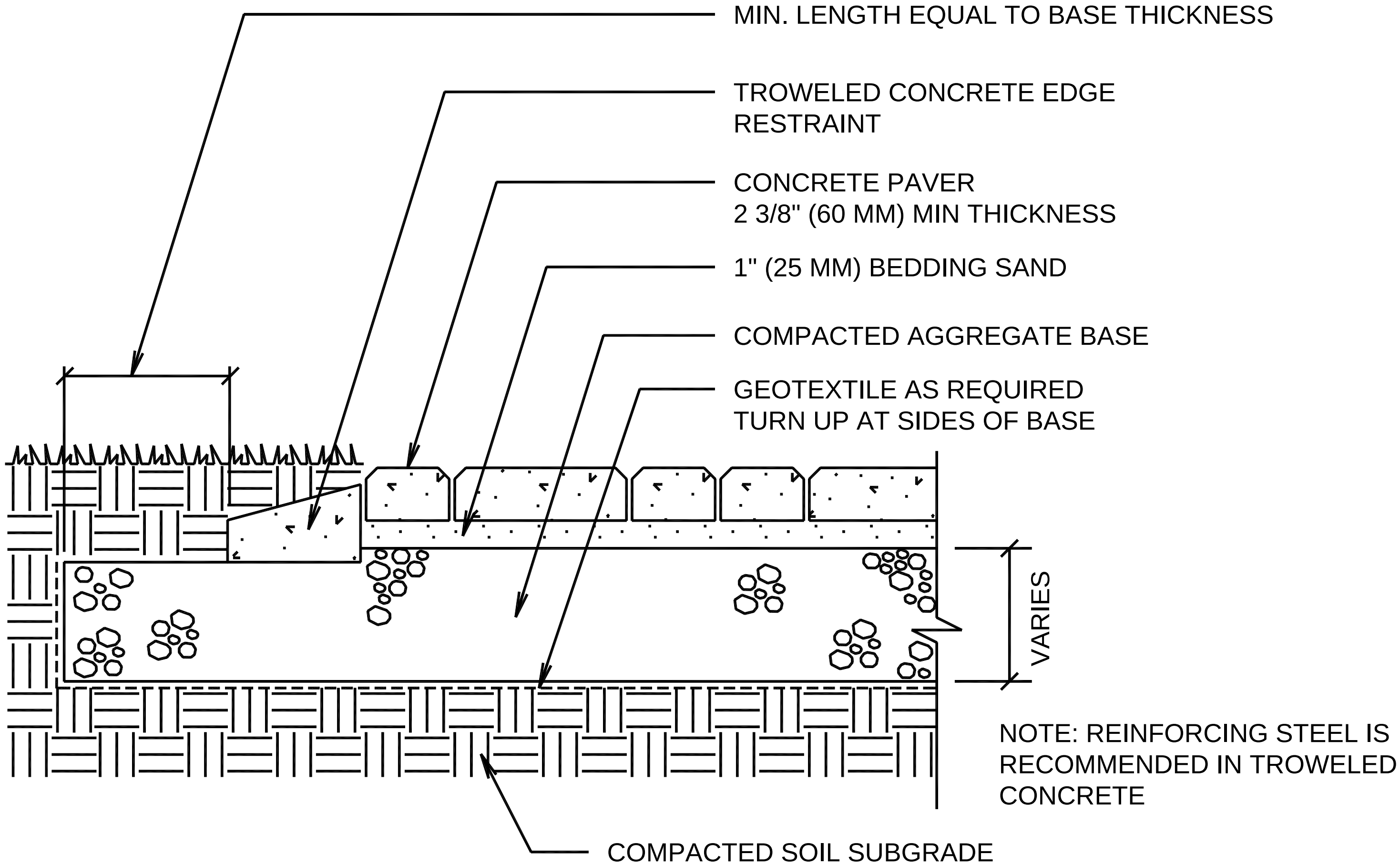
SOLDIER COURSE EDGE WITH BASKET WEAVE PATTERN

DRAWING NO.	ICPI-48
SCALE	F.S.



PEDESTRIAN DRIVEWAY WITH SUBMERGED CONCRETE CURB

DRAWING NO.	ICPI-49
SCALE	F.S.

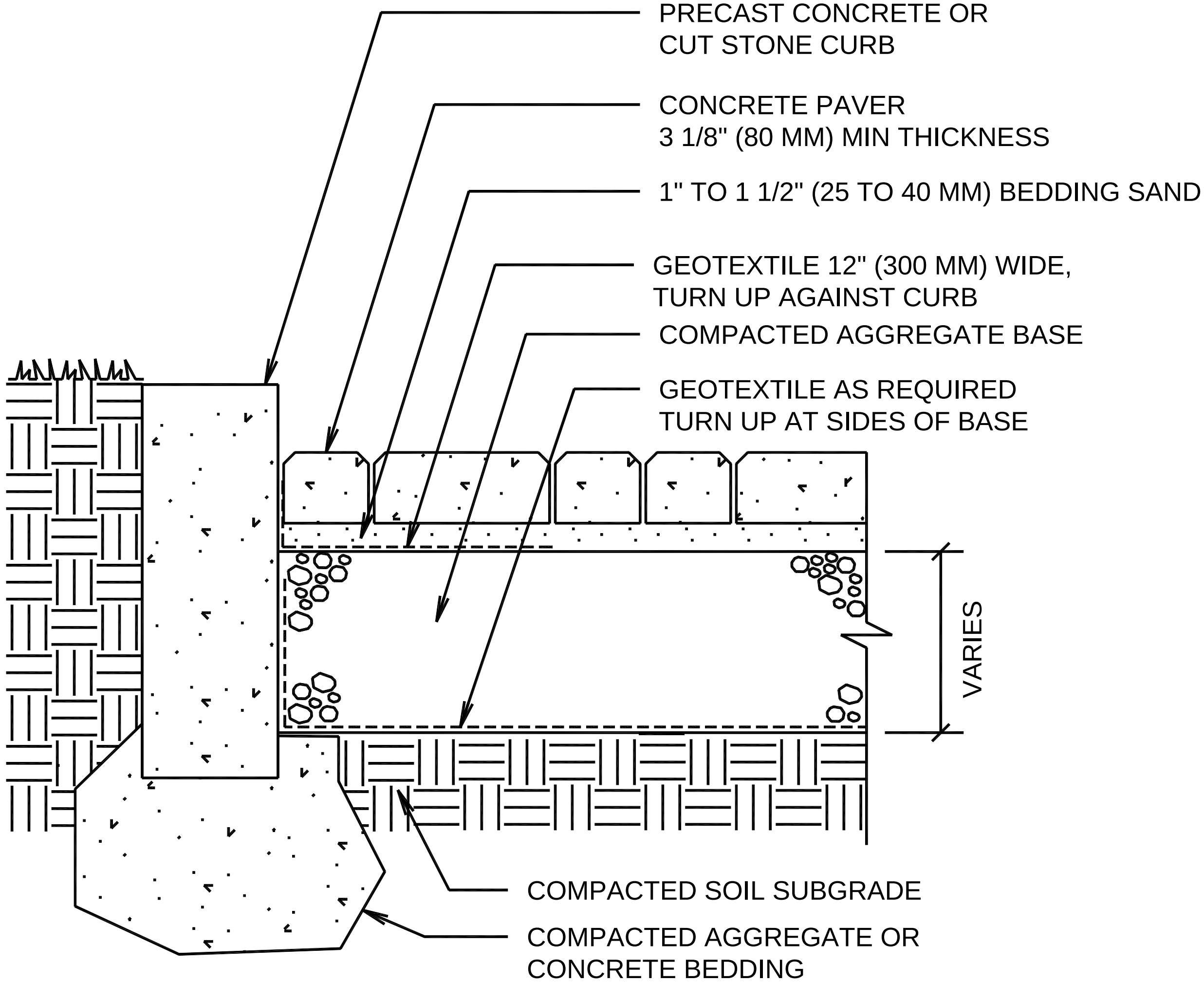


NOTE: REINFORCING STEEL IS RECOMMENDED IN TROWELED CONCRETE

NOTE:
1. USE 5:1 (AGGREGATE: CEMENT) MIX FOR CONCRETE EDGE.
2. RECOMMENDED FOR NON-FREEZE THAW AREAS.
3. CONSTRUCTION OF THIS DETAIL CAN BE USED ON RESIDENTIAL DRIVEWAYS IN NON-FREEZE THAW AREAS. REINFORCING MAY BE REQUIRED IN THE EDGE RESTRAINT.
4. THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE. COLDER CLIMATES MAY REQUIRE THICKER BASES.

PATIO/WALK/RESIDENTIAL DRIVEWAY W/ TROWELED CONCRETE EDGE RESTRAINT

DRAWING NO.	ICPI-50
SCALE	F.S.

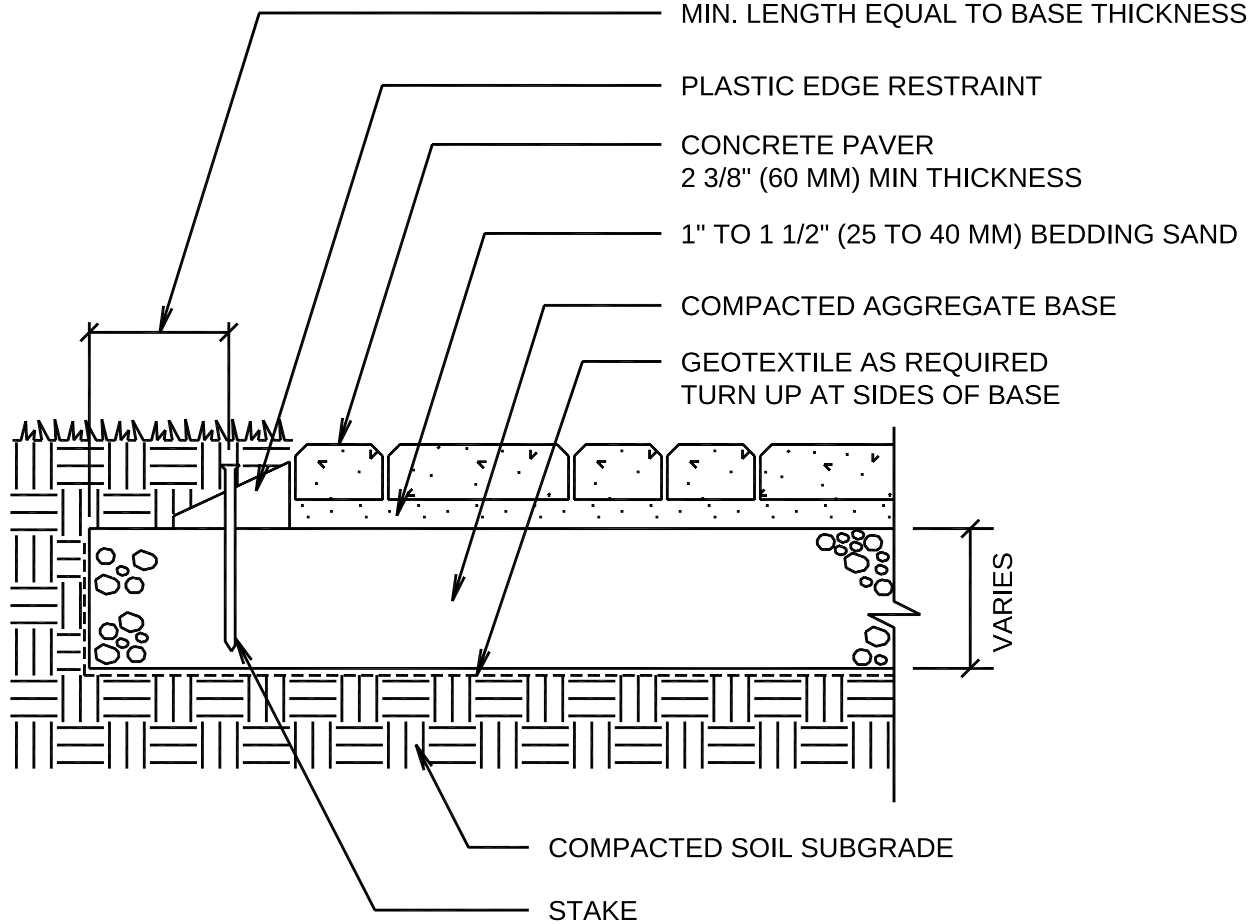


NOTE:

1. EDGE RESTRAINT SHOULD BE MINIMUM 6 IN. (150 MM) WIDE FOR STREET APPLICATIONS.
2. EDGE RESTRAINT MAY BE EVEN WITH TOP OF CONCRETE PAVERS.
3. THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE. COLDER CLIMATES MAY REQUIRE THICKER BASES.

STREET PAVEMENT WITH FULL-DEPTH PRECAST CONCRETE OR CUT STONE CURB

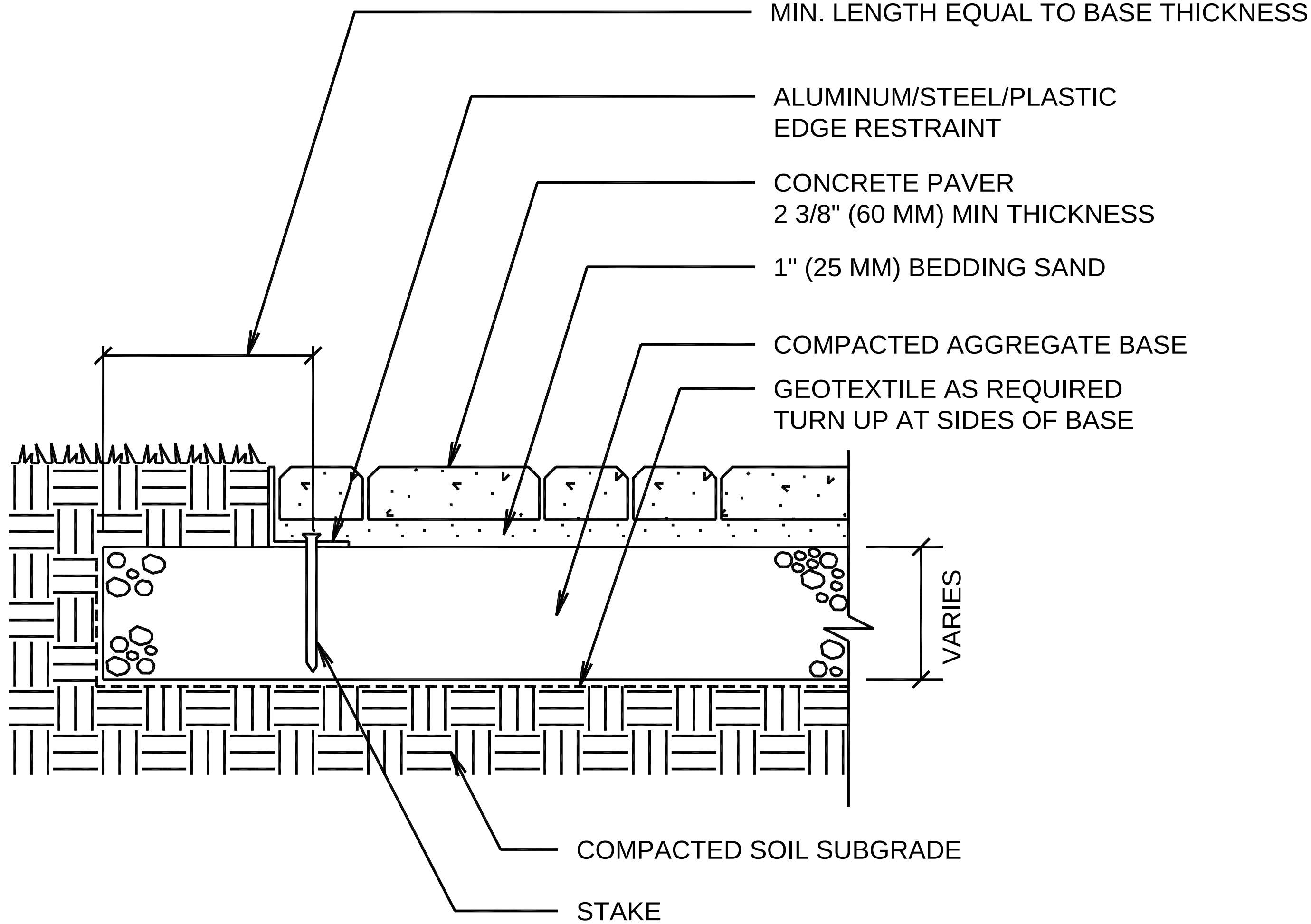
DRAWING NO.	ICPI-51
SCALE	F.S.



NOTE:

1. THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE. COLDER CLIMATES MAY REQUIRE THICKER BASES.

PATIO/ WALK/ RESIDENTIAL DRIVEWAY WITH PLASTIC EDGE RESTRAINT	DRAWING NO.	ICPI-52
	SCALE	F.S.

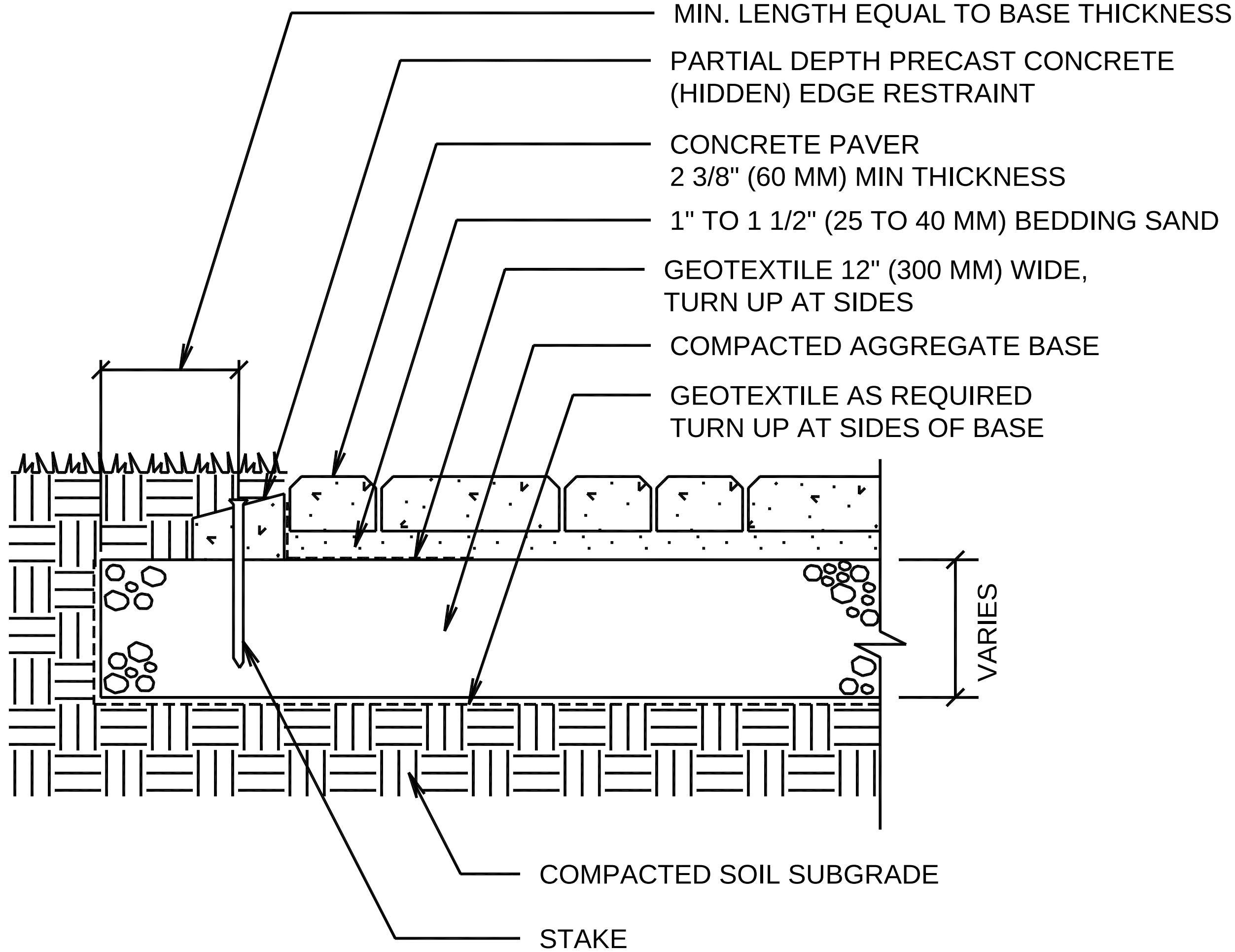


NOTE:

1. THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE. COLDER CLIMATES MAY REQUIRE THICKER BASES.

PATIO/WALK/RESIDENTIAL DRIVEWAY W/ ALUMINUM / STEEL / PLASTIC EDGE

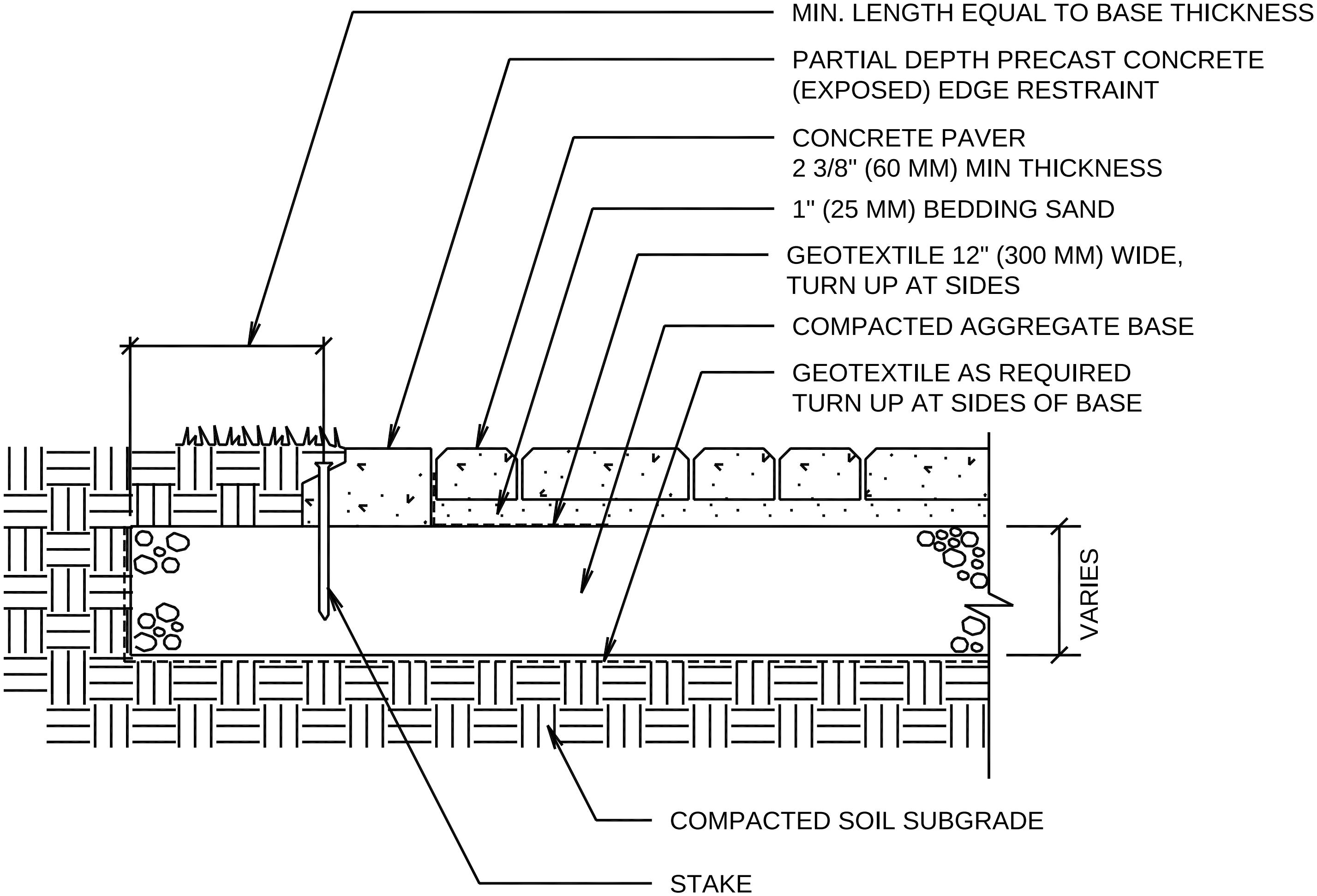
DRAWING NO.	ICPI-53
SCALE	F.S.



NOTE:
THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE.
COLDER CLIMATES MAY REQUIRE THICKER BASES.

PATIO/WALK/RESIDENTIAL DRIVEWAY WITH PARTIAL DEPTH CONCRETE EDGE RESTRAINT

DRAWING NO.	ICPI-54
SCALE	F.S.

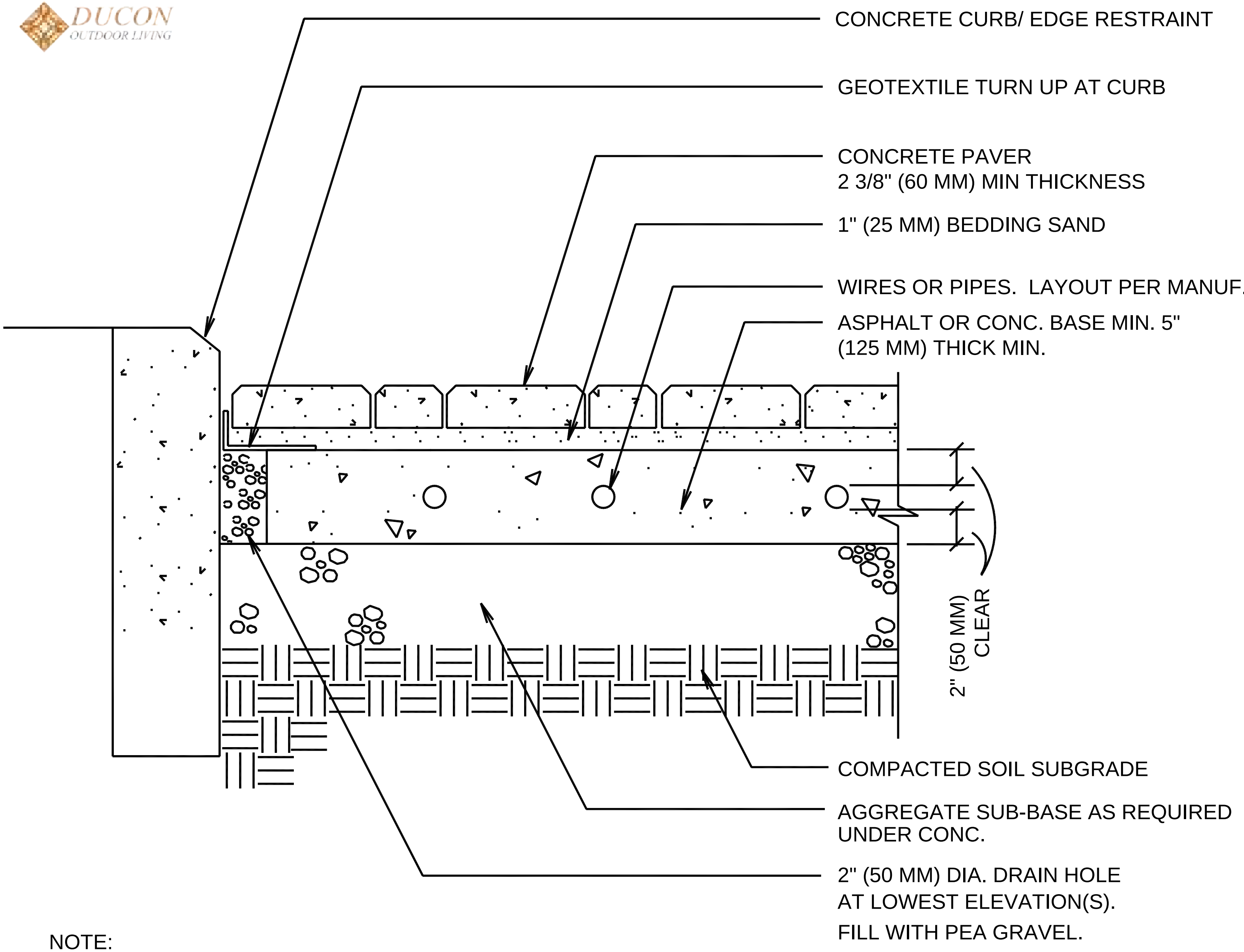


NOTE:

1. THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE. COLDER CLIMATES MAY REQUIRE THICKER BASES.

PATIO/WALK/RESID'L DRIVEWAY WITH PARTIAL DEPTH CONCRETE EDGE RESTRAINT

DRAWING NO.	ICPI-55
SCALE	F.S.

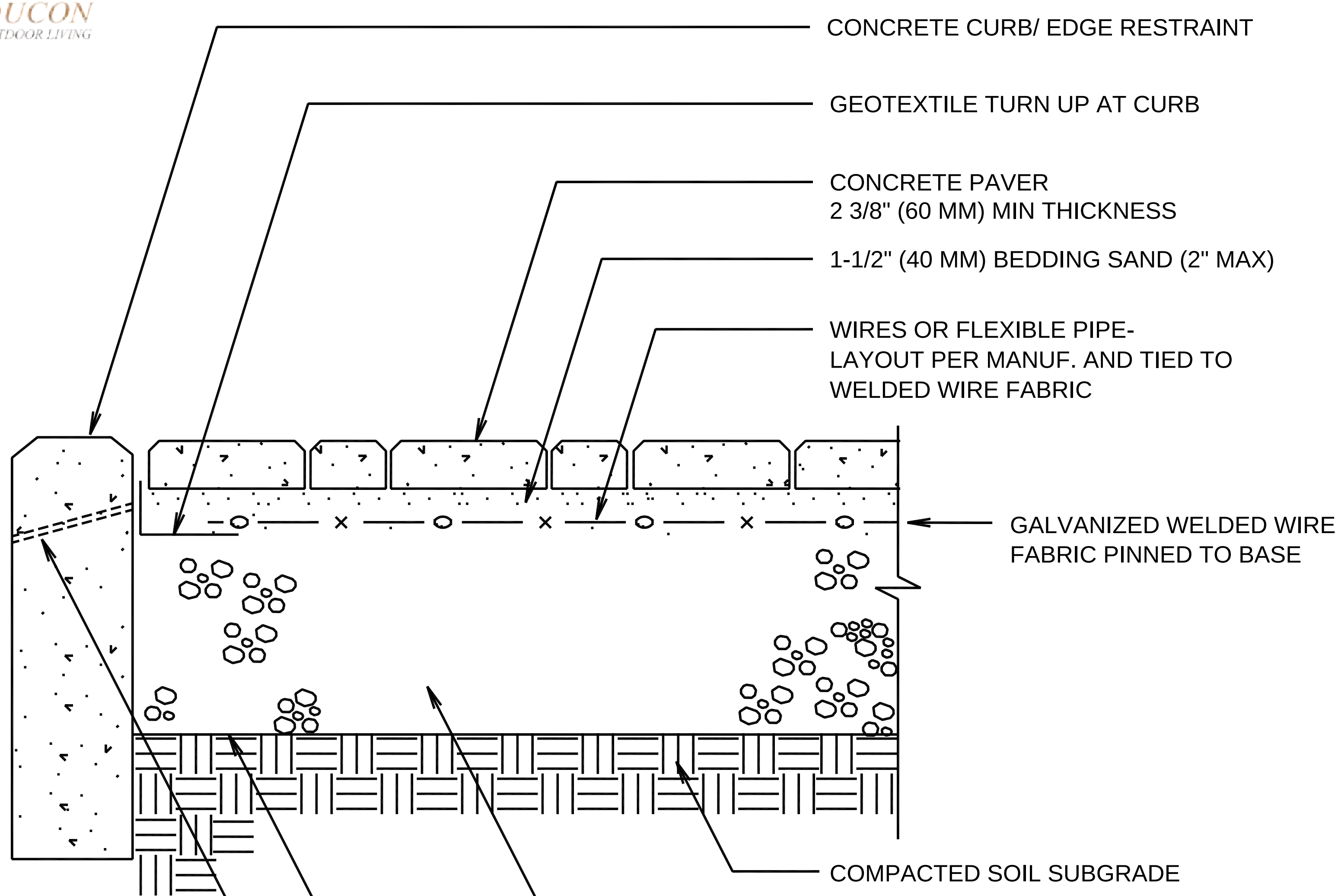


NOTE:

THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE.
COLDER CLIMATES MAY REQUIRE THICKER BASES.

HEATED CROSSWALK OR STREET ON ASPHALT OR CONCRETE BASE

DRAWING NO.	ICPI-57
SCALE	F.S.

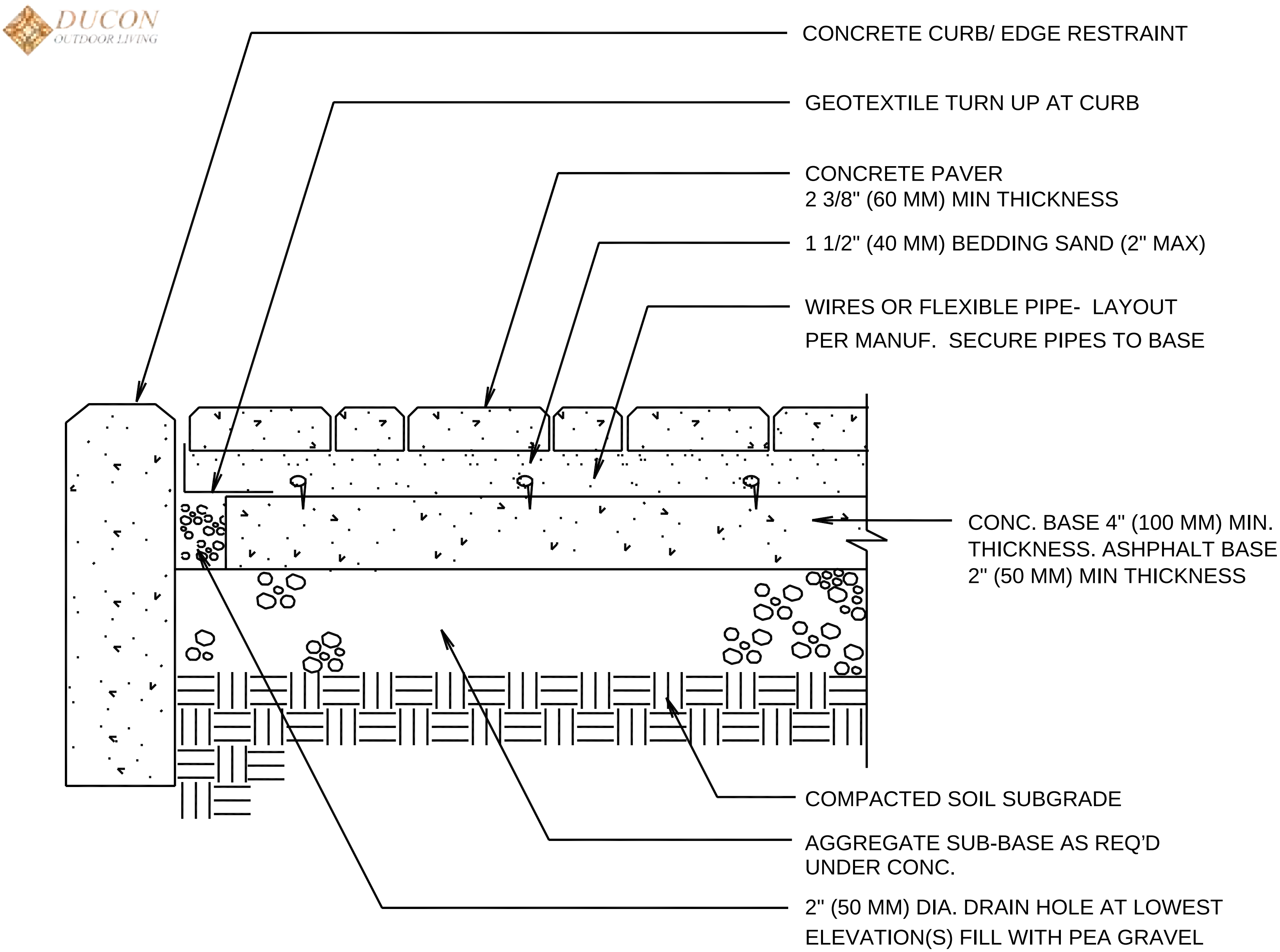


NOTE:
OMIT WELDED WIRE FABRIC FOR PEDESTRIAN APPLICATIONS.

HEATED SIDEWALK/ RESIDENTIAL DRIVEWAY ON AGGREGATE BASE

DRAWING NO. ICPI-58

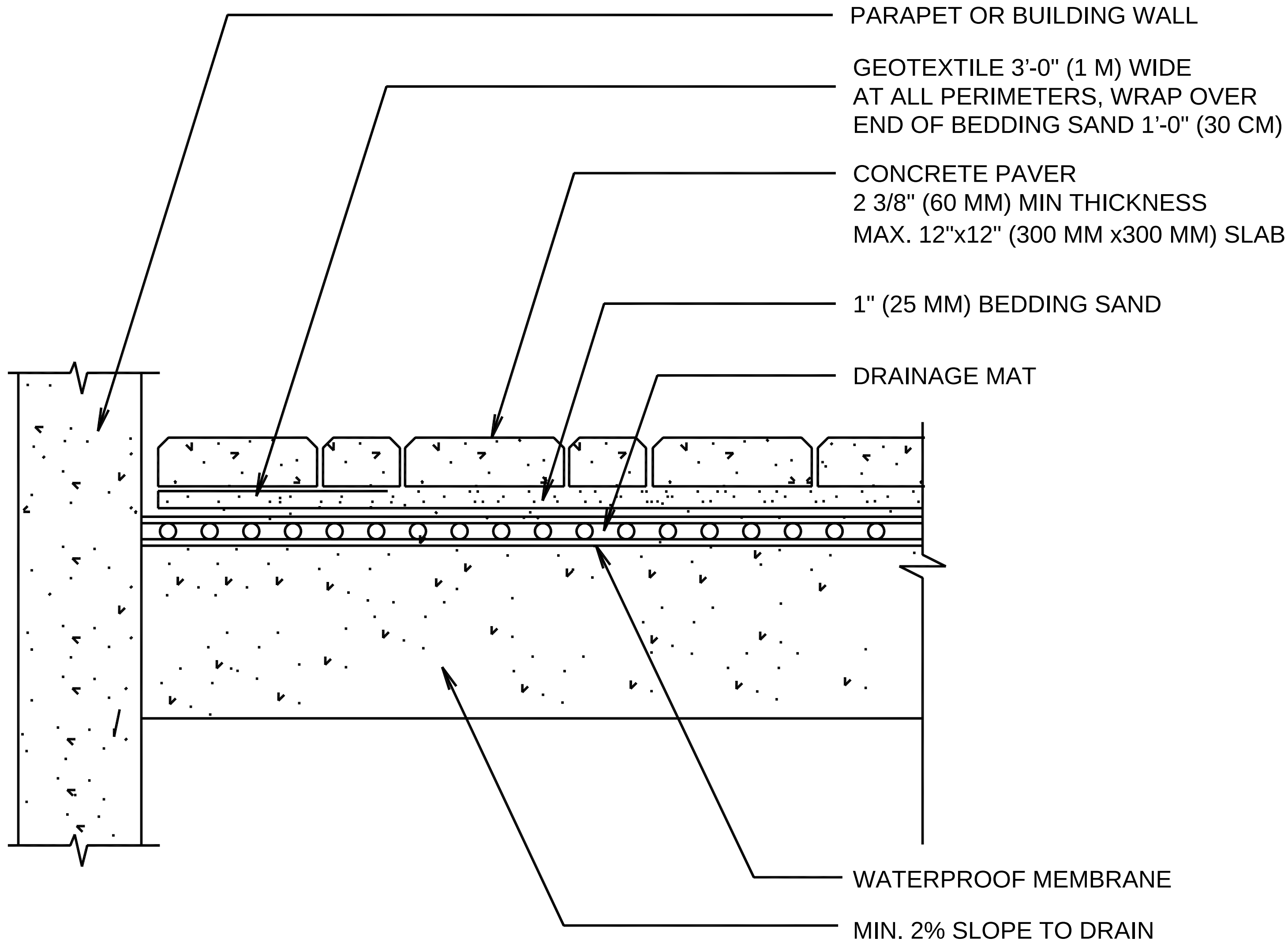
SCALE F.S.



NOTE:
SECURING PIPES OR WIRES TO BASE IS NOT REQUIRED FOR PEDESTRIAN APPLICATIONS

HEATED SIDEWALK/ RESIDENTIAL DRIVEWAY ON CONC. OR ASPHALT BASE

DRAWING NO.	ICPI-59
SCALE	F.S.

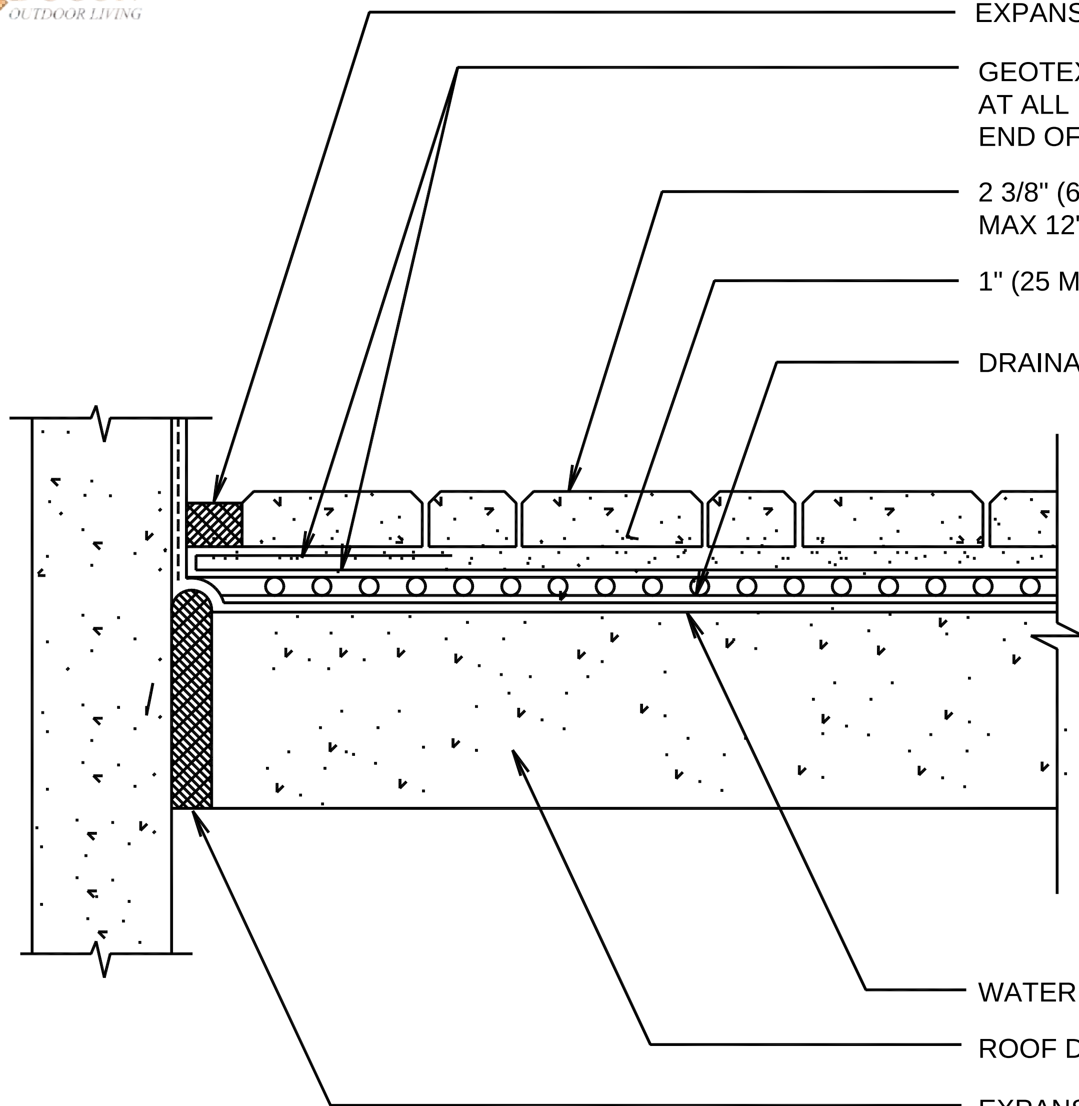


NOTE:

1. ROOF DECK IS TIED TO PARAPET OR BUILDING WALL
2. PEDESTRIAN USE ONLY

PEDESTRIAN ROOF PLAZA DECK WITH DRAINAGE MAT

DRAWING NO.	ICPI-60
SCALE	F.S.

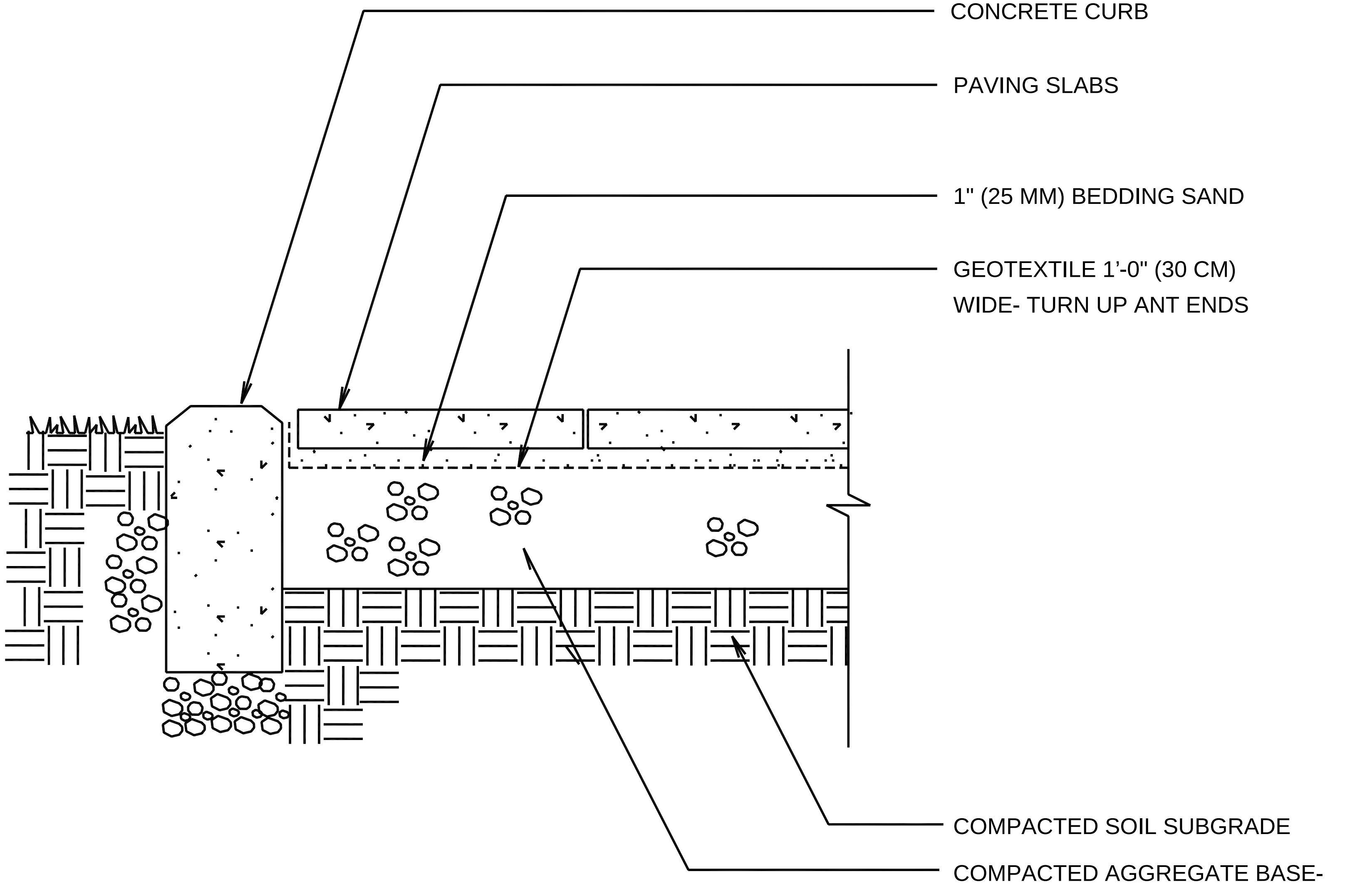


NOTES:

1. ROOF DECK IS NOT JOINED TO WALL/PARAPET.
2. PEDESTRIAN USE ONLY.

PEDESTRIAN ROOF PLAZA DECK WITH DRAINAGE MAT

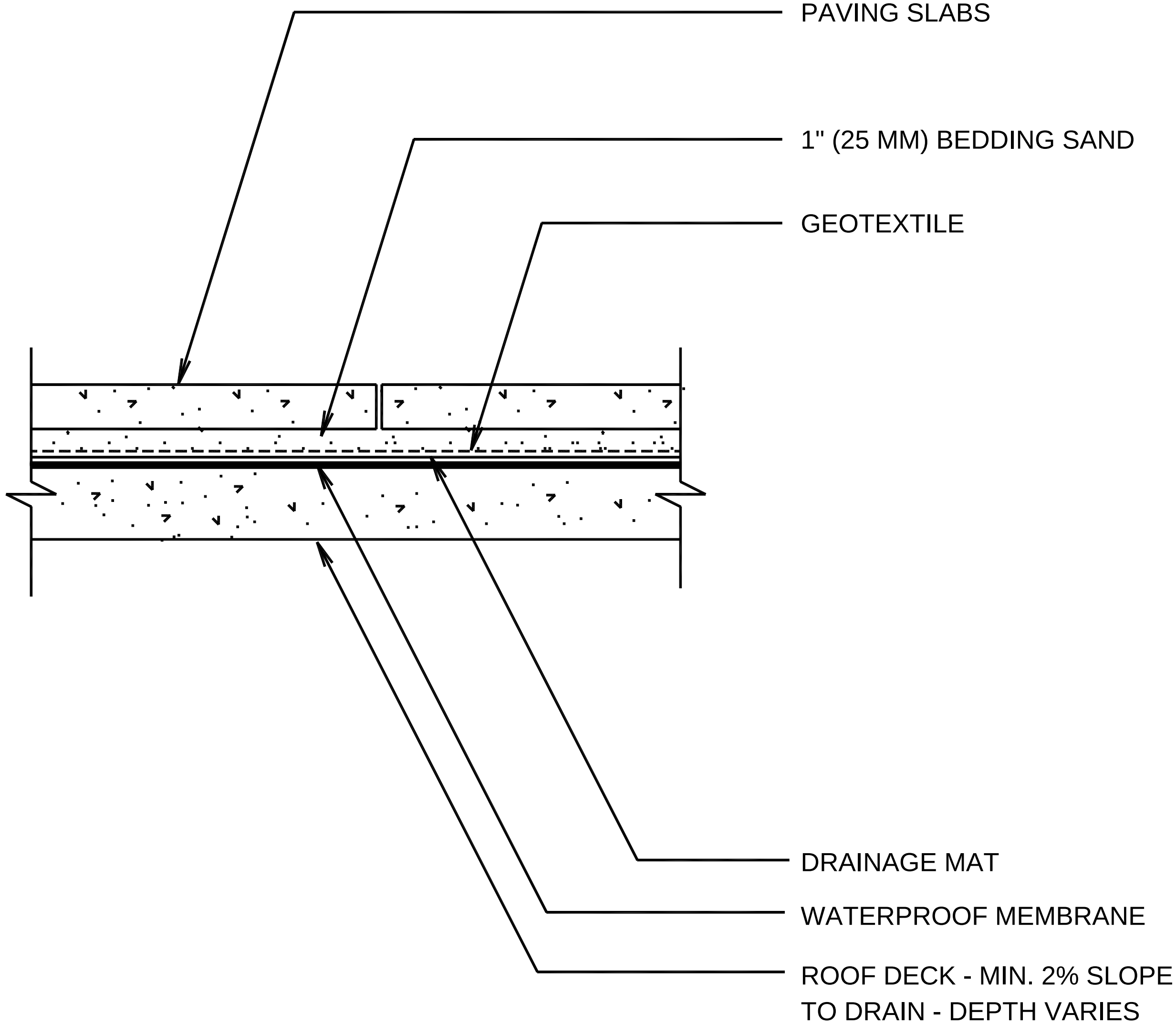
DRAWING NO.	ICPI-61
SCALE	F.S.



NOTES:

1. BASE AND SUBGRADE MAY REQUIRE DRAINS
2. RESIDENTIAL PEDESTRIAN APPLICATIONS ONLY

PAVING SLABS ON AGGREGATE BASE FOR PATIO	DRAWING NO.	ICPI-62
	SCALE	F.S.

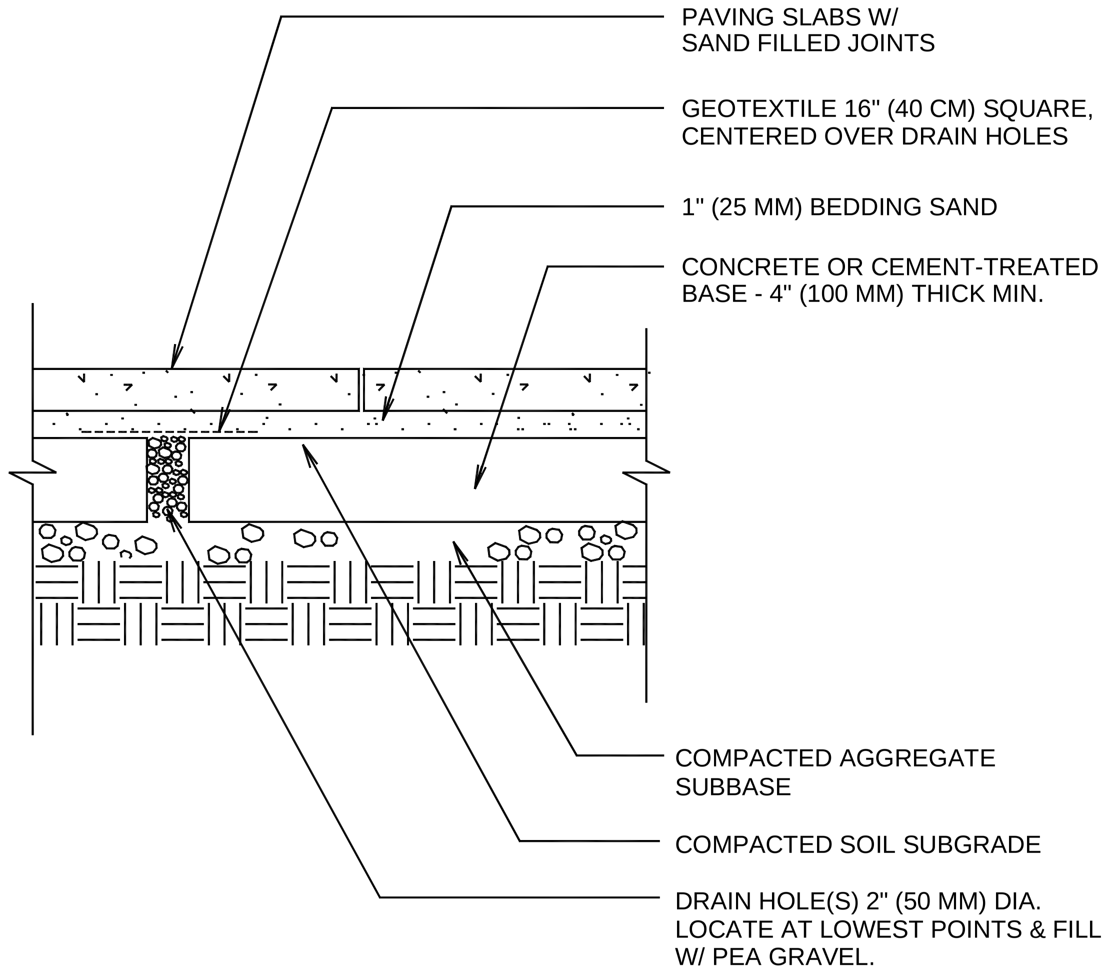


NOTE:

CONSULT WATERPROOF MEMBRANE MANUFACTURER ON NEED
FOR PROTECTION BOARD.

PAVING SLABS FOR ROOF PLAZA DECK

DRAWING NO.	ICPI-63
SCALE	F.S.



NOTES:

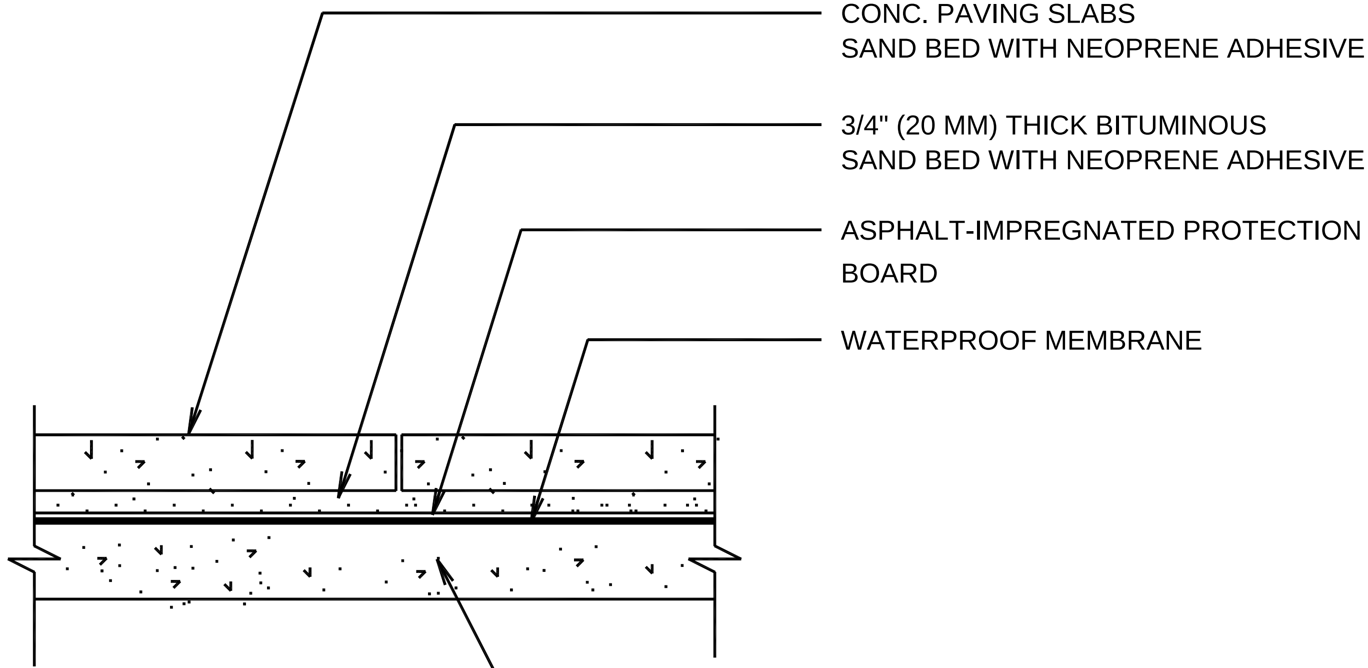
1. AGGREGATE SUBBASE AND SUBGRADE SOIL MAY REQUIRE DRAINS.
2. COVER ENTIRE SURFACE OF CEMENT-TREATED BASE WITH GEOTEXTILE TO PREVENT LOSS OF BEDDING SAND IN SHRINKAGE CRACKS.
3. MAXIMUM PAVING SLAB UNIT SIZE IS 12" X 12" (300 X 300 MM) FOR SAND SET DECK APPLICATIONS.

PAVING SLABS FOR SIDEWALKS ON A CONCRETE OR CEMENT TREATED BASE

DRAWING NO. ICPI-64

SCALE NO SCALE

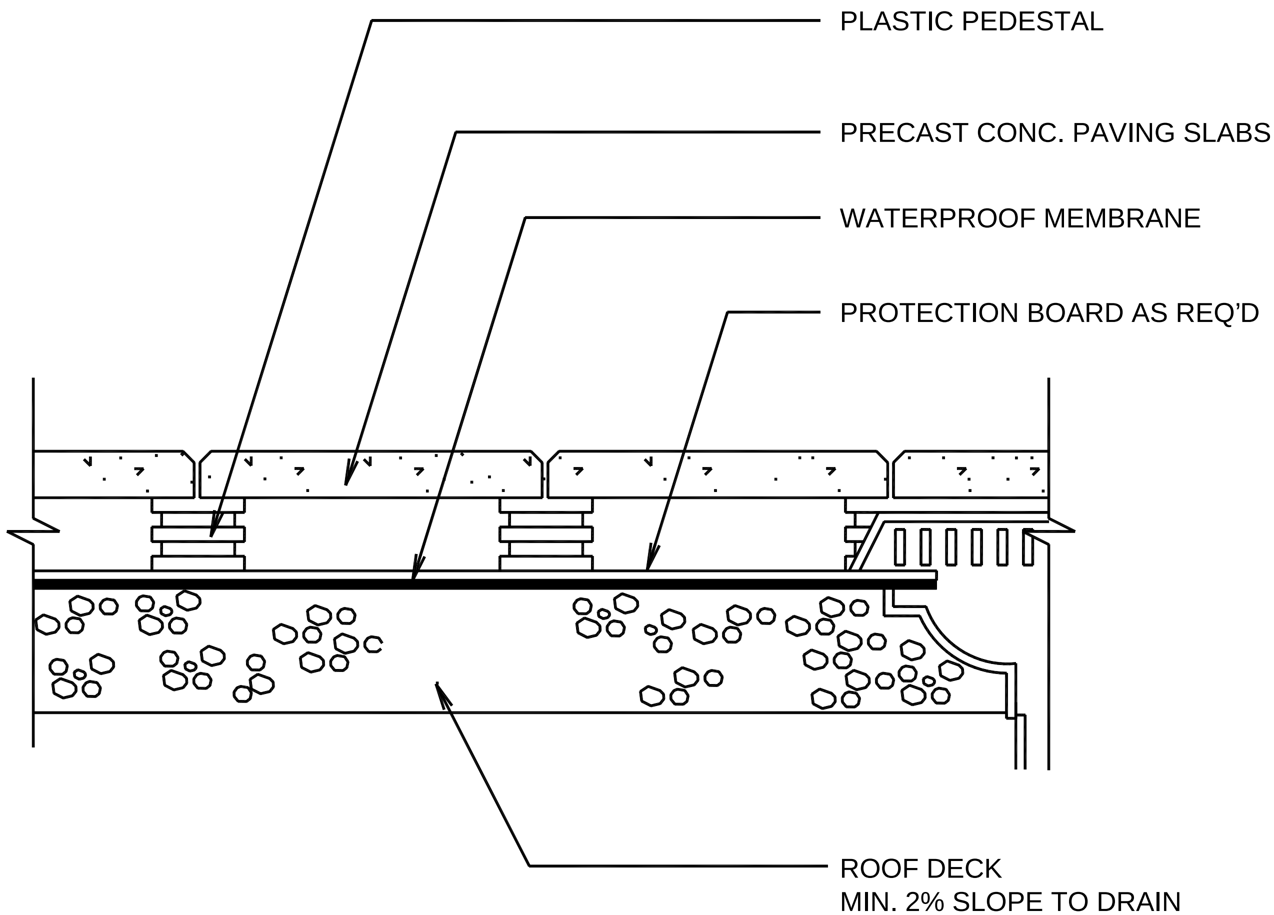
SAW CUT PAVER - NOT LESS THAN 1/3 UNIT



PAVING SLABS BITUMINOUS SET FOR SIDEWALKS

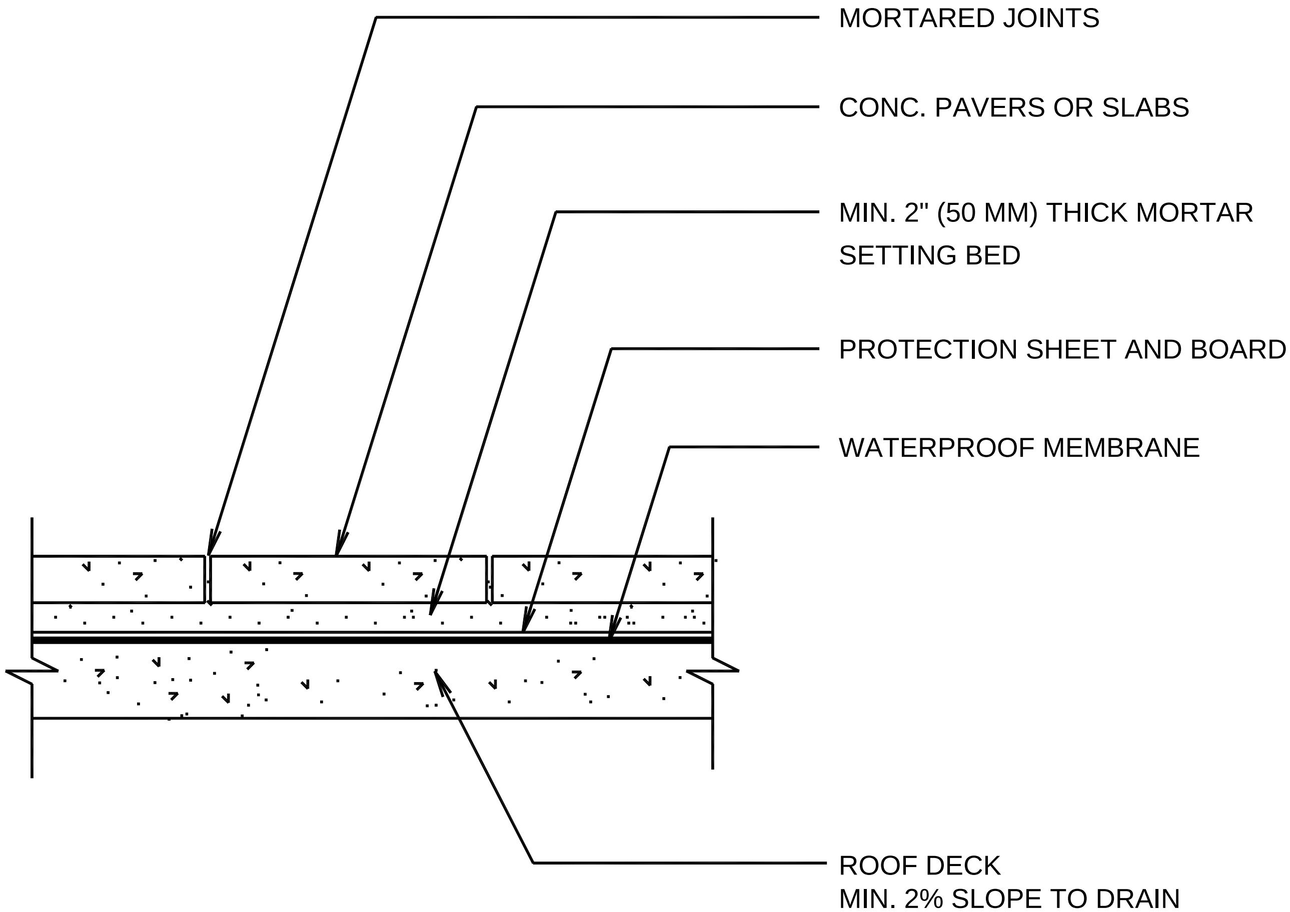
DRAWING NO. ICPI-65

SCALE F.S.



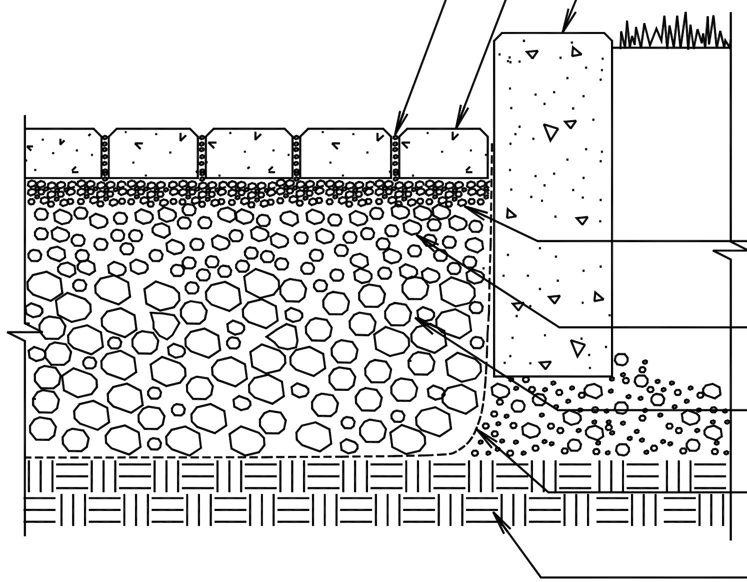
PAVING SLABS FOR ROOF PLAZA DECKS

DRAWING NO.	ICPI-66
SCALE	F.S.



ROOF PLAZA DECK- PAVING SLABS ON MORTAR SETTING BED

DRAWING NO.	ICPI-67
SCALE	F.S.



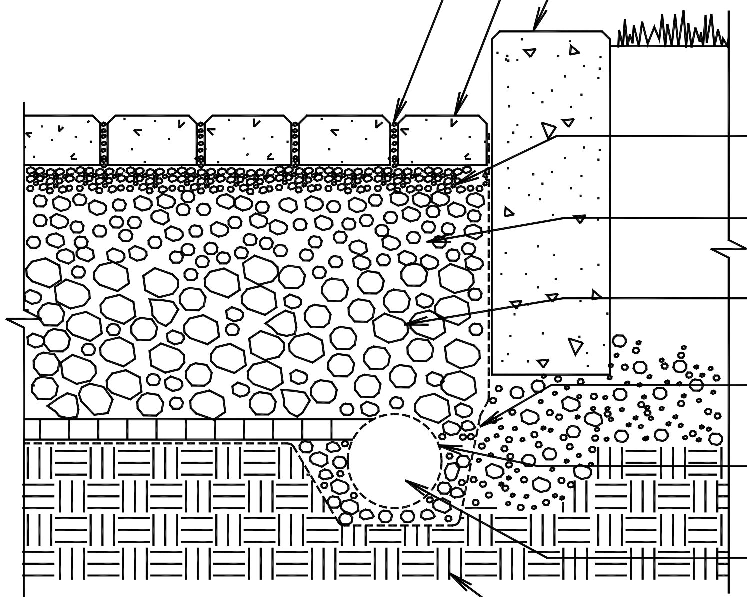
NOTES:

1. 2 3/8" (60 MM) THICK PAVERS MAY BE USED IN PEDESTRIAN APPLICATIONS.
2. NO. 2 STONE SUBBASE THICKNESS VARIES WITH DESIGN.
   CONSULT ICPI PERMEABLE INTERLOCKING CONCRETE PAVEMENT MANUAL.

PERMEABLE PAVEMENT WITH FULL EXFILTRATION TO SOIL SUBGRADE

DRAWING NO. ICPI-68

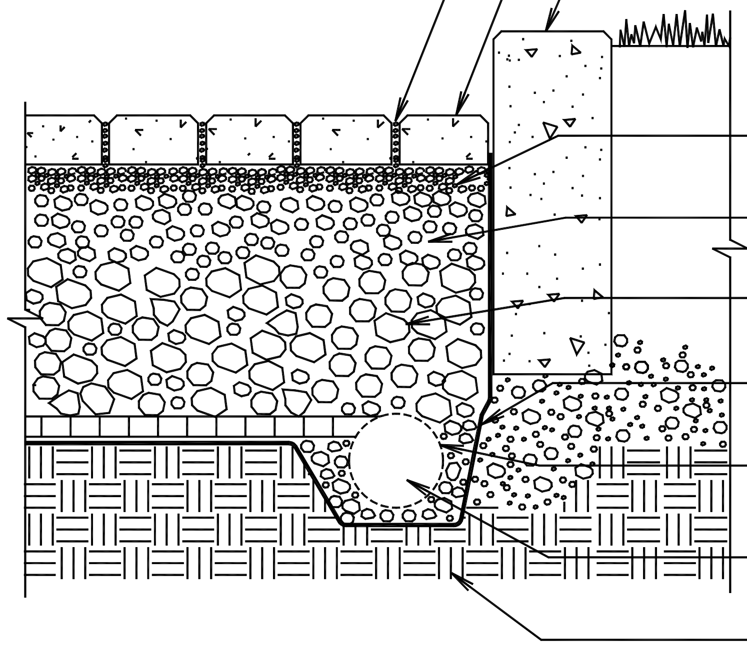
SCALE NO SCALE



NOTES:

1. 2 3/8" (60 MM) THICK PAVERS MAY BE USED IN PEDESTRIAN APPLICATIONS.
2. NO. 2 STONE SUBBASE THICKNESS VARIES WITH DESIGN.
   CONSULT ICPI PERMEABLE INTERLOCKING CONCRETE PAVEMENT MANUAL.

PERMEABLE PAVEMENT WITH PARTIAL EXFILTRATION TO SOIL SUBGRADE	DRAWING NO.	ICPI-69
	SCALE	NO SCALE

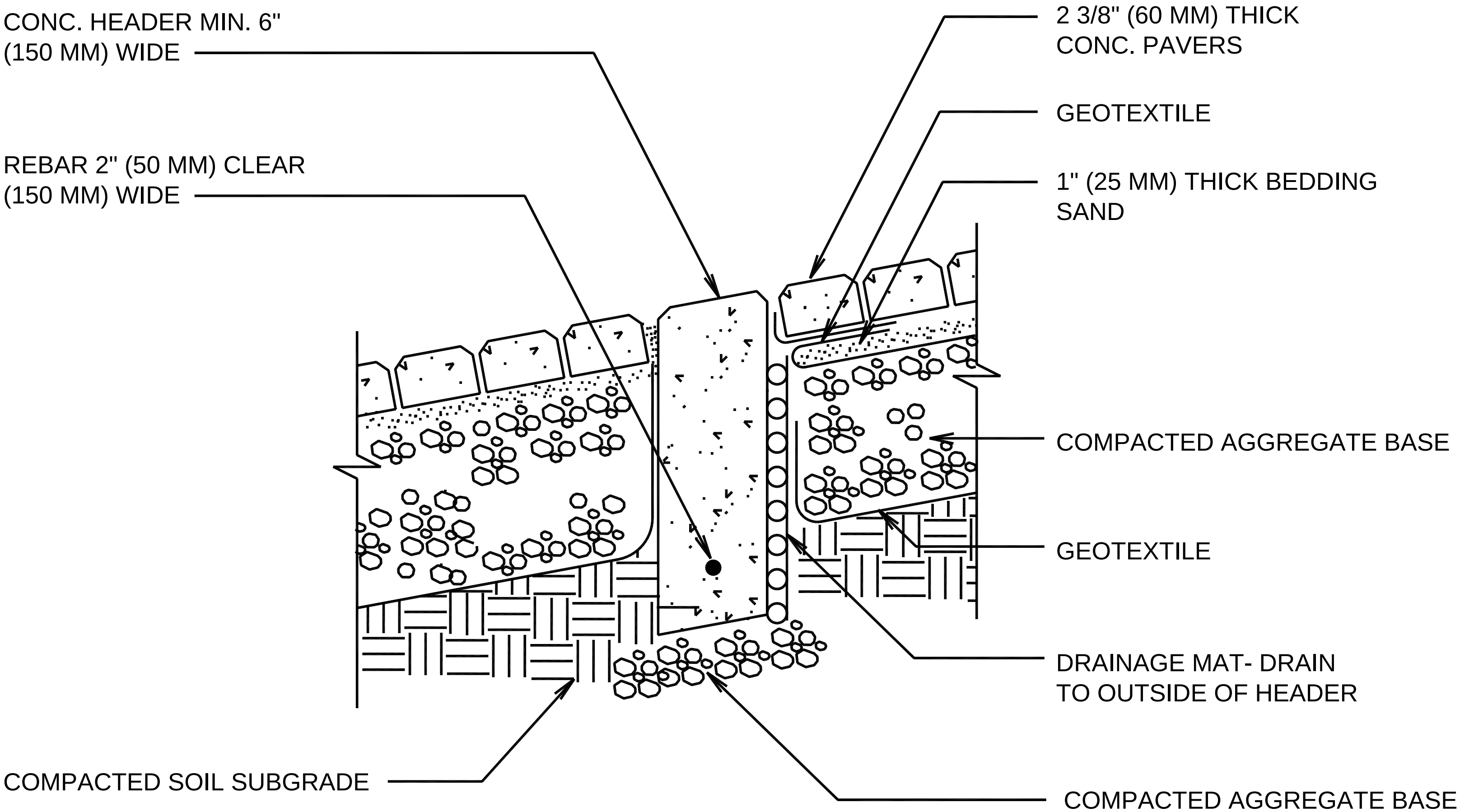


NOTES:

1. 2 3/8" (60 MM) THICK PAVERS MAY BE USED IN PEDESTRIAN APPLICATIONS.
2. NO. 2 STONE SUBBASE THICKNESS VARIES WITH DESIGN.
   CONSULT ICPI PERMEABLE INTERLOCKING CONCRETE PAVEMENT MANUAL.

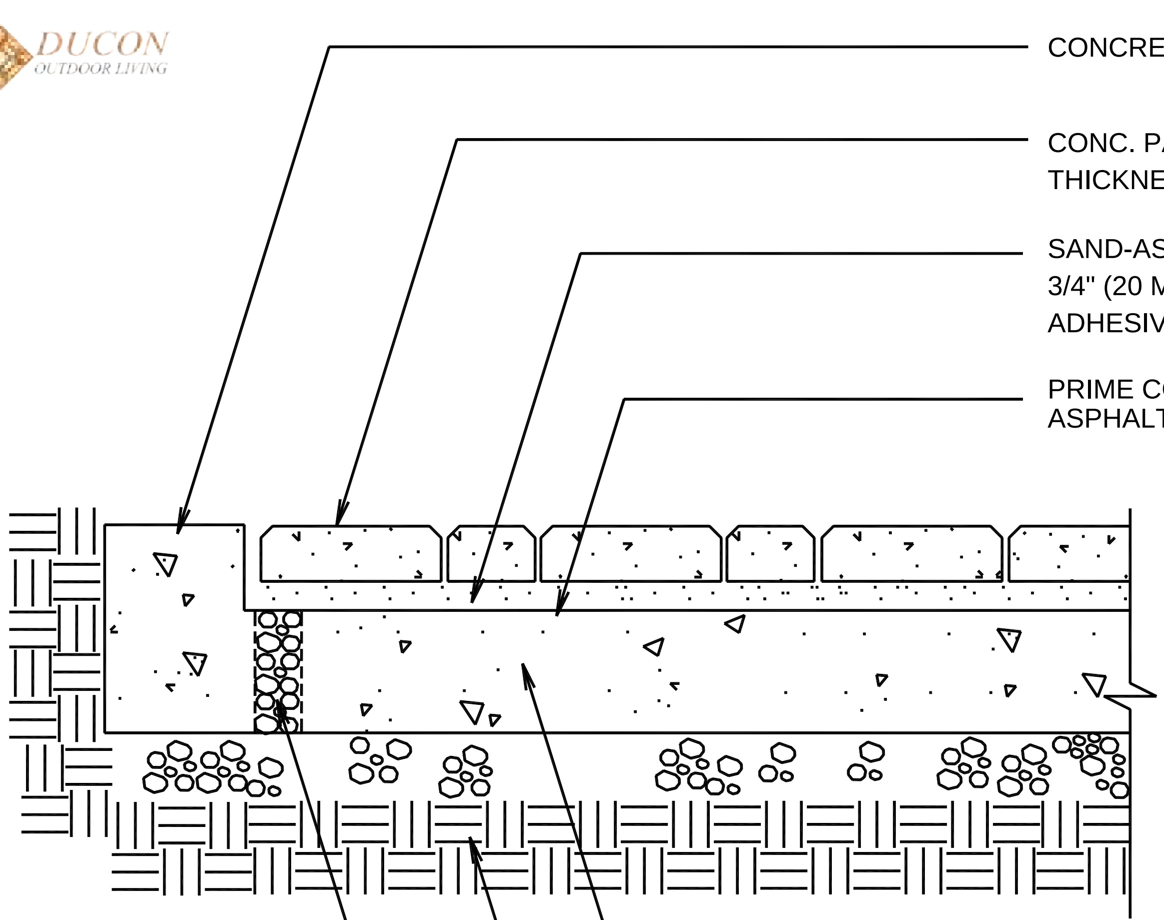
PERMEABLE PAVEMENT WITH NO EXFILTRATION TO SOIL SUBGRADE

DRAWING NO.	ICPI-70
SCALE	NO SCALE



HEADER FOR HIGH SLOPE WALK/ RESIDENTIAL DRIVEWAY

DRAWING NO.	ICPI-71
SCALE	F.S.

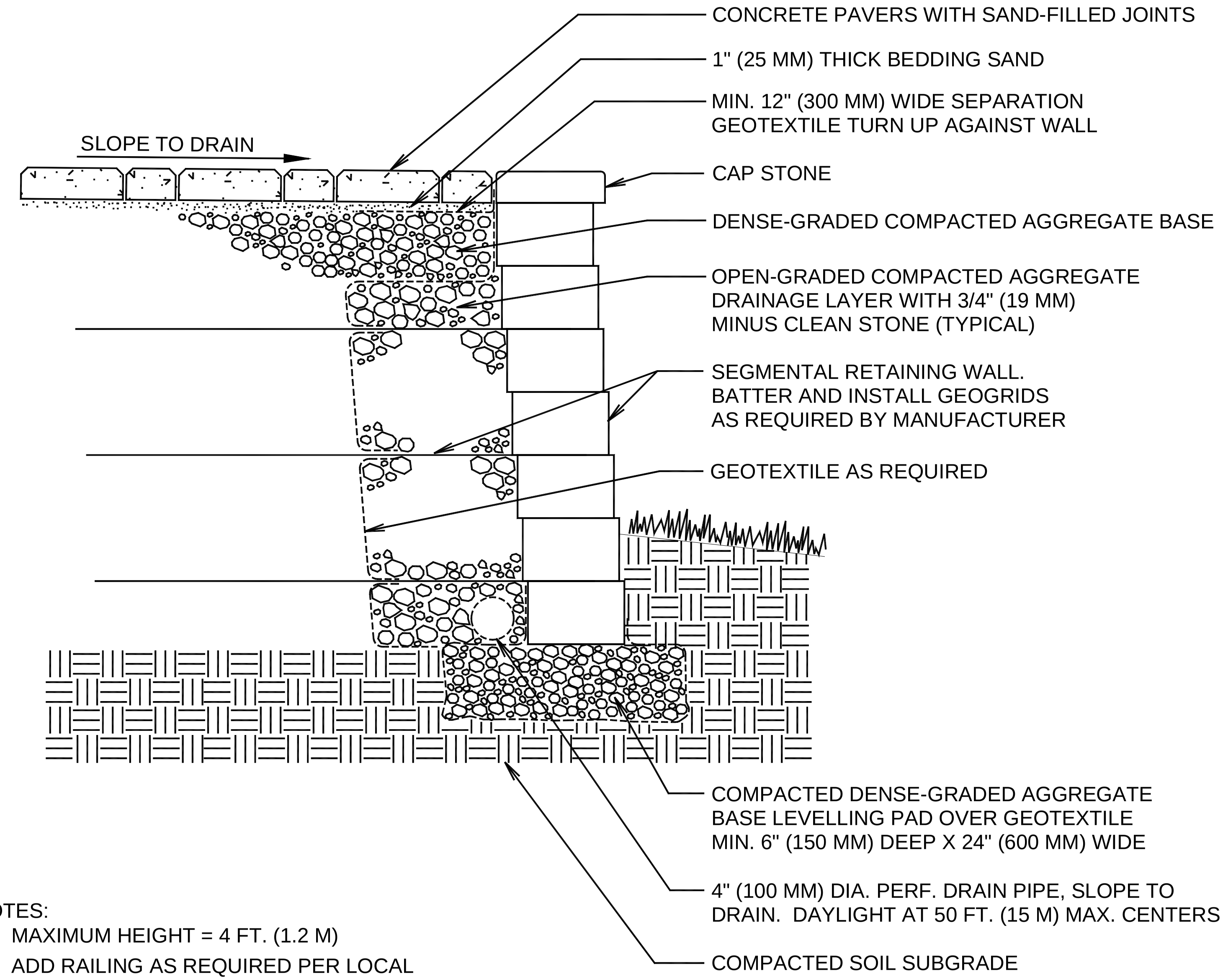


NOTES:

1. DO NOT COVER WEEP HOLES WITH SAND-ASPHALT SETTING BED.
2. 2 3/8 IN. (60 MM) THICK PAVERS MAY BE USED FOR PEDESTRIAN APPLICATIONS.

SAND-ASPHALT SET CONCRETE PAVERS FOR PEDESTRIANS & VEHICLES

DRAWING NO.	ICPI-72
SCALE	F.S.

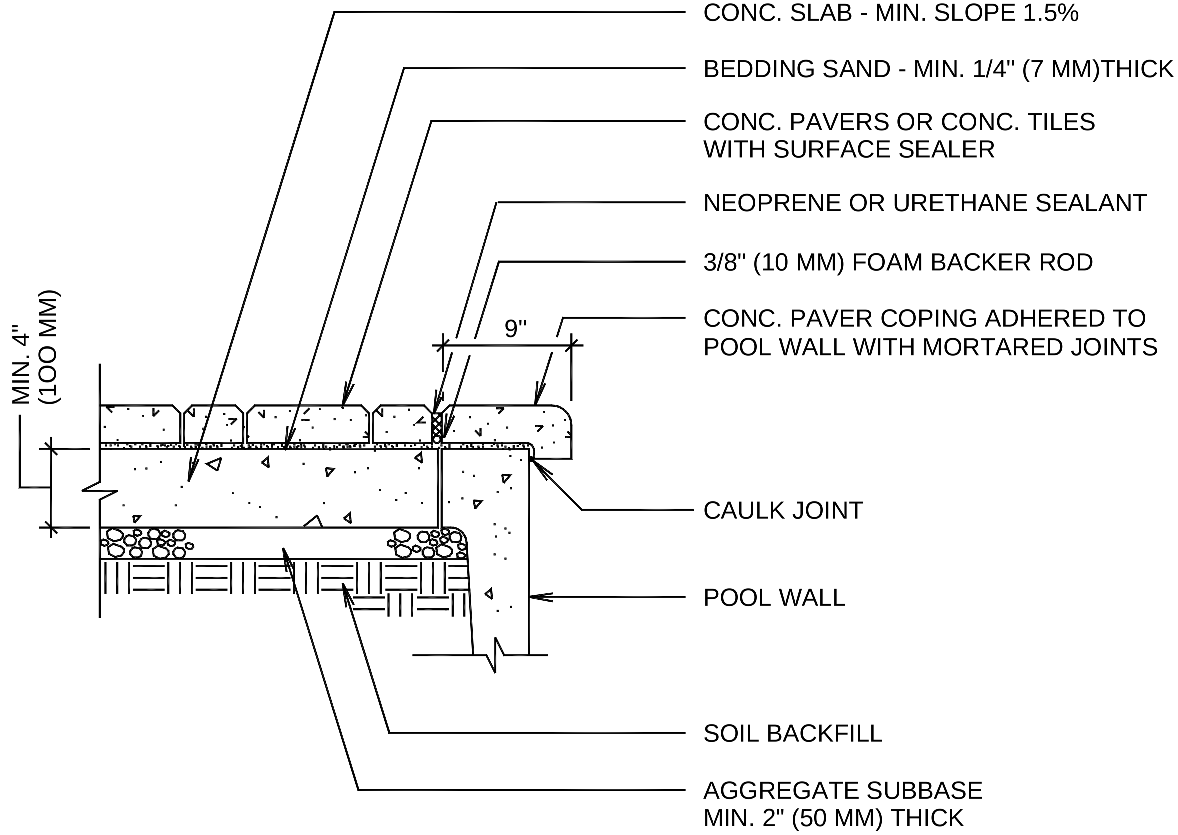


NOTES:
1. MAXIMUM HEIGHT = 4 FT. (1.2 M)
2. ADD RAILING AS REQUIRED PER LOCAL BUILDING CODE.

RAISED PATIO

DRAWING NO. ICPI-73

SCALE NO SCALE

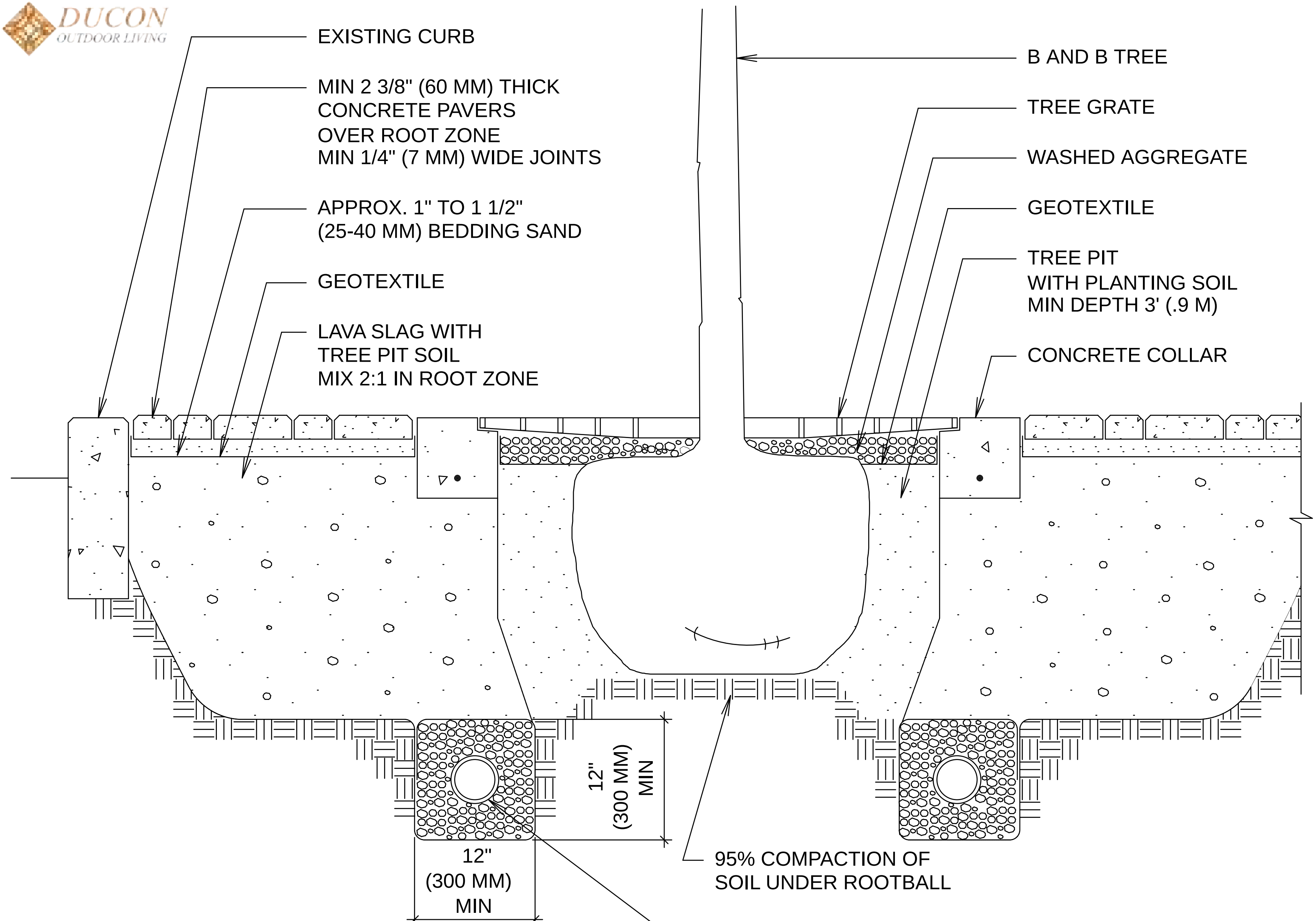


NOTE:
COVER JOINTS WITH GEOTEXTILE AND FILL ALL CRACKS TO PREVENT LOSS OF BEDDING SAND.

SWIMMING POOL DECK AND COPING

DRAWING NO.	ICPI-74
SCALE	NO SCALE

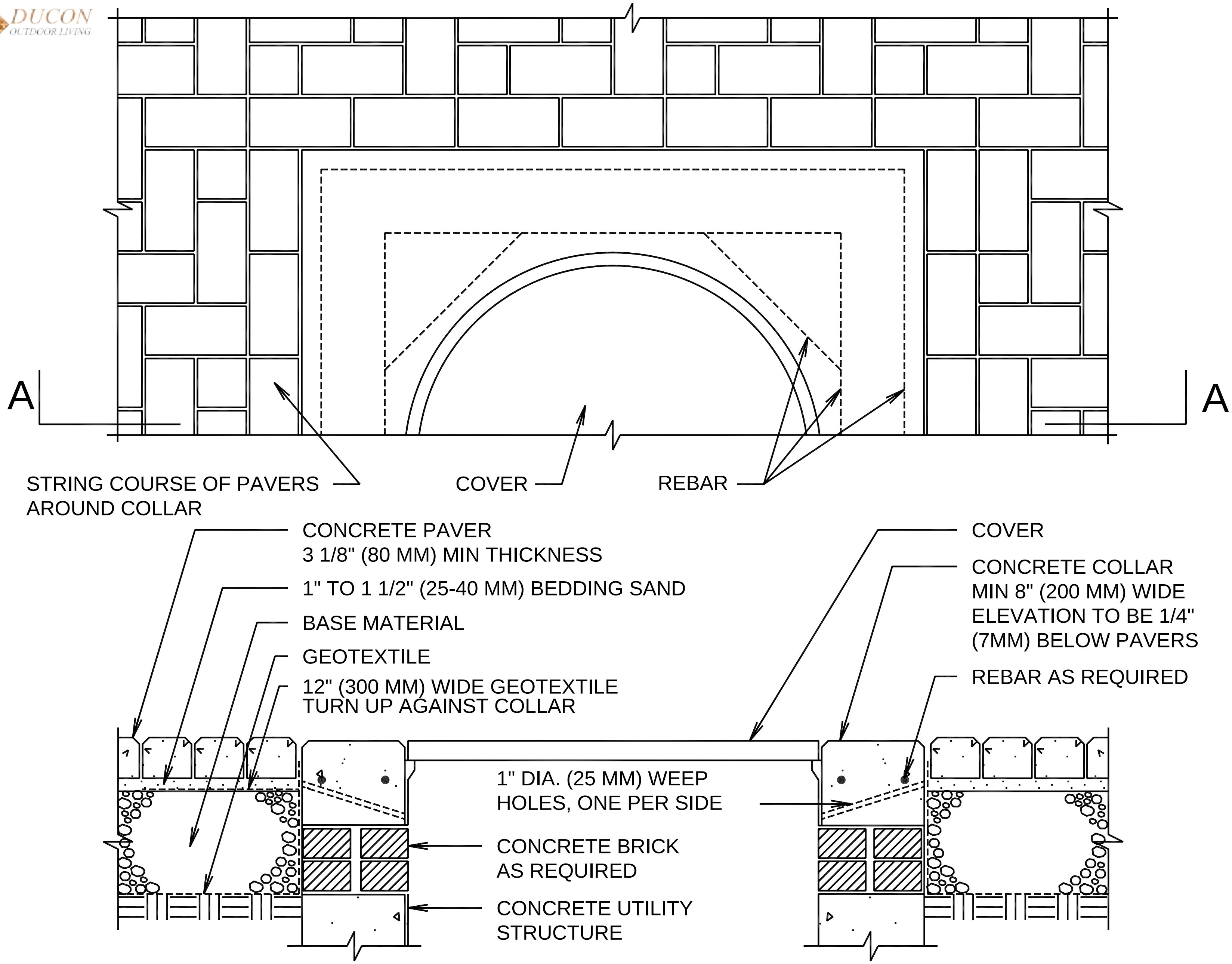
DUCON OUTDOOR LIVING



NOTE: ROOT BARRIER MAY BE REQUIRED INSIDE OF CONCRETE COLLAR DEPENDING ON TREE SPECIES. CONSULT ABORIST FOR THIS APPLICATION.

TREE PIT - NON-COMPACTED ROOT ZONE UNDER PAVERS

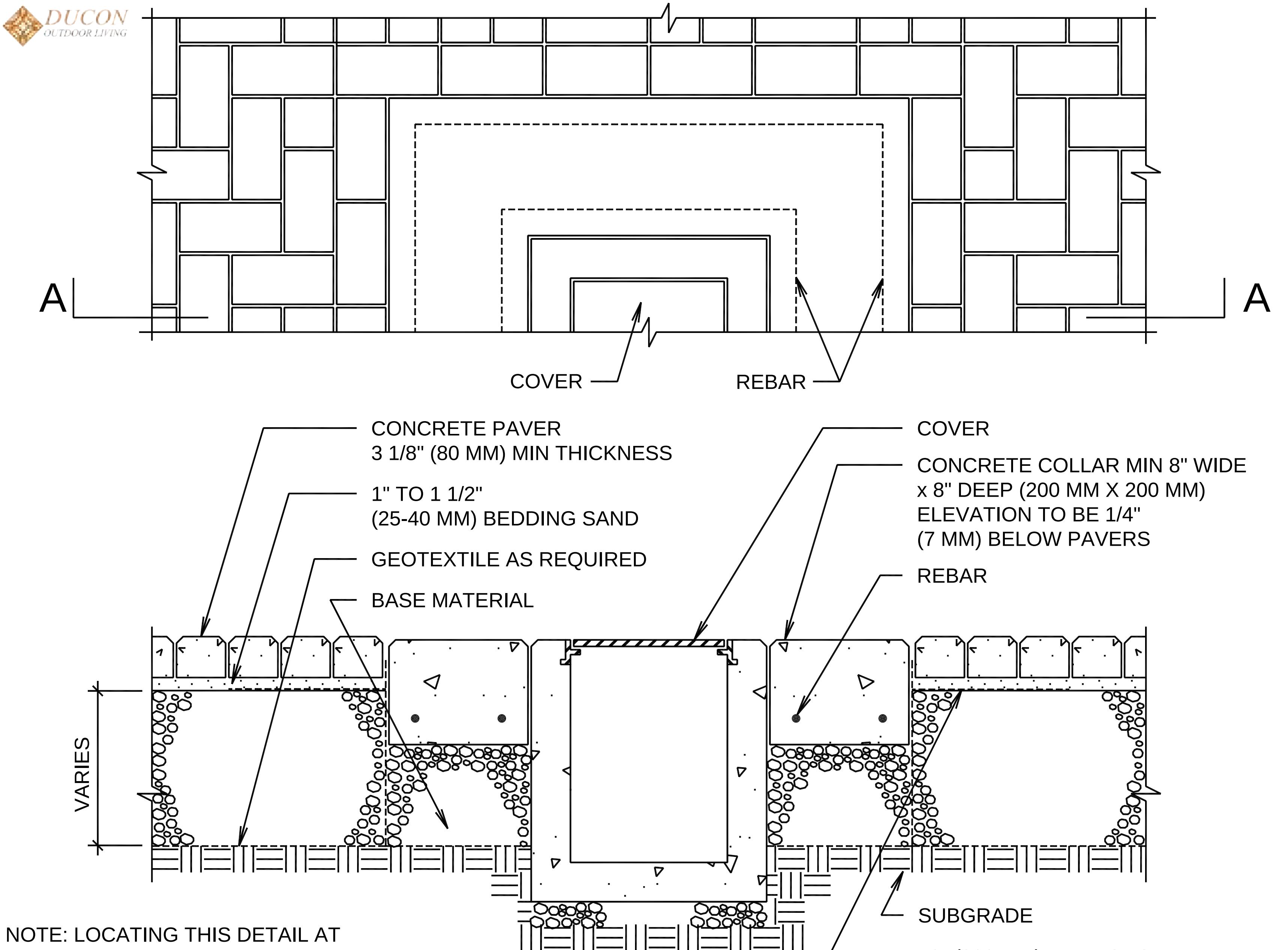
DRAWING NO.	ICPI-23
SCALE	F.S.



SECTION AA

UTILITY STRUCTURE MANHOLE

DRAWING NO.	ICPI-24
SCALE	F.S.



NOTE: LOCATING THIS DETAIL AT LOWEST PAVEMENT ELEVATION IS NOT RECOMMENDED.

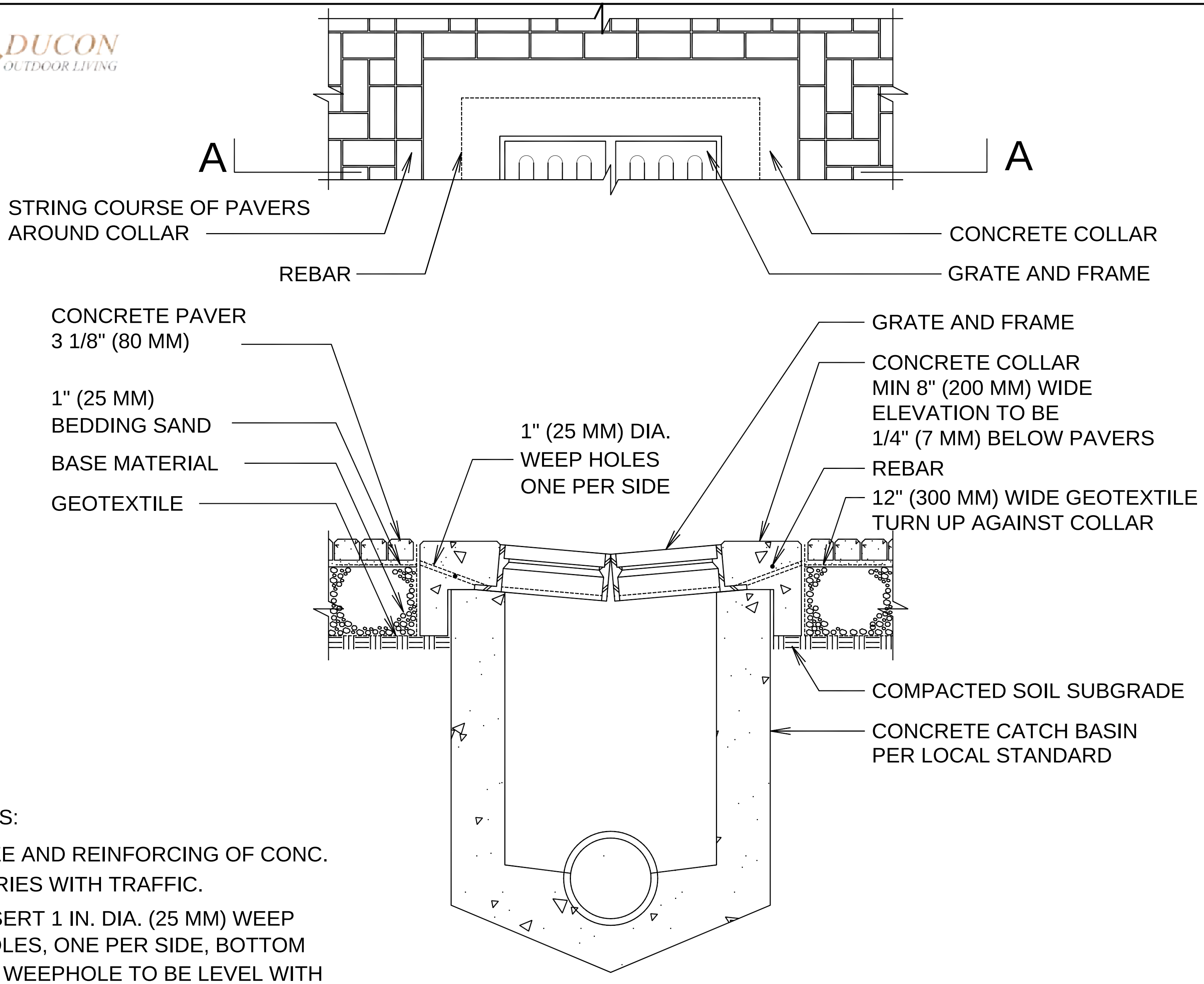
SECTION AA

UTILITY STRUCTURE

VALVE BOX \ PULL BOX \ LAMPHOLE

DRAWING NO. ICPI-25

SCALE F.S.



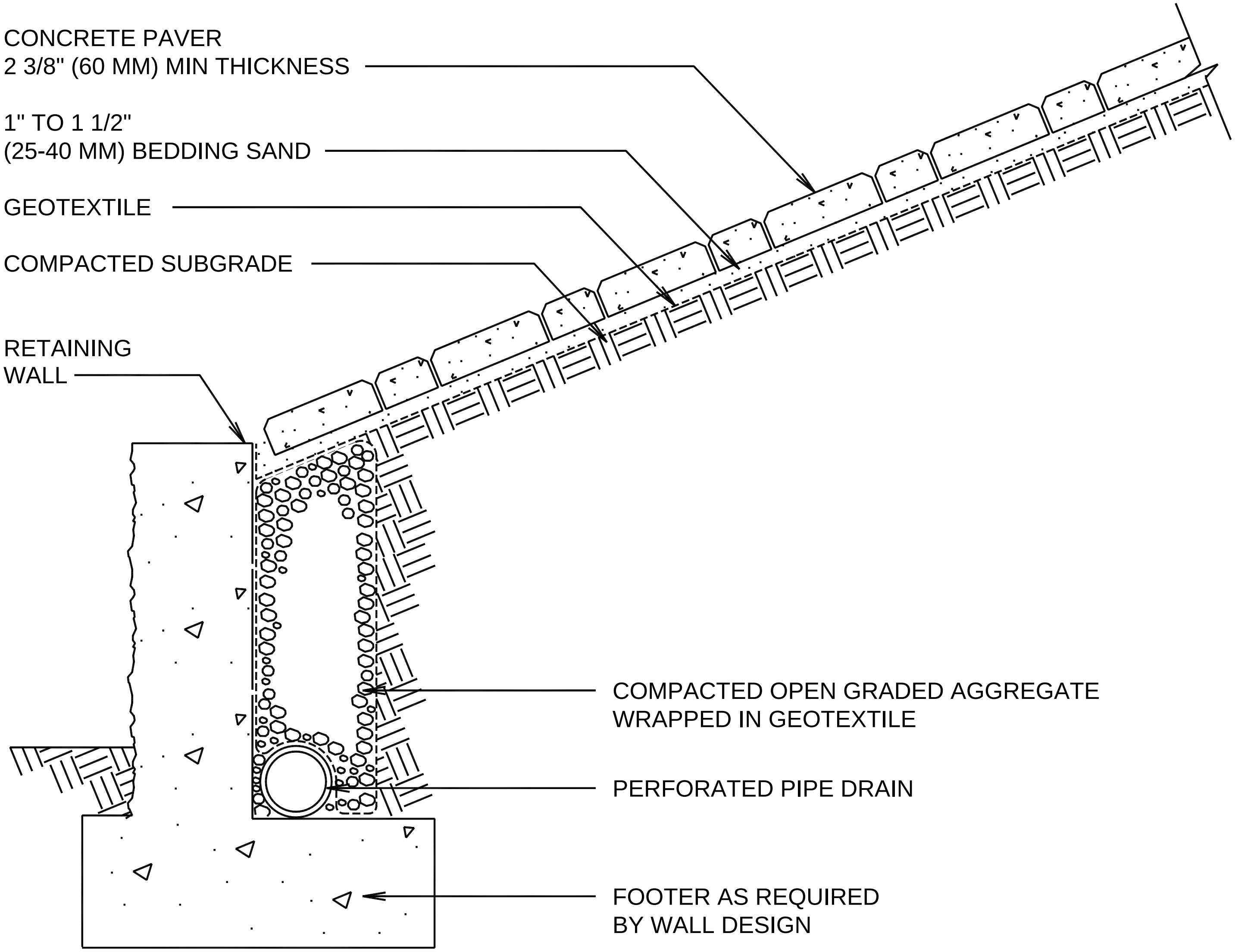
SECTION AA

NOTES:

1. SIZE AND REINFORCING OF CONC. VARIES WITH TRAFFIC.
2. INSERT 1 IN. DIA. (25 MM) WEEP HOLES, ONE PER SIDE, BOTTOM OF WEEPHOLE TO BE LEVEL WITH SURFACE OF BASE. COVER WITH GEOTEXTILE.

CATCH BASIN

DRAWING NO.	ICPI-26
SCALE	F.S.



NOTE:

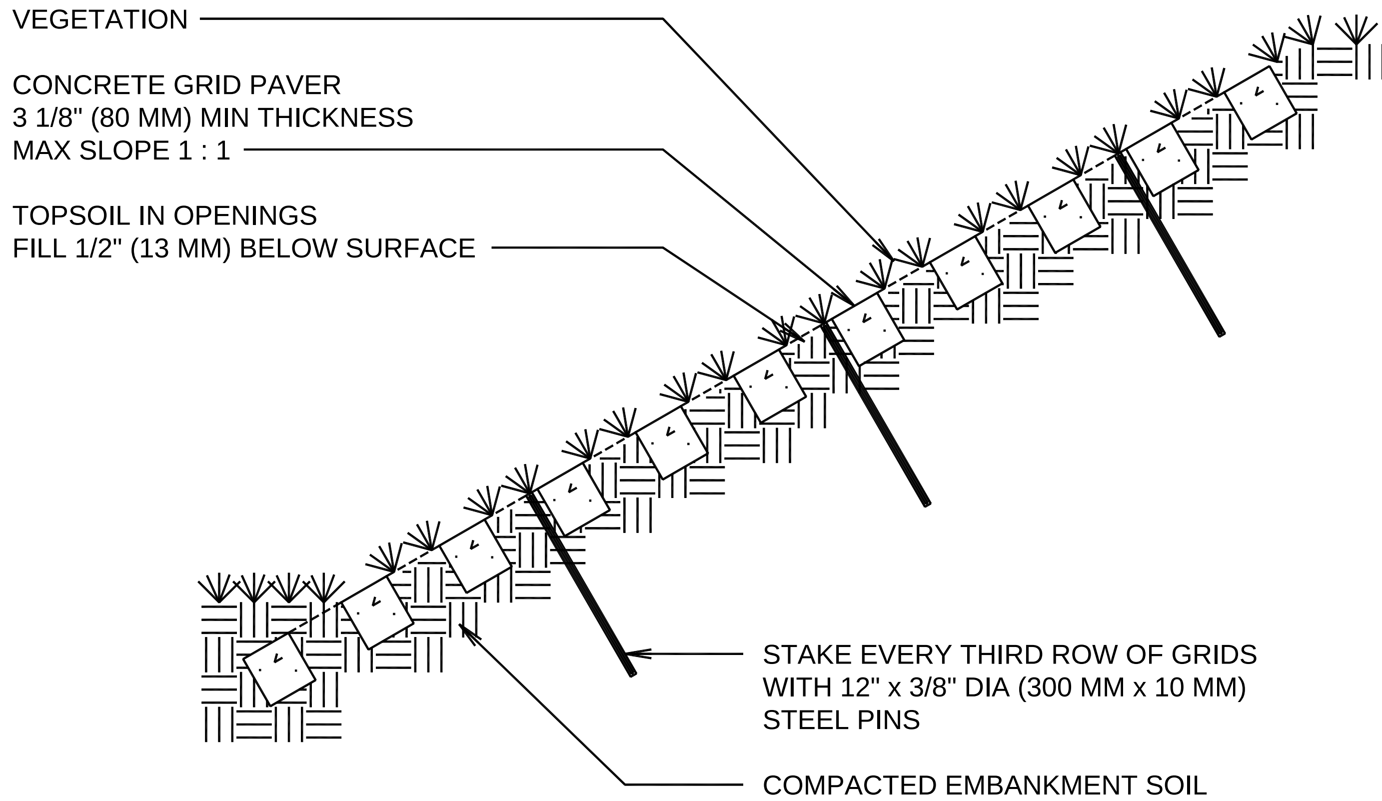
1. MAXIMUM SLOPE SHOULD NOT EXCEED ANGLE OF REPOSE FOR BEDDING SAND.
2. PROVIDE EDGE RESTRAINTS ON SIDES OF INSTALLATION.
3. ENGINEERING OF THE SEGMENTAL RETAINING WALL IS REQUIRED WHEN HEIGHT EXCEEDS 4 FT. (1.0 M).

SLOPE PROTECTION
CONCRETE PAVERS

DRAWING NO. ICPI-27

SCALE F.S.

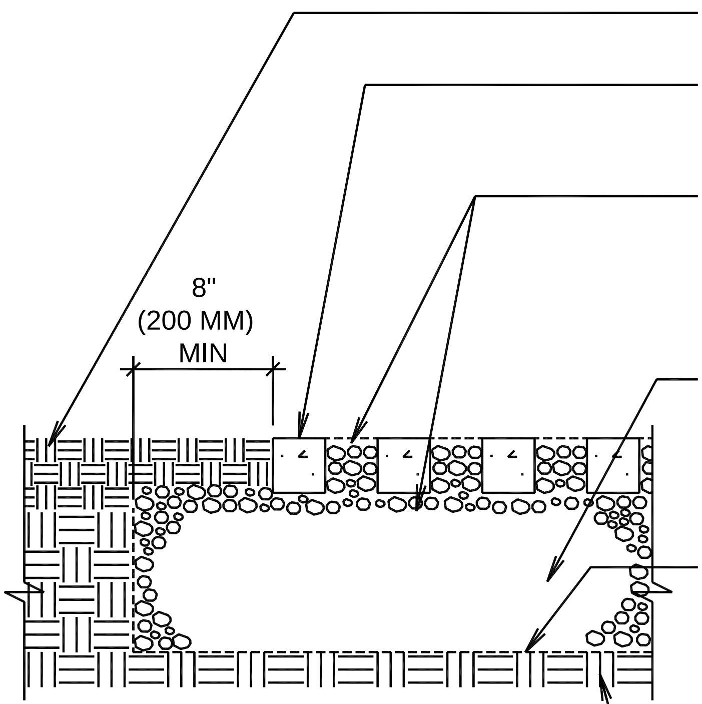
DUCON
OUTDOOR LIVING



SLOPE PROTECTION
CONCRETE GRIDS

DRAWING NO. ICPI-28

SCALE F.S.



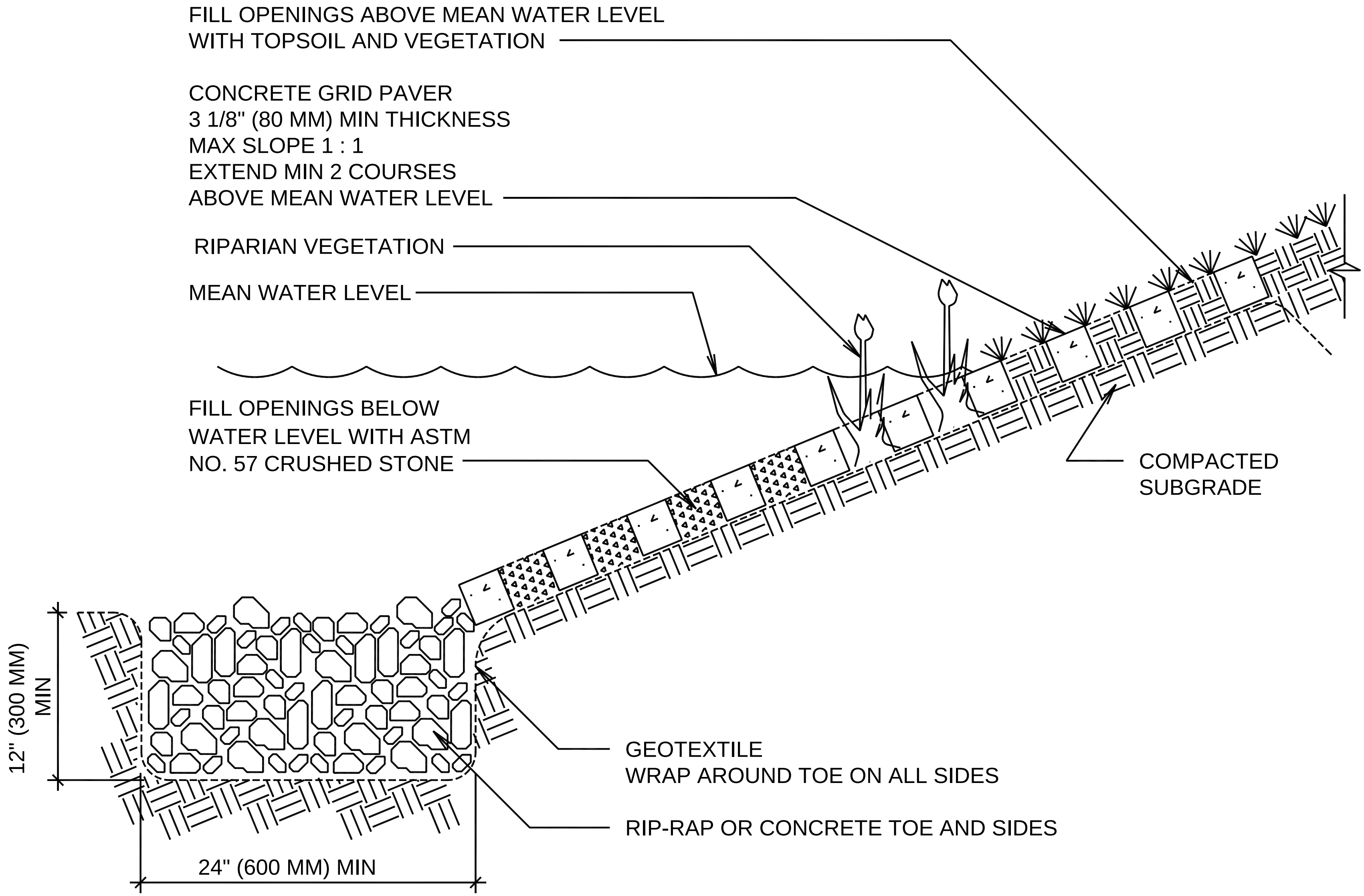
NOTES:

1. DEPTH OF OPEN GRADED BASE WILL EFFECT RUNOFF STORAGE CAPACITY
2. BEARING CAPACITY AND PERMEABILITY OF SOIL SUBGRADE SHOULD BE EVALUATED FOR SUITABILITY WITH APPLICATION, TRAFFIC & STORM WATER STORAGE CRITERIA. DRAINAGE OF SUBGRADE MAY BE REQUIRED.

CONCRETE GRID PAVERS FOR STORM WATER RUN-OFF CONTROL

DRAWING NO. ICPI-29

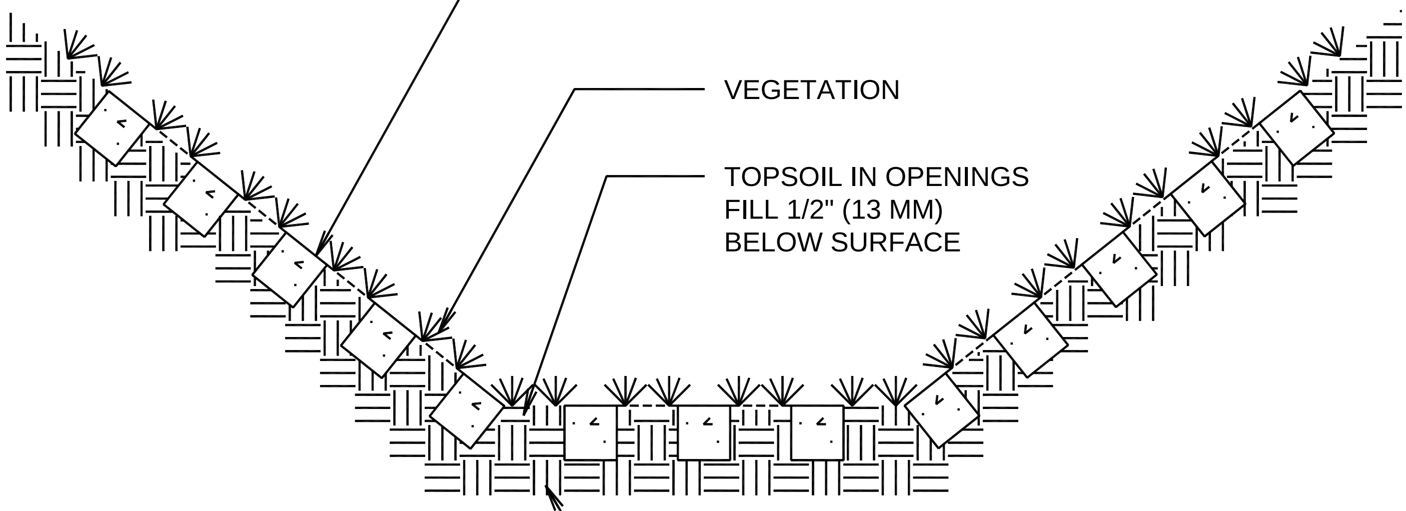
SCALE F.S.



RIPARIAN STABILIZATION

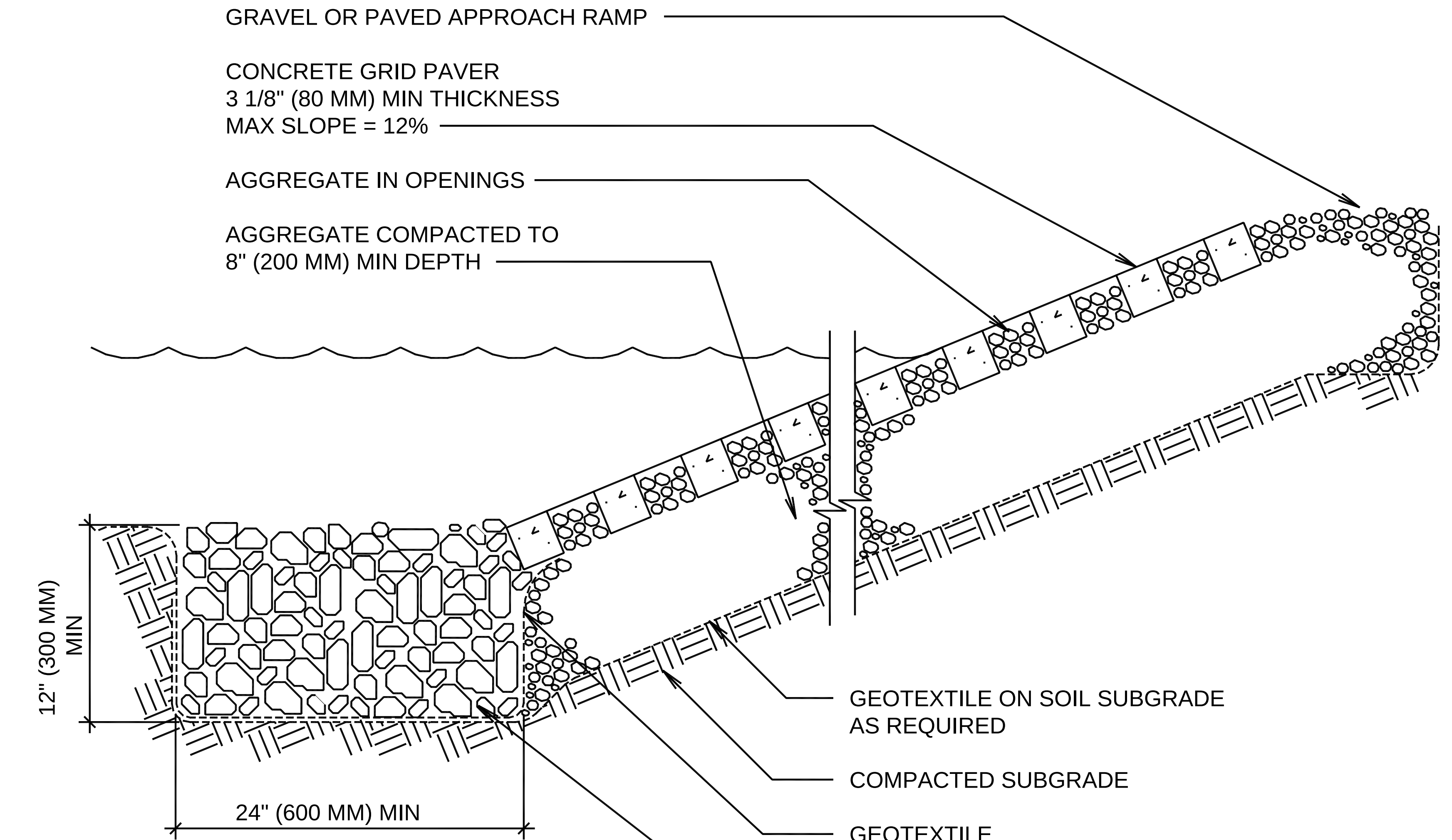
CONCRETE GRIDS FOR STREAM BANKS AND LAKESIDES

DRAWING NO.	ICPI-30
SCALE	F.S.



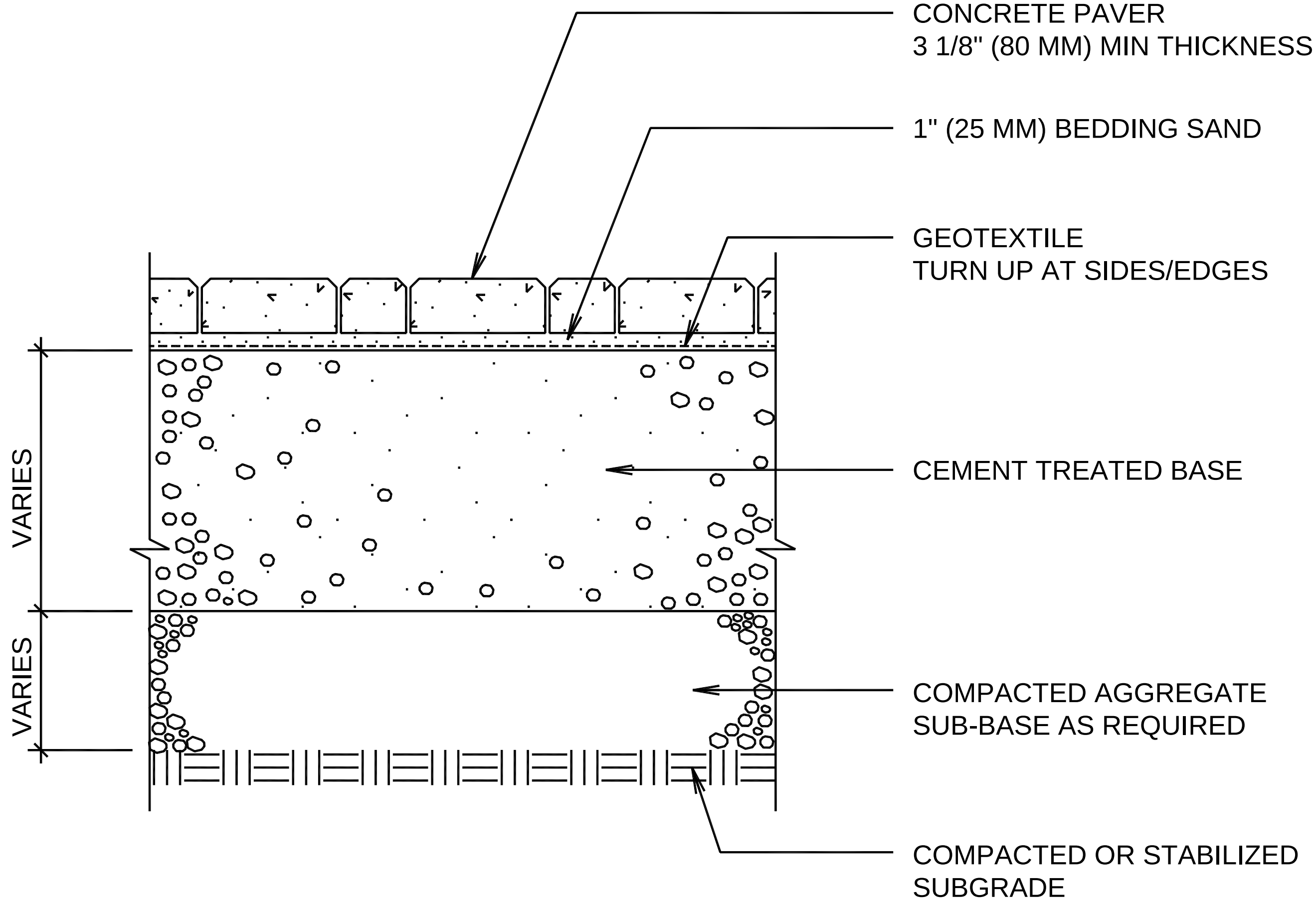
NOTE: AGGREGATE MAY BE USED IN OPENINGS OF GRID PAVERS.

DITCH LINER FOR INTERMITTENT FLOWS - CONCRETE GRID PAVERS	DRAWING NO.	ICPI-31
	SCALE	F.S.



NOTE: USE FOR NON-TIDAL FRESHWATER APPLICATIONS.

BOAT RAMP CONCRETE GRID PAVEMENT	DRAWING NO.	ICPI-32
	SCALE	F.S.

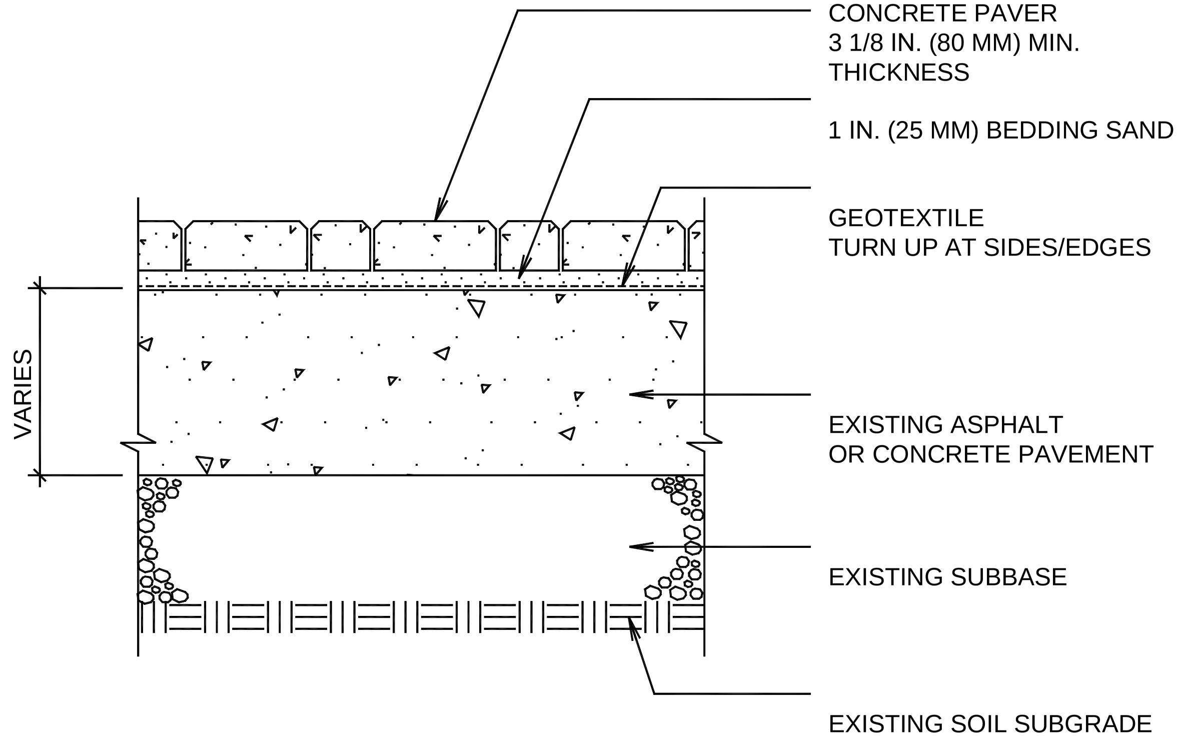


NOTE: BASE, SUB-BASE, AND SUBGRADE THICKNESS VARY WITH LOADS, SUBGRADE STRENGTH, AND CLIMATE.

PORT / INDUSTRIAL PAVEMENT WITH CEMENT TREATED BASE

DRAWING NO. ICPI-33

SCALE F.S.

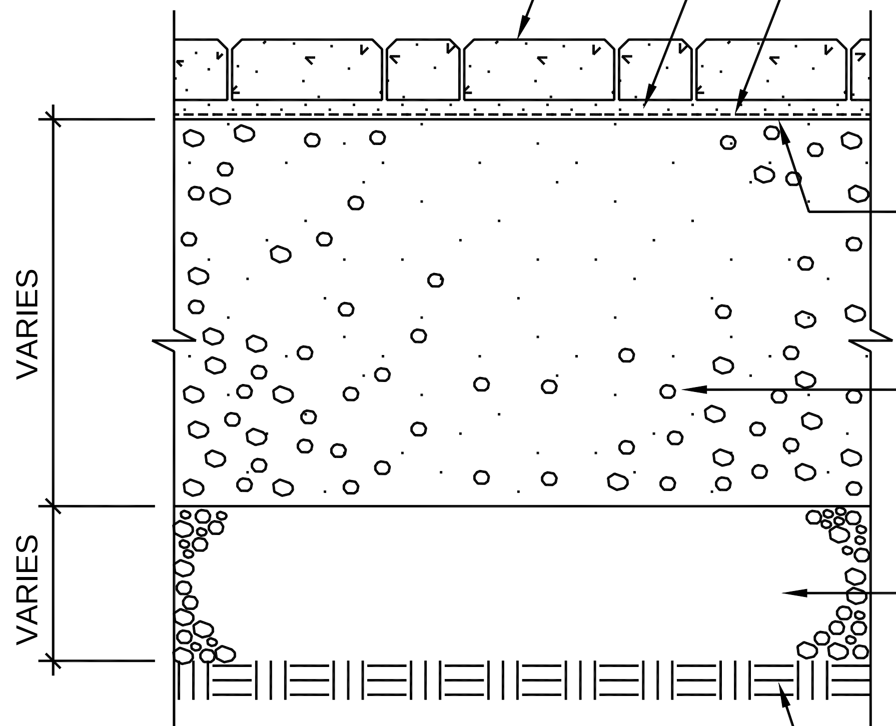


NOTES:

1. EXISTING ASPHALT OR CONCRETE PAVEMENT SHALL BE THOROUGHLY INSPECTED FOR AREAS IN NEED OF PATCHING OR REPLACEMENT. CONDUCT ALL REPAIRS AND FILL ALL CRACKS GREATER THAN 1/4 IN. (6 MM) WIDE PRIOR TO PLACING GEOTEXTILE, SAND, AND PAVERS.
2. PROVIDE DRAINAGE OF SAND LAYER THROUGH WEEP HOLE(S) INTO CATCH BASIN(S).

PORT / INDUSTRIAL PAVEMENT ON EXISTING ASPHALT OR CONCRETE

DRAWING NO.	ICPI-34
SCALE	NO SCALE



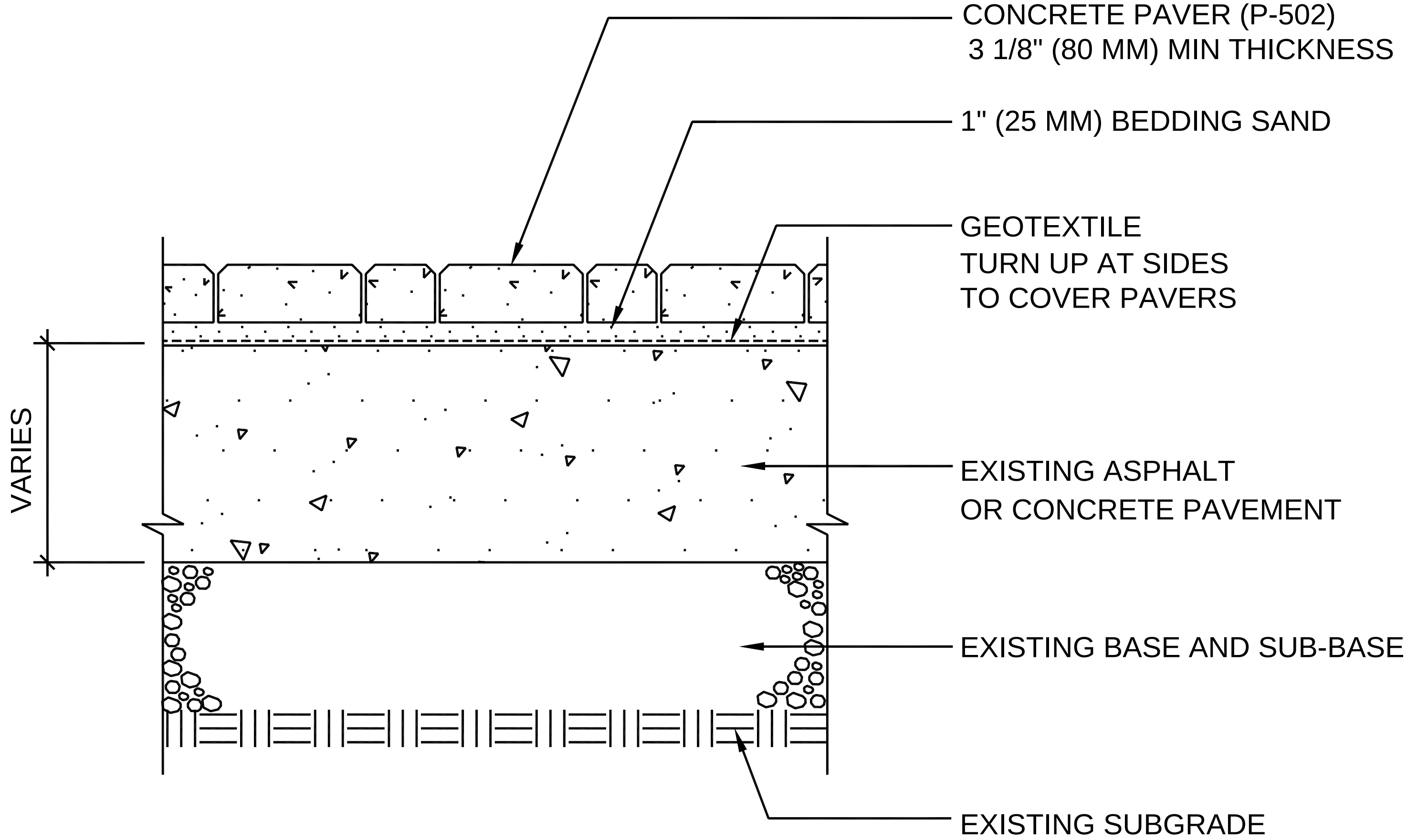
NOTE:

BASE, SUB-BASE, AND SUBGRADE THICKNESS VARY WITH LOADS, SOIL STRENGTH, AND CLIMATE.

AIRFIELD PAVEMENT WITH CEMENT TREATED OR ASPHALT BASE

DRAWING NO. ICPI-35

SCALE F.S.

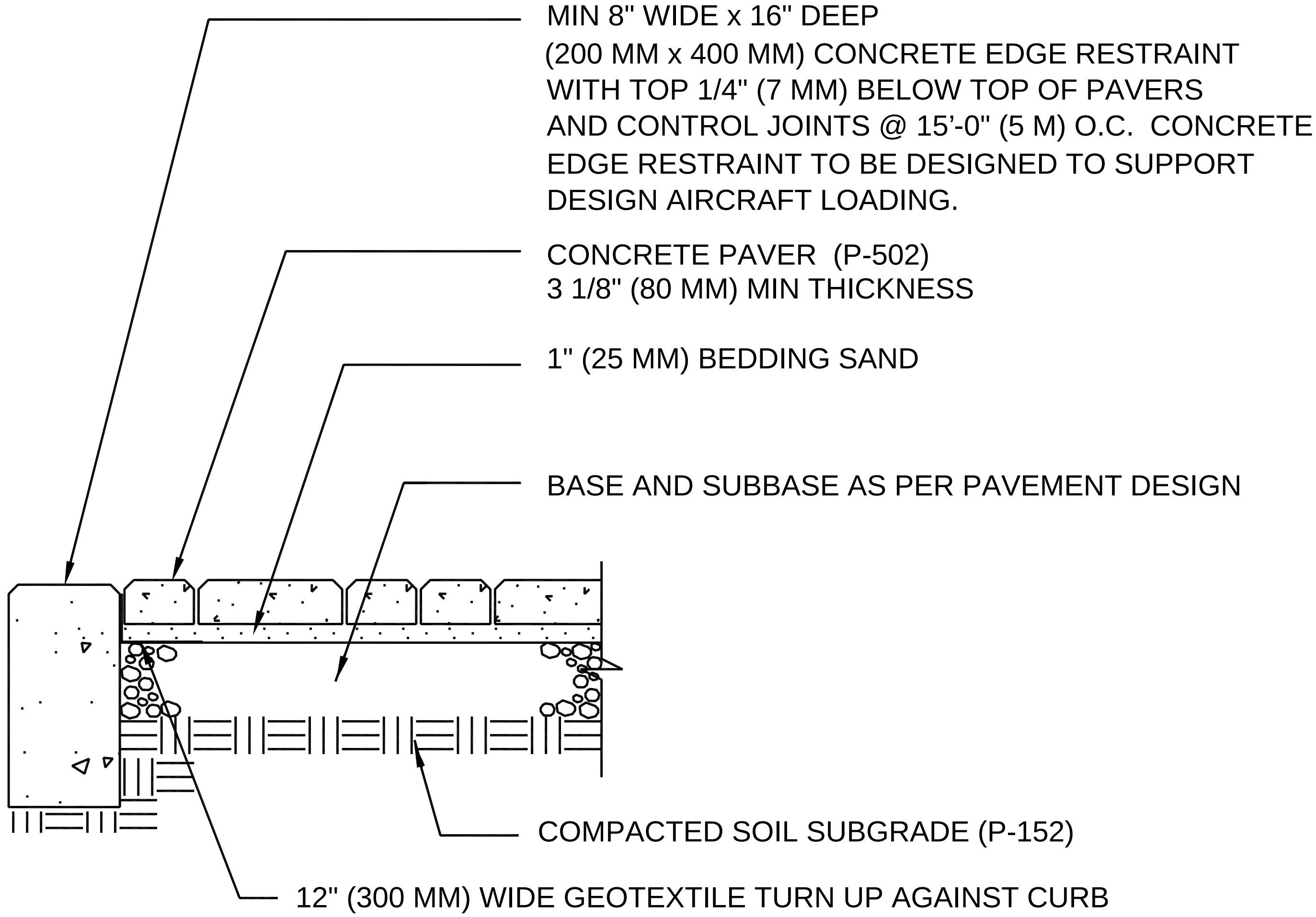


NOTE:

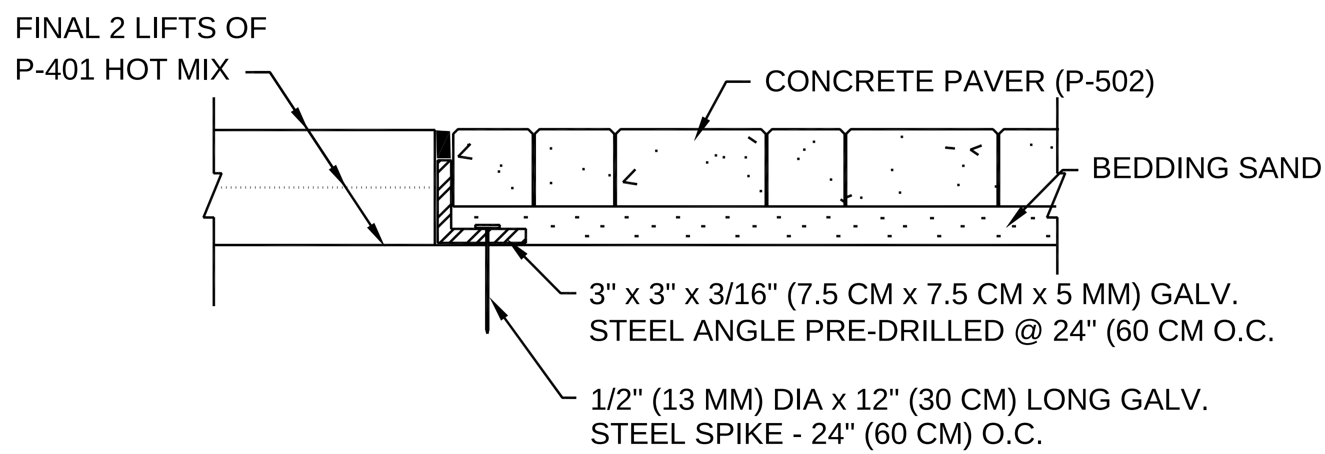
EXISTING ASPHALT OR CONCRETE PAVEMENT SHALL BE THOROUGHLY INSPECTED FOR AREAS IN NEED OF PATCHING OR REPLACEMENT. CONDUCT ALL REPAIRS AND FILL ALL CRACKS GREATER THAN 1/4 IN. (7 MM) WIDE PRIOR TO PLACING GEOTEXTILE, SAND, AND PAVERS.

AIRFIELD PAVEMENT ON EXISTING ASPHALT OR CONCRETE

DRAWING NO.	ICPI-36
SCALE	F.S.



AIRFIELD PAVEMENT AT CONCRETE EDGE RESTRAINT	DRAWING NO.	ICPI-37
	SCALE	F.S.



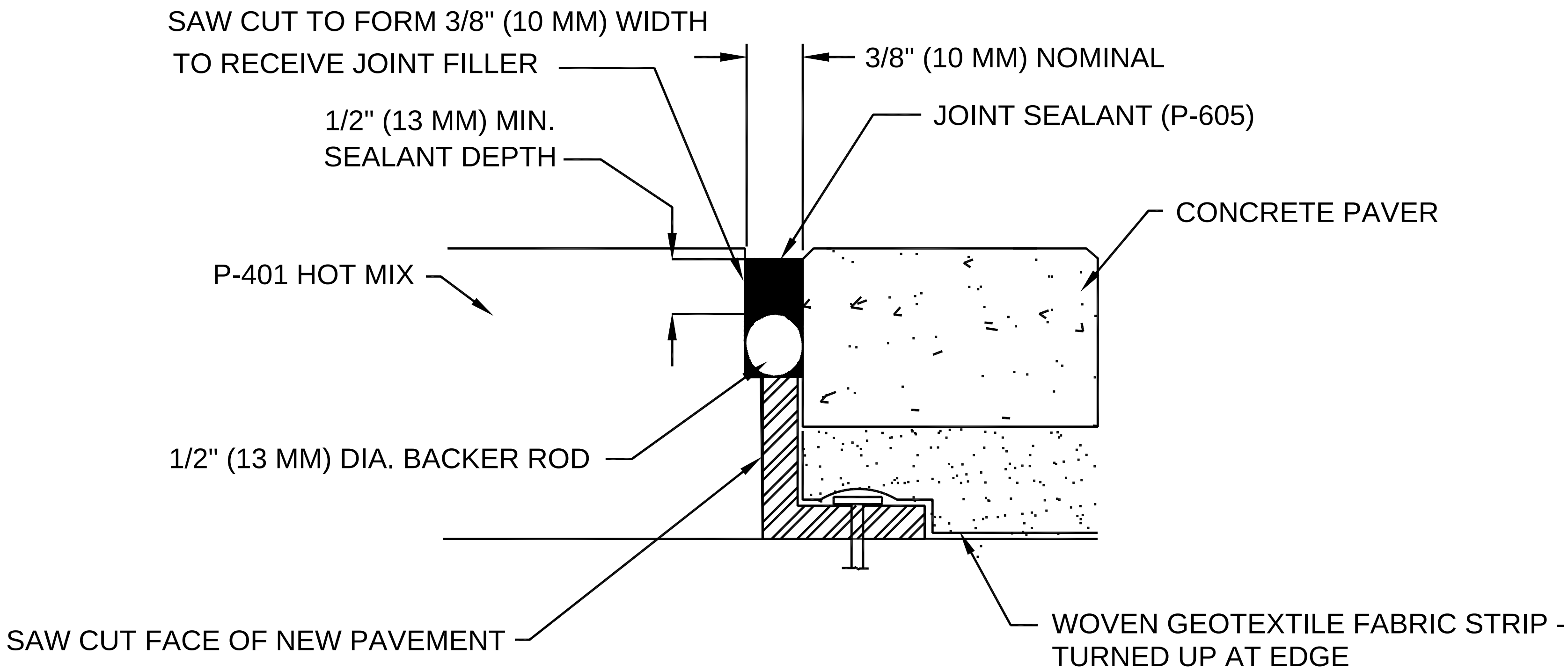
NOTES:

1. CONSTRUCT P-401 OVERLAY APPROX. 2 FT. (60 CM) PAST ANGLE LOCATION AND CUT BACK FOR ANGLE INSTALLATION
2. ADJUST ANGLE LOCATION +/- 2 IN. (5 CM) TO MINIMIZE CUTTING BLOCKS
3. ADD DRAIN HOLES AS NECESSARY AT LOWEST ELEVATIONS. COVER WITH GEOTEXTILE.

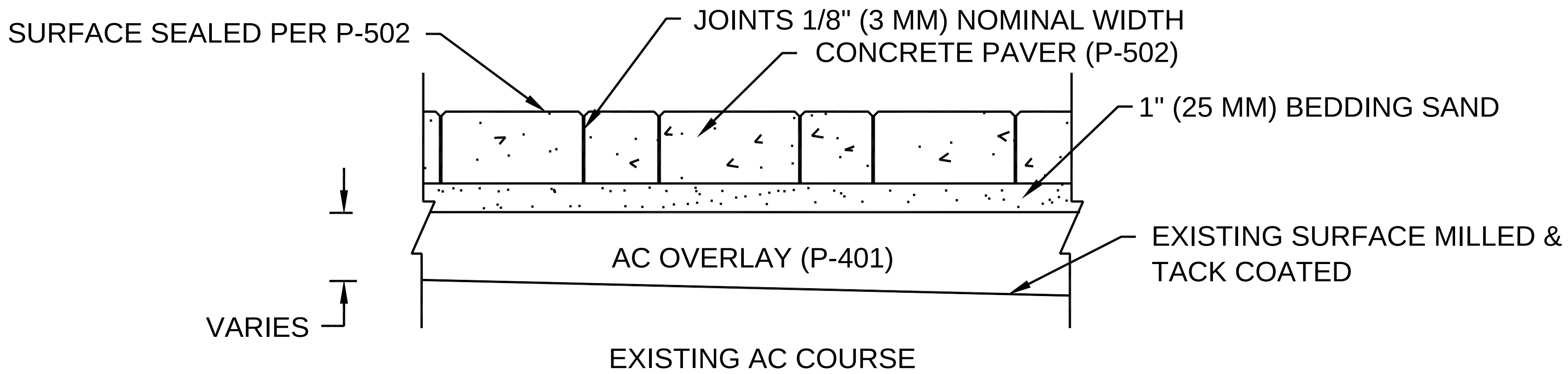
AIRFIELD PAVEMENT INLAY

AT STEEL ANGLE EDGE RESTRAINT DETAIL

DRAWING NO.	ICPI-38
SCALE	F.S.

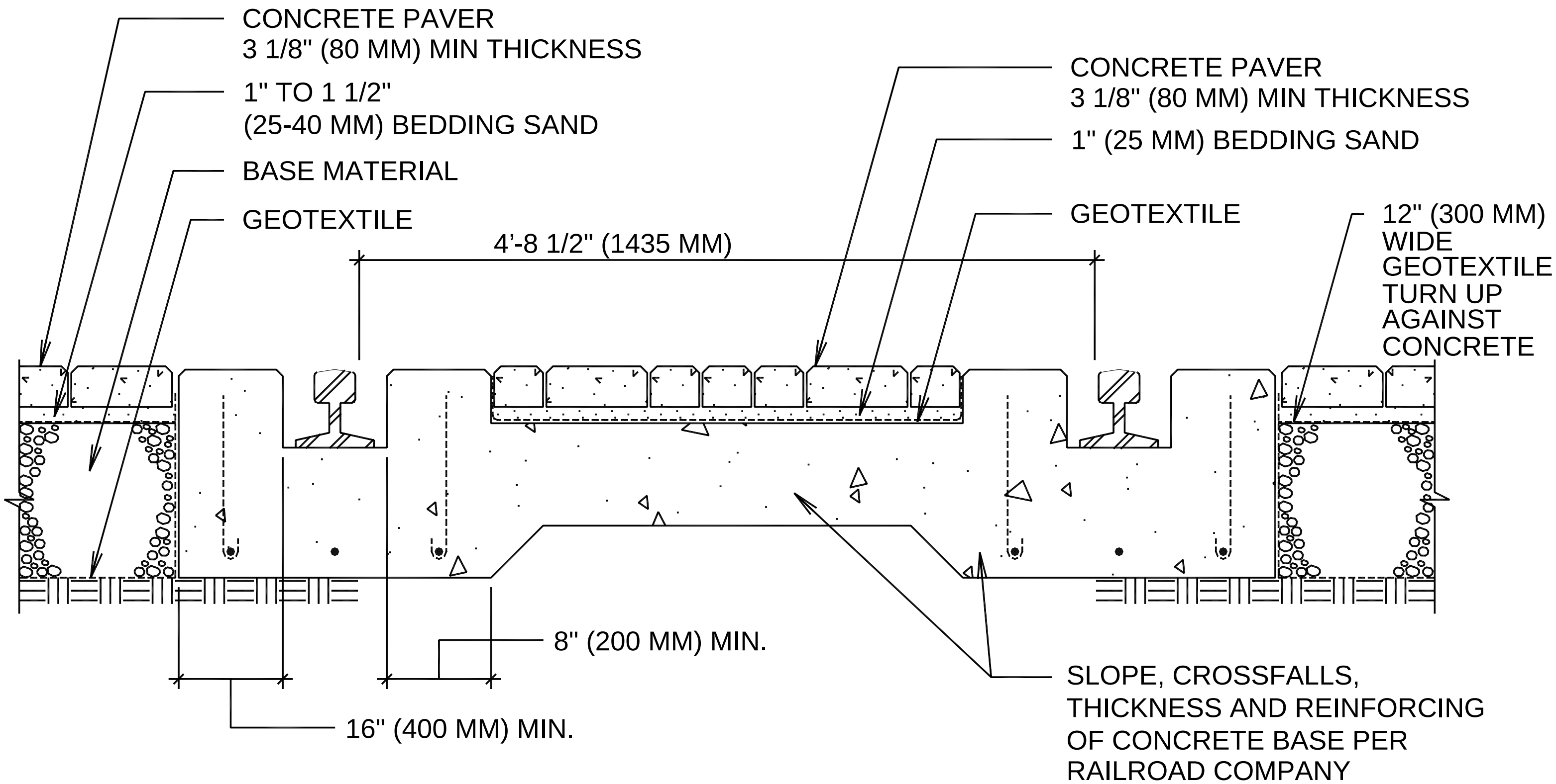


AIRFIELD PAVEMENT INLAY **IN ASPHALT AT EDGE RESTRAINT**	DRAWING NO.	ICPI-39
	SCALE	F.S.



AIRFIELD PAVEMENT OVERLAY
OF EXISTING FLEXIBLE PAVEMENT

DRAWING NO.	ICPI-40
SCALE	F.S.

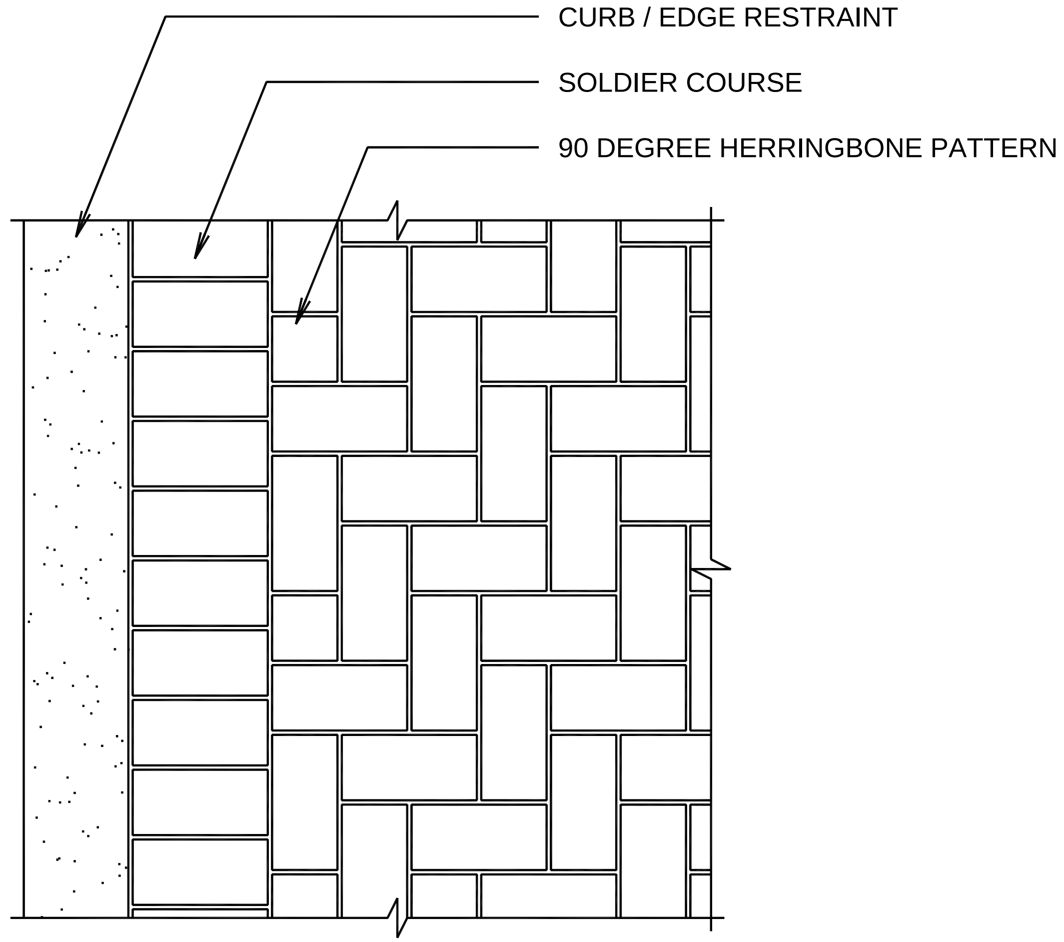


NOTE: DRAIN SAND LAYER THROUGH CONCRETE SLAB WITH PEA GRAVEL FILLED WEEP HOLE(S) OR AT CATCH BASIN(S).

RAILROAD CROSSING

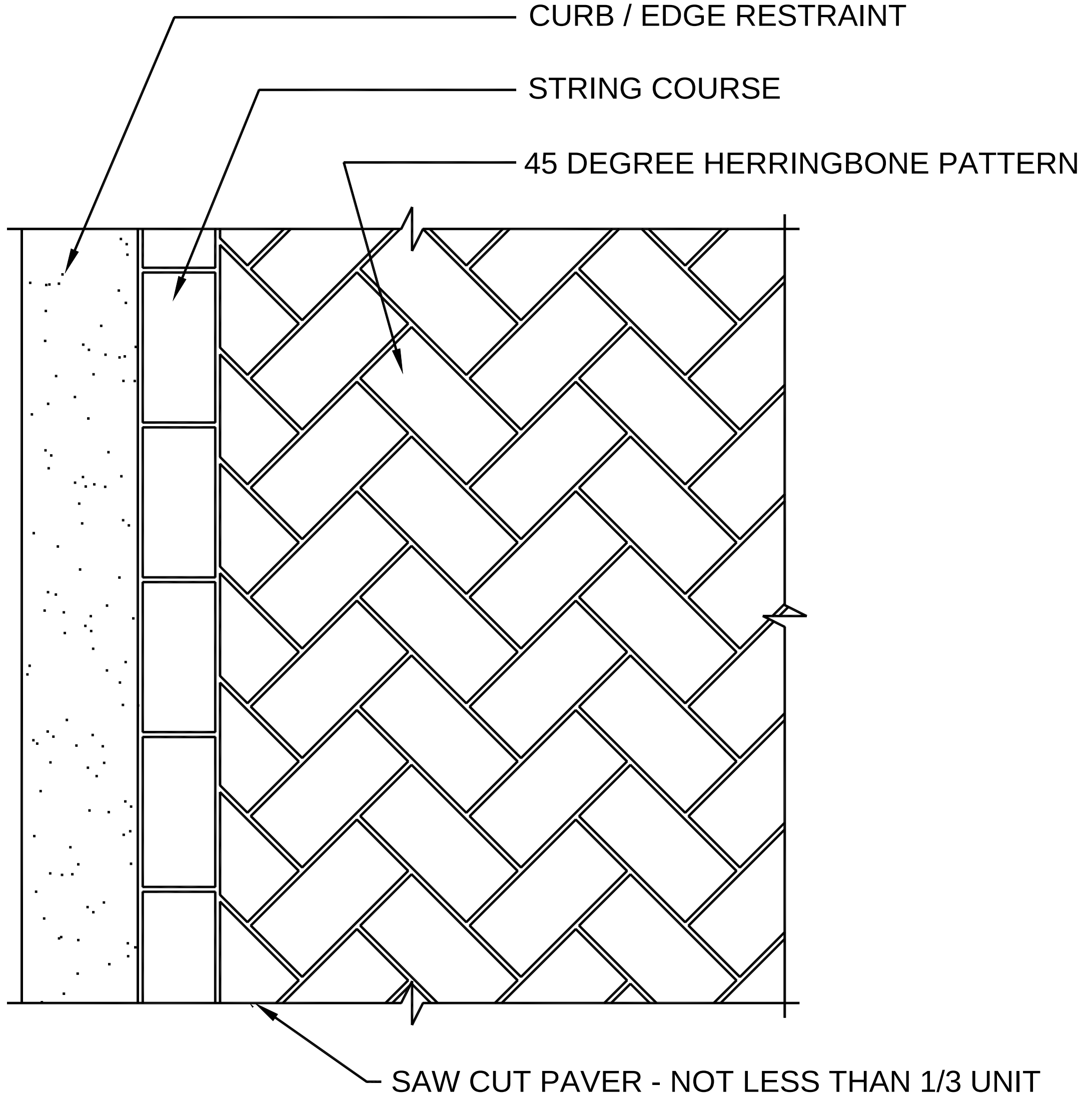
DRAWING NO. ICPI-41

SCALE F.S.



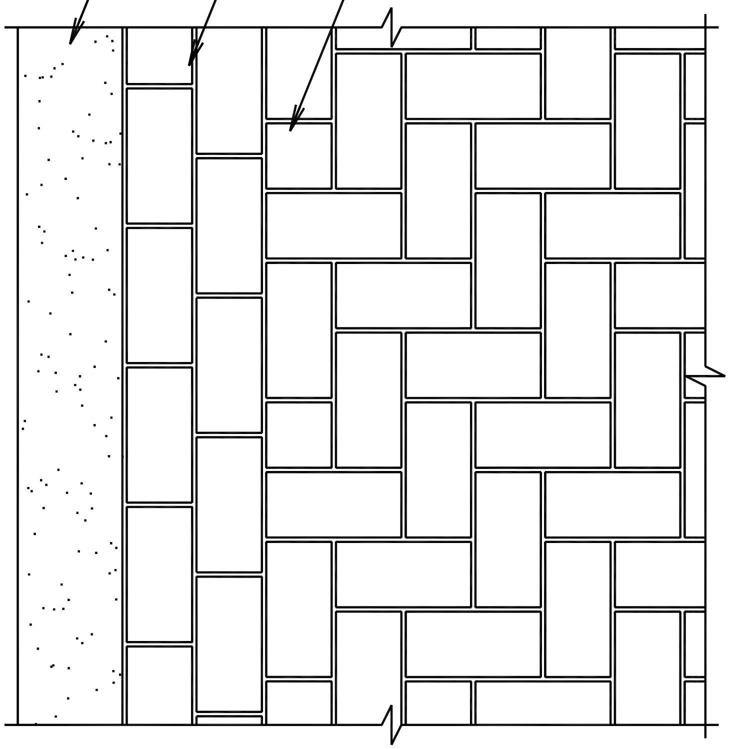
SOLDIER COURSE EDGE WITH 90 DEGREE HERRING BONE PATTERN

DRAWING NO.	ICPI-42
SCALE	F.S.



STRING COURSE EDGE WITH 45 DEGREE HERRINGBONE PATTERN

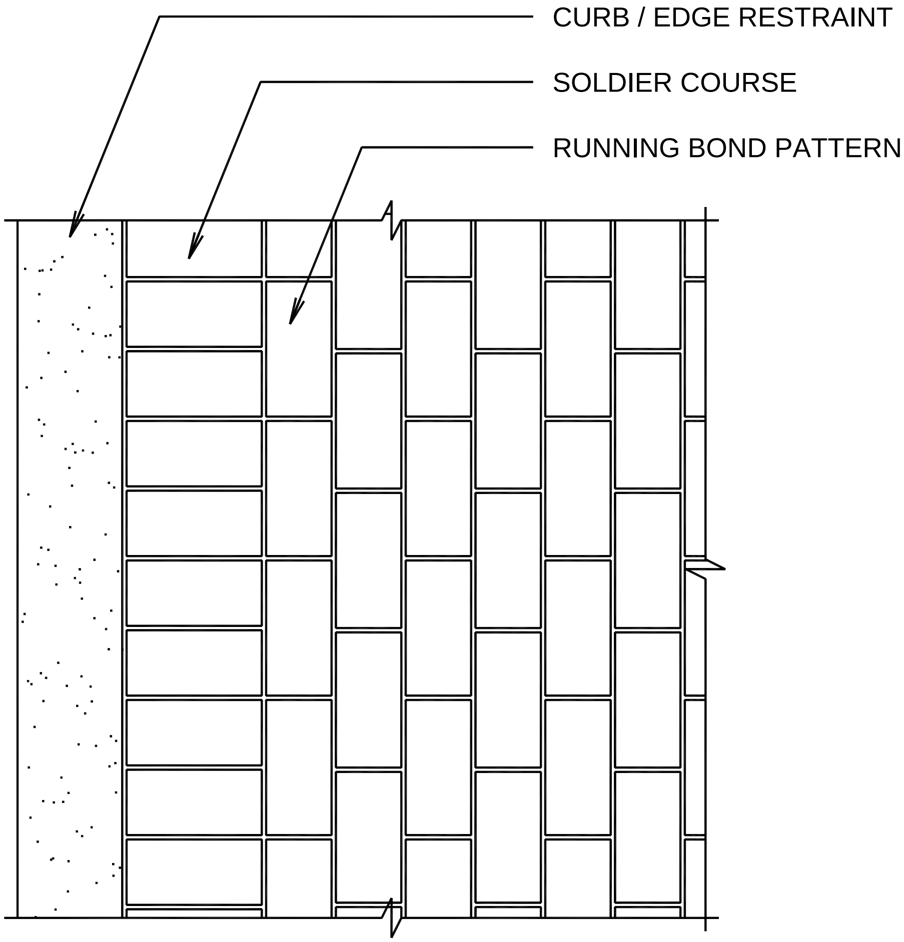
DRAWING NO.	ICPI-43
SCALE	F.S.



DOUBLE STRING SOLDIER COURSE EDGE WITH
90 DEGREE HERRING BONE PATTERN

DRAWING NO. ICPI-44

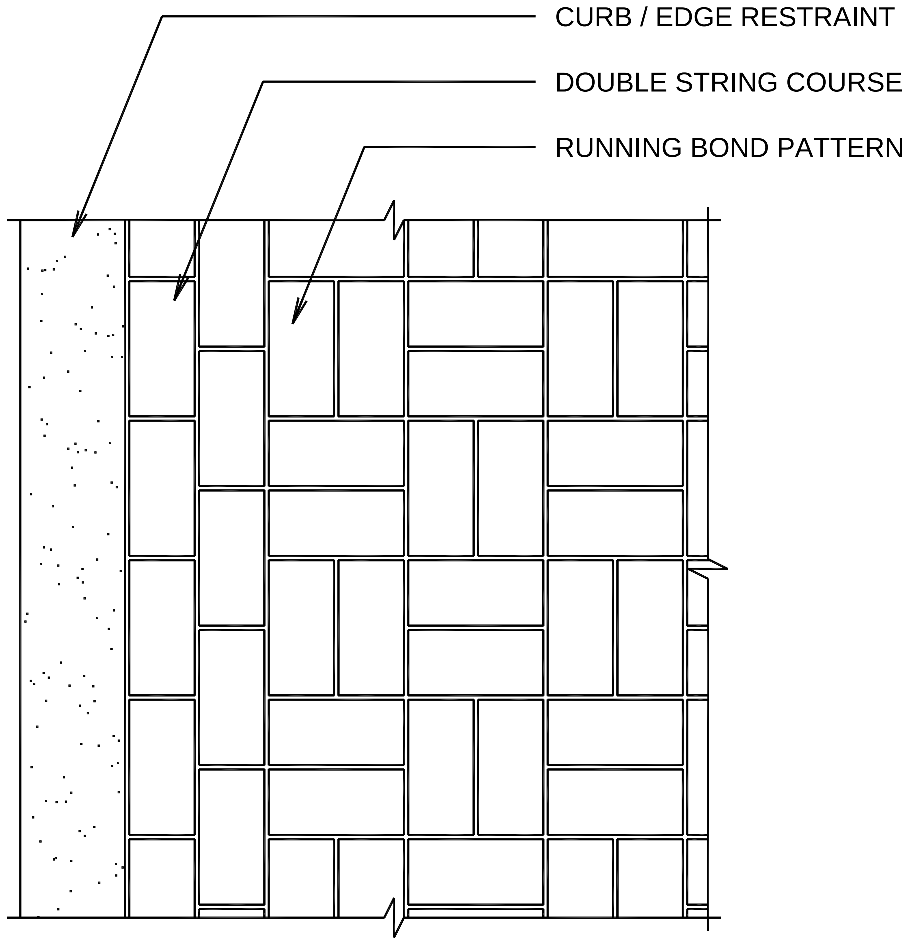
SCALE F.S.



SOLDIER COURSE EDGE WITH RUNNING BOND PATTERN

DRAWING NO. ICPI-45

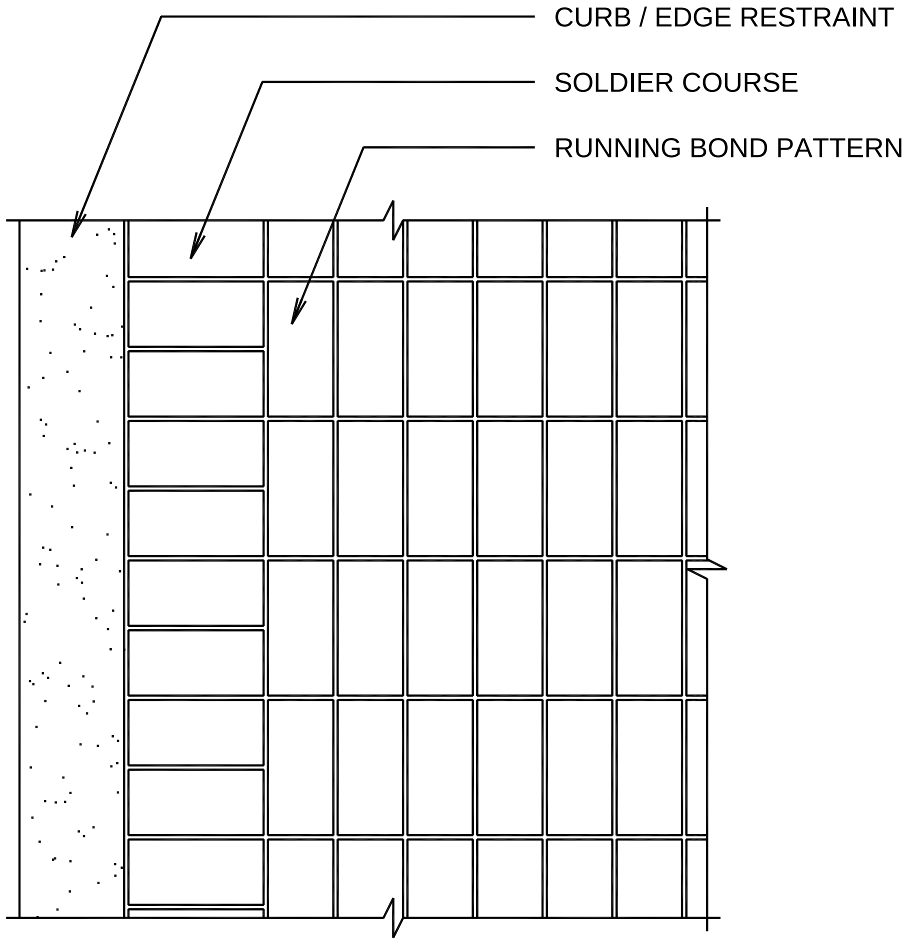
SCALE F.S.



DOUBLE STRING COURSE EDGE WITH PARQUET PATTERN

DRAWING NO. ICPI-46

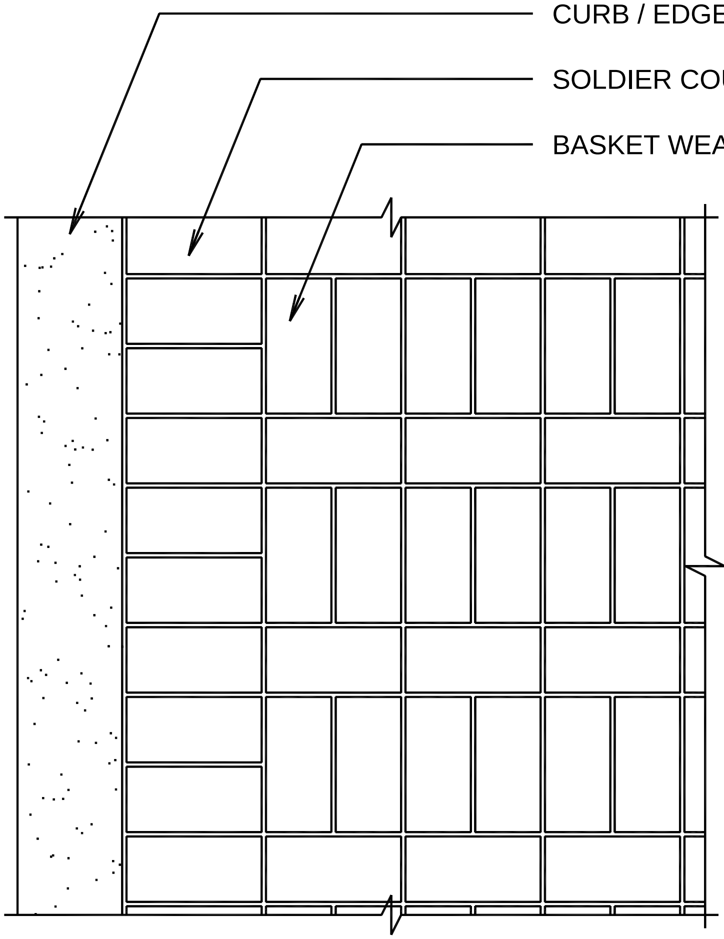
SCALE F.S.



SOLDIER COURSE EDGE WITH STACK BOND PATTERN

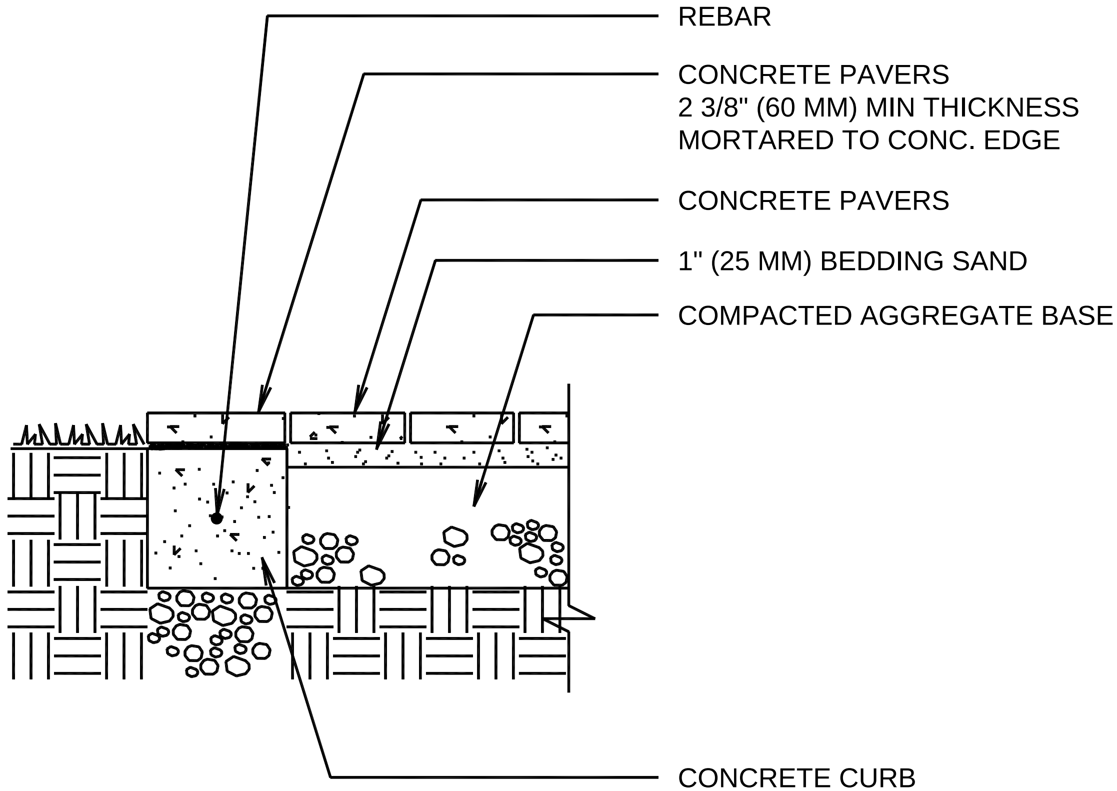
DRAWING NO.	ICPI-47
SCALE	F.S.

DUCON
OUTDOOR LIVING



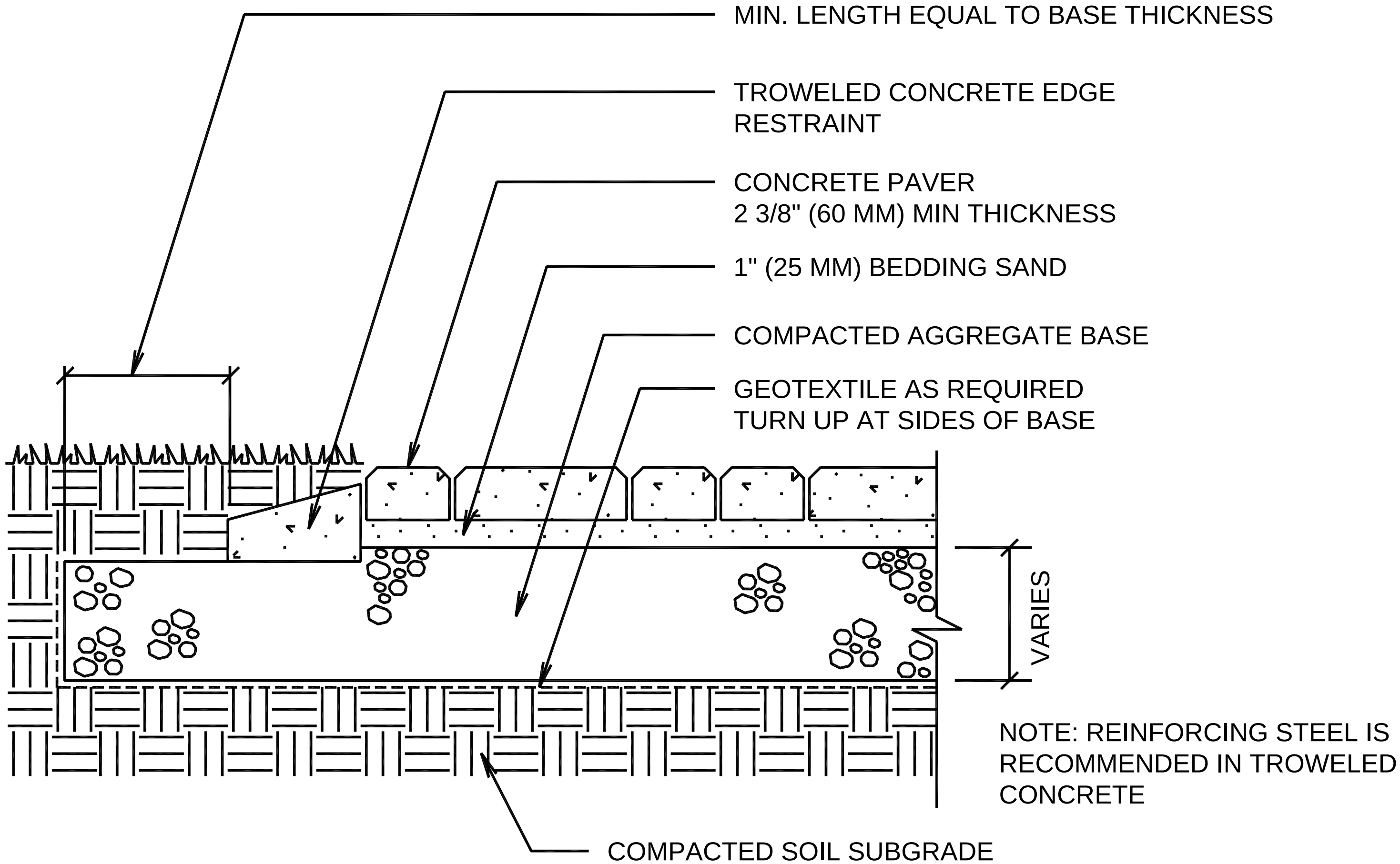
SOLDIER COURSE EDGE WITH BASKET WEAVE PATTERN

DRAWING NO.	ICPI-48
SCALE	F.S.



PEDESTRIAN DRIVEWAY WITH SUBMERGED CONCRETE CURB

DRAWING NO.	ICPI-49
SCALE	F.S.

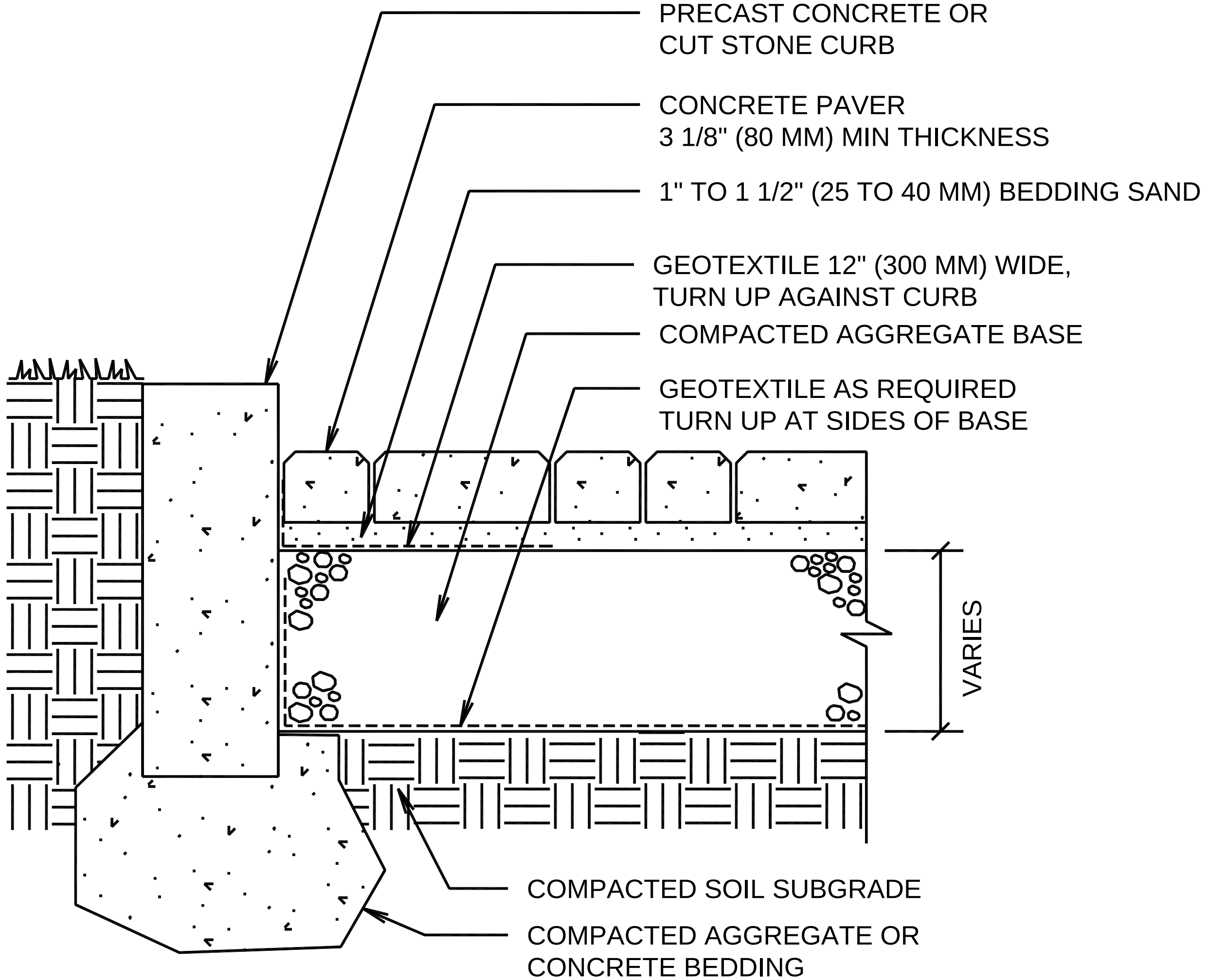


NOTE:

1. USE 5:1 (AGGREGATE: CEMENT) MIX FOR CONCRETE EDGE.
2. RECOMMENDED FOR NON-FREEZE THAW AREAS.
3. CONSTRUCTION OF THIS DETAIL CAN BE USED ON RESIDENTIAL DRIVEWAYS IN NON-FREEZE THAW AREAS. REINFORCING MAY BE REQUIRED IN THE EDGE RESTRAINT.
4. THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE. COLDER CLIMATES MAY REQUIRE THICKER BASES.

PATIO/WALK/RESIDENTIAL DRIVEWAY W/ TROWELED CONCRETE EDGE RESTRAINT

DRAWING NO.	ICPI-50
SCALE	F.S.

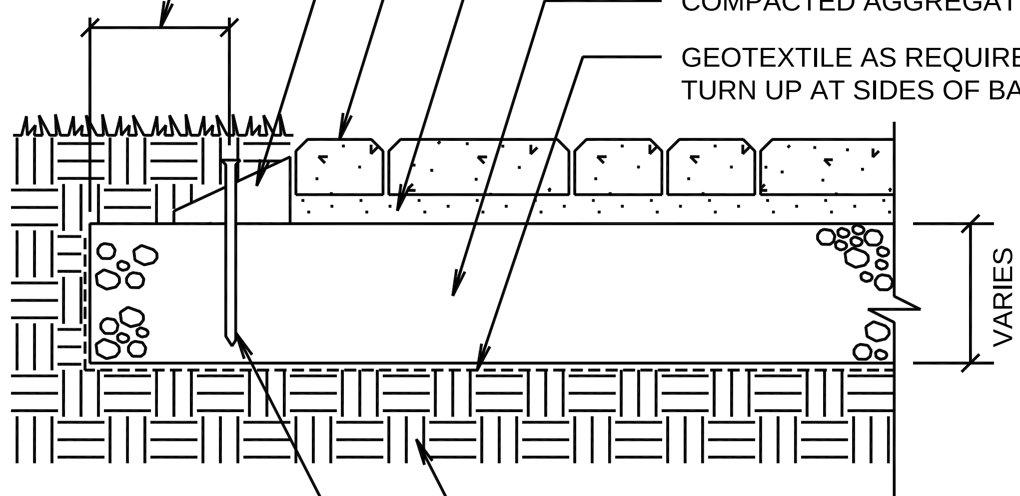


NOTE:

1. EDGE RESTRAINT SHOULD BE MINIMUM 6 IN. (150 MM) WIDE FOR STREET APPLICATIONS.
2. EDGE RESTRAINT MAY BE EVEN WITH TOP OF CONCRETE PAVERS.
3. THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE. COLDER CLIMATES MAY REQUIRE THICKER BASES.

STREET PAVEMENT WITH FULL-DEPTH PRECAST CONCRETE OR CUT STONE CURB

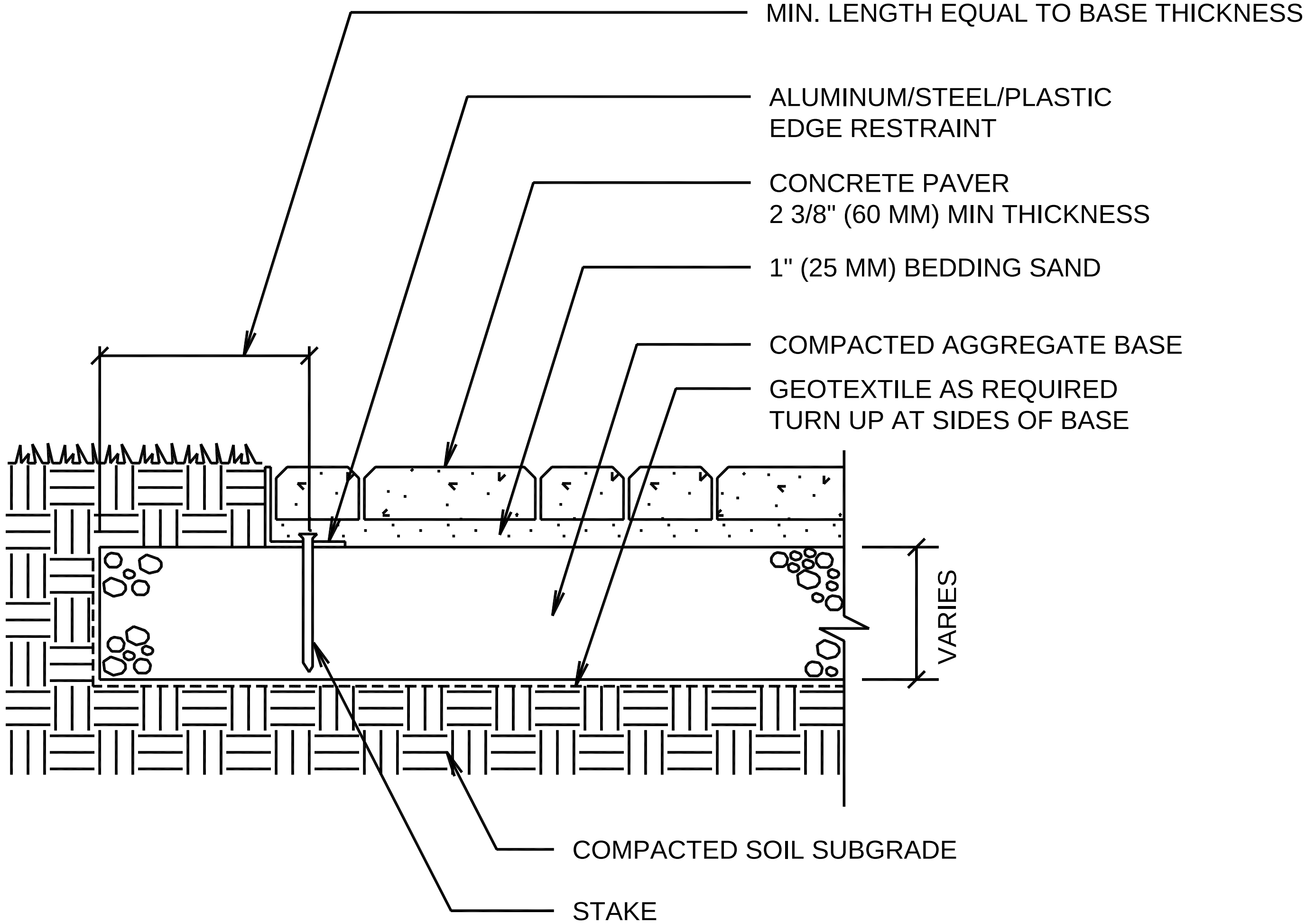
DRAWING NO.	ICPI-51
SCALE	F.S.



NOTE:
1. THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE. COLDER CLIMATES MAY REQUIRE THICKER BASES.

PATIO/ WALK/ RESIDENTIAL DRIVEWAY WITH PLASTIC EDGE RESTRAINT

DRAWING NO.	ICPI-52
SCALE	F.S.



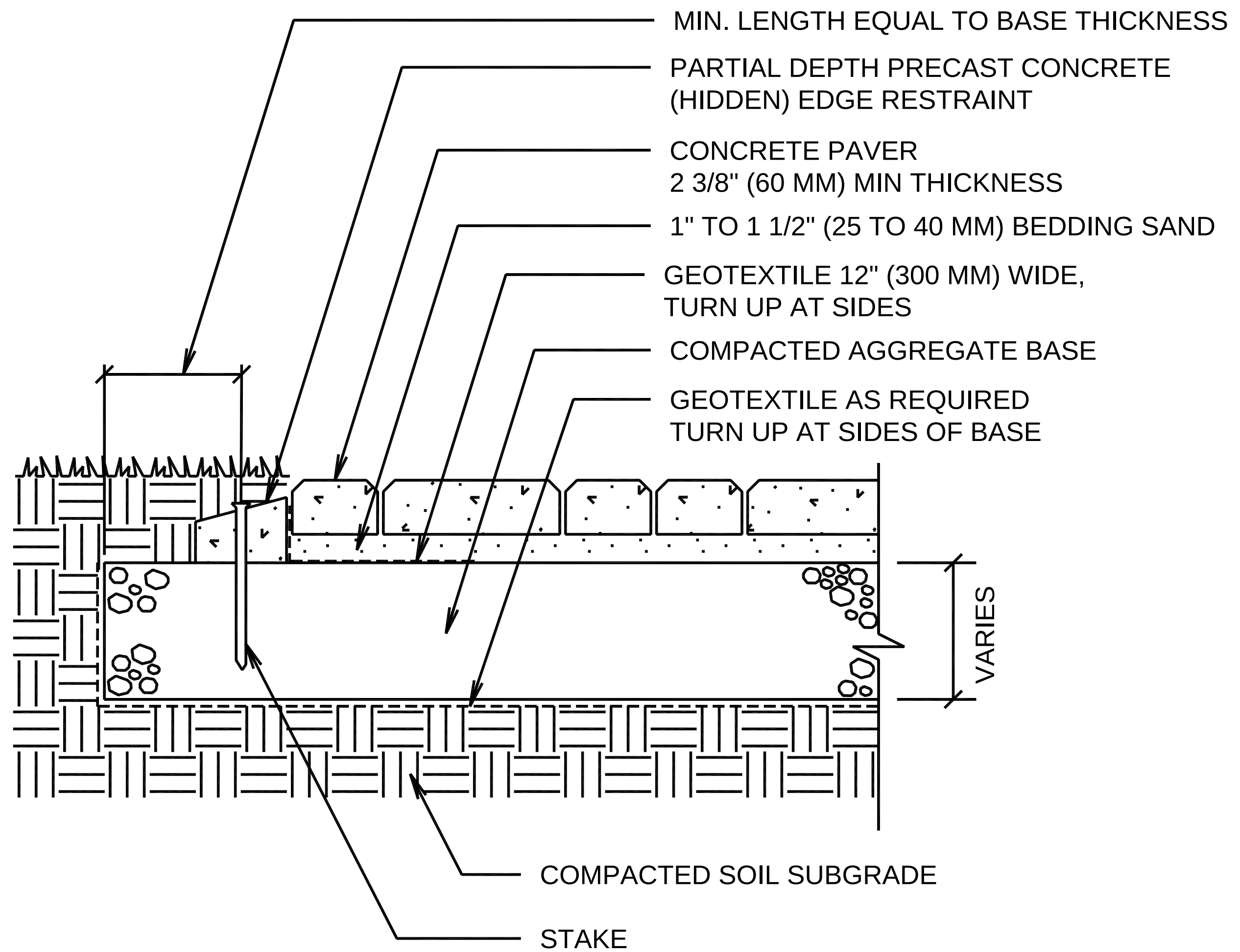
NOTE:

1. THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE. COLDER CLIMATES MAY REQUIRE THICKER BASES.

PATIO/WALK/RESIDENTIAL DRIVEWAY W/ ALUMINUM / STEEL / PLASTIC EDGE

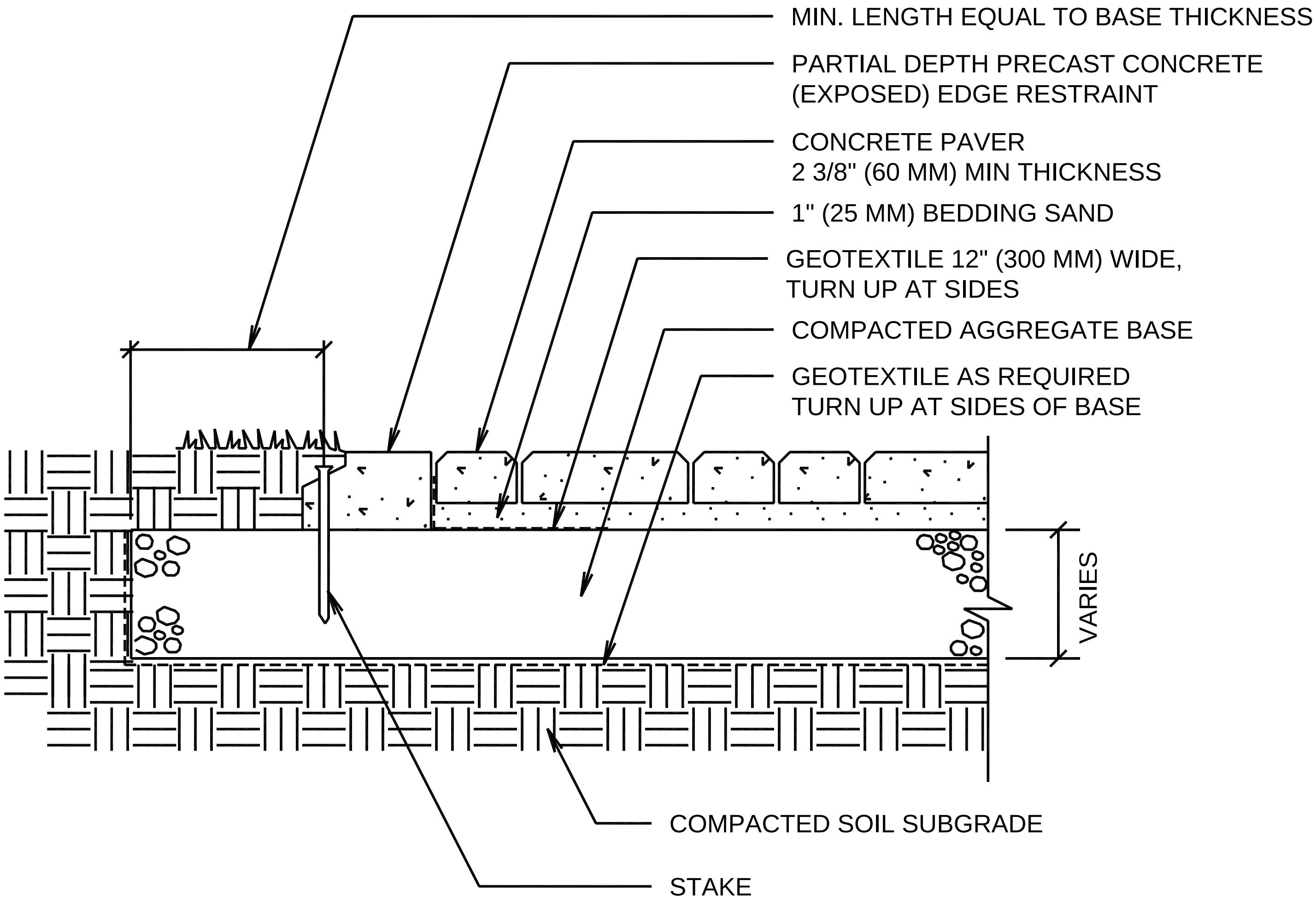
DRAWING NO.	ICPI-53
SCALE	F.S.

DUCON
OUTDOOR LIVING



NOTE:
THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE.
COLDER CLIMATES MAY REQUIRE THICKER BASES.

PATIO/WALK/RESIDENTIAL DRIVEWAY WITH PARTIAL DEPTH CONCRETE EDGE RESTRAINT	DRAWING NO.	ICPI-54
	SCALE	F.S.



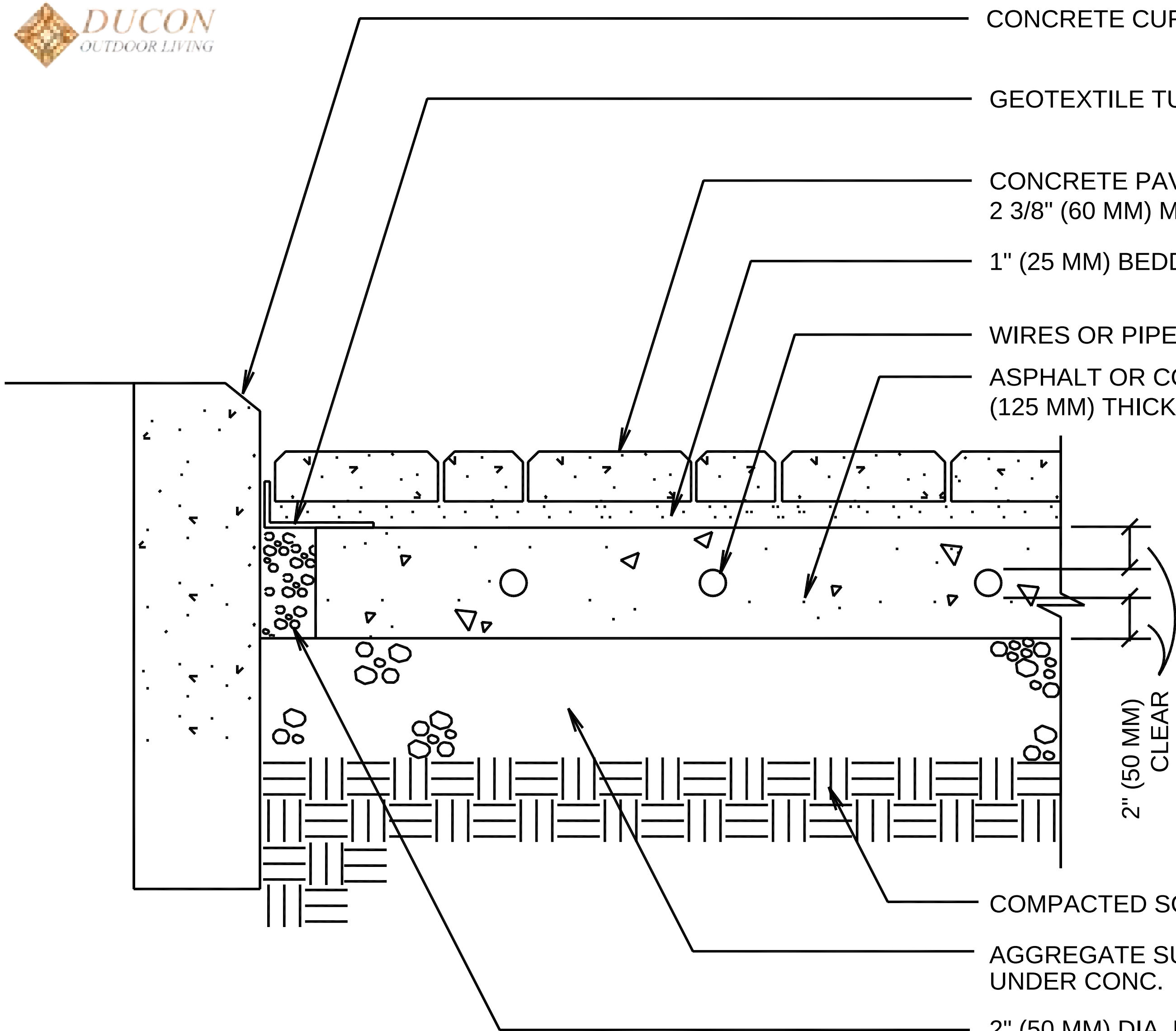
NOTE:

1. THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE. COLDER CLIMATES MAY REQUIRE THICKER BASES.

PATIO/WALK/RESID'L DRIVEWAY WITH PARTIAL DEPTH CONCRETE EDGE RESTRAINT

DRAWING NO.	ICPI-55
SCALE	F.S.

DUCON
OUTDOOR LIVING

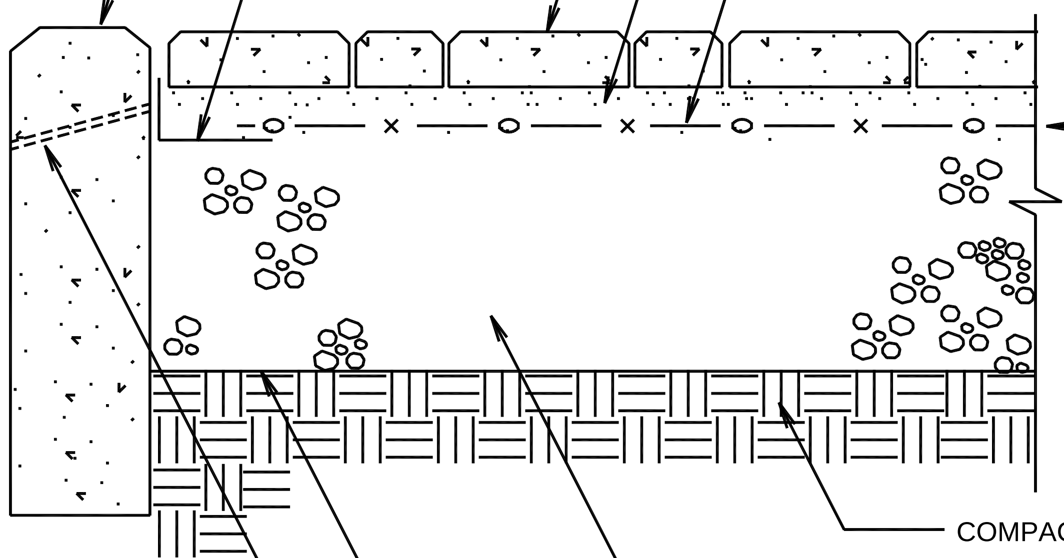


NOTE:

THICKNESS OF AGGREGATE BASE WILL VARY WITH SUBGRADE CONDITIONS AND CLIMATE.
COLDER CLIMATES MAY REQUIRE THICKER BASES.

HEATED CROSSWALK OR STREET ON ASPHALT OR CONCRETE BASE

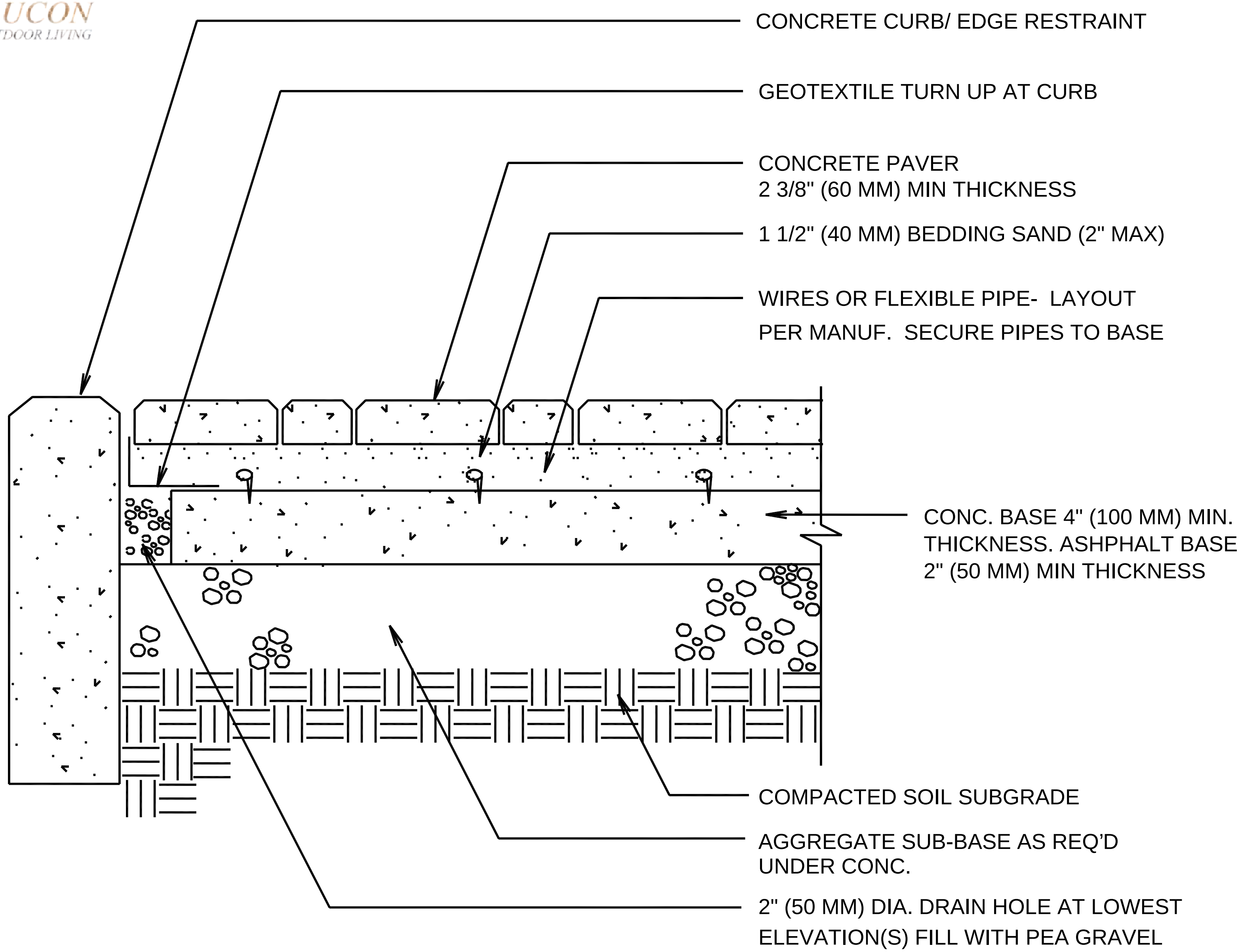
DRAWING NO.	ICPI-57
SCALE	F.S.



NOTE:
OMIT WELDED WIRE FABRIC FOR PEDESTRIAN APPLICATIONS.

HEATED SIDEWALK/ RESIDENTIAL DRIVEWAY ON AGGREGATE BASE

DRAWING NO.	ICPI-58
SCALE	F.S.



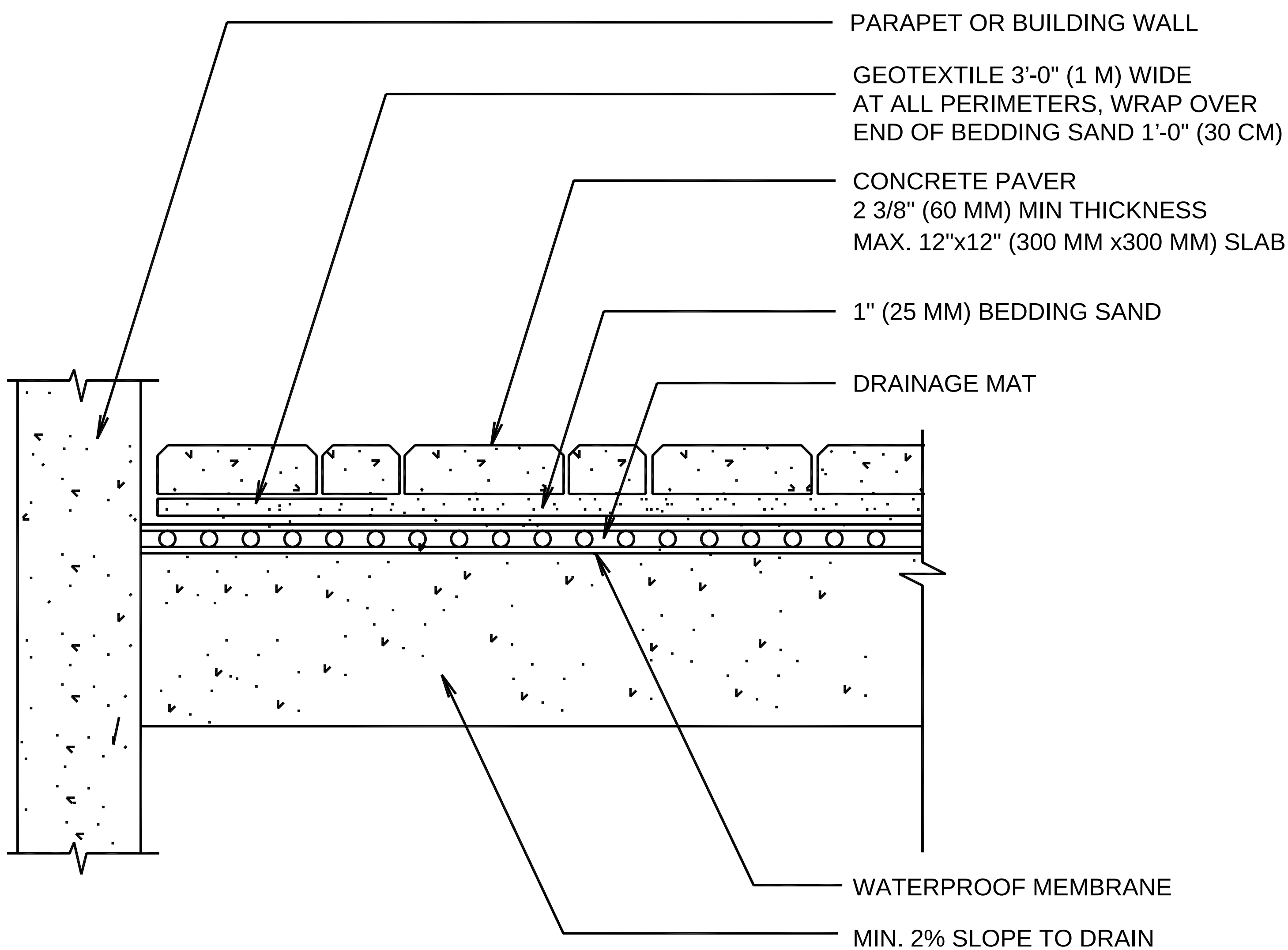
NOTE:
SECURING PIPES OR WIRES TO BASE IS NOT REQUIRED FOR PEDESTRIAN APPLICATIONS

HEATED SIDEWALK/ RESIDENTIAL DRIVEWAY ON CONC. OR ASPHALT BASE

DRAWING NO. ICPI-59

SCALE F.S.

DUCON
OUTDOOR LIVING



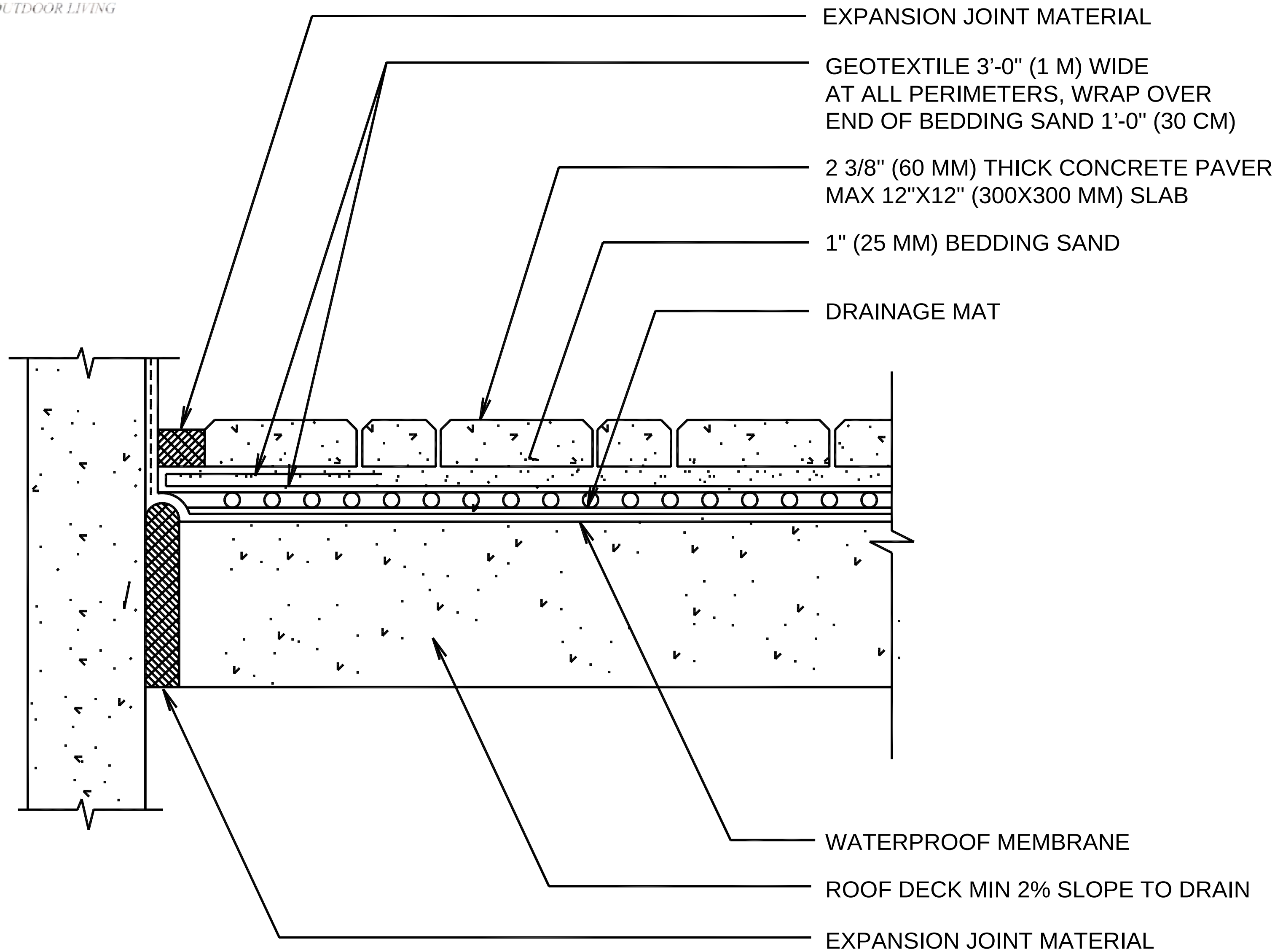
NOTE:

1. ROOF DECK IS TIED TO PARAPET OR BUILDING WALL
2. PEDESTRIAN USE ONLY

PEDESTRIAN ROOF PLAZA DECK WITH DRAINAGE MAT

DRAWING NO. ICPI-60

SCALE F.S.



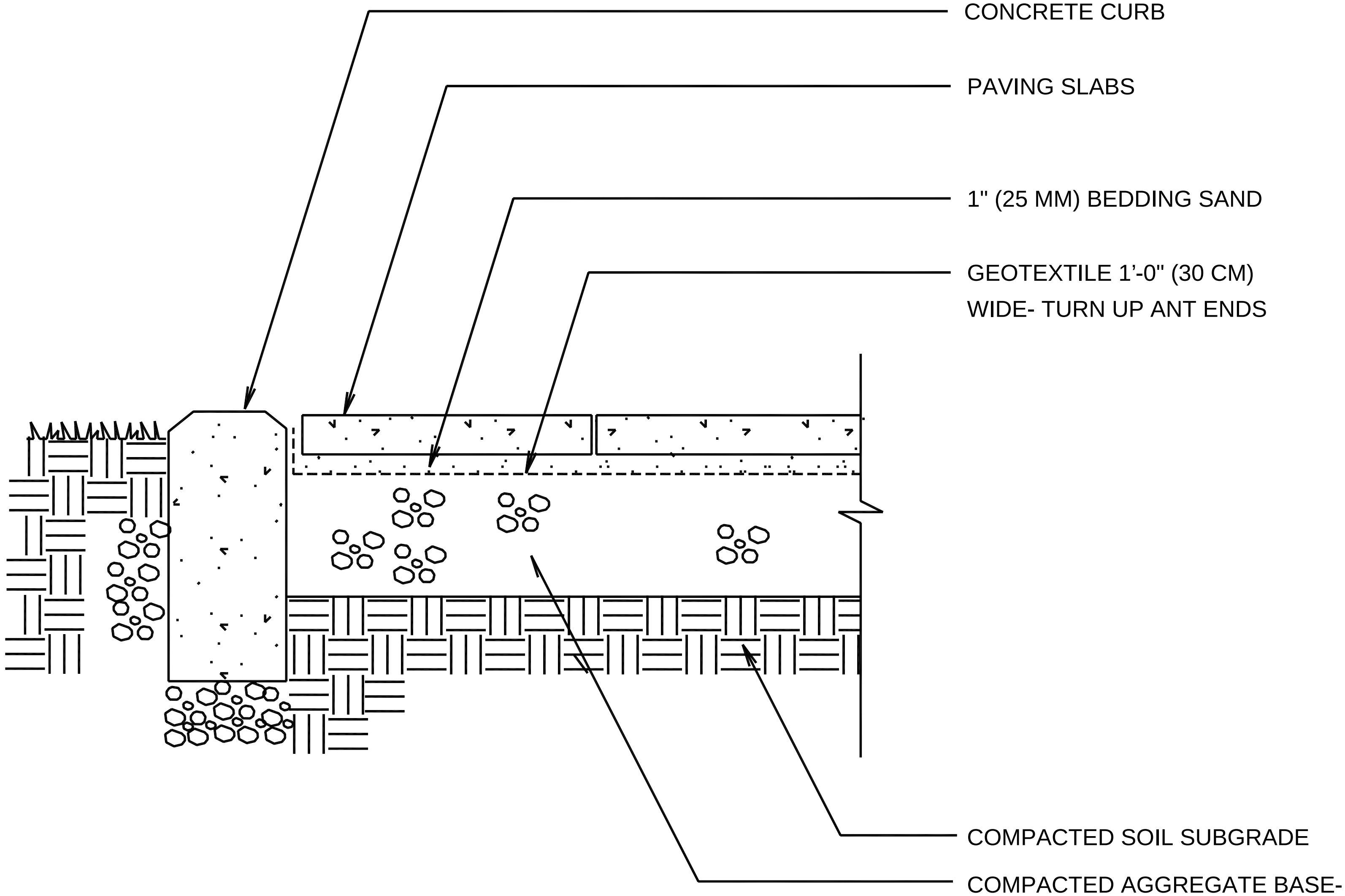
NOTES:

1. ROOF DECK IS NOT JOINED TO WALL/PARAPET.
2. PEDESTRIAN USE ONLY.

PEDESTRIAN ROOF PLAZA DECK WITH DRAINAGE MAT

DRAWING NO. ICPI-61

SCALE F.S.

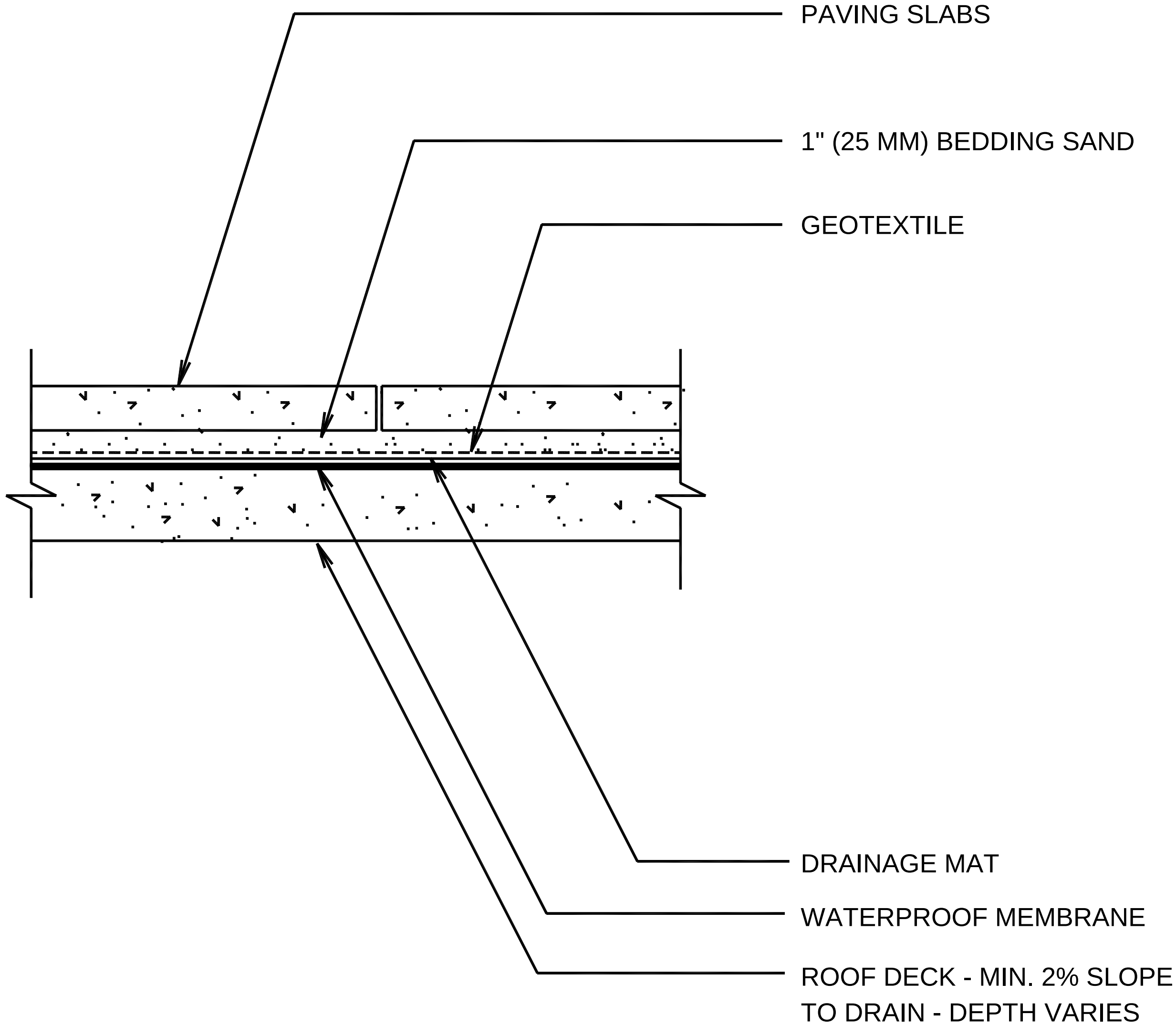


NOTES:

1. BASE AND SUBGRADE MAY REQUIRE DRAINS
2. RESIDENTIAL PEDESTRIAN APPLICATIONS ONLY

PAVING SLABS ON AGGREGATE BASE FOR PATIO

DRAWING NO.	ICPI-62
SCALE	F.S.



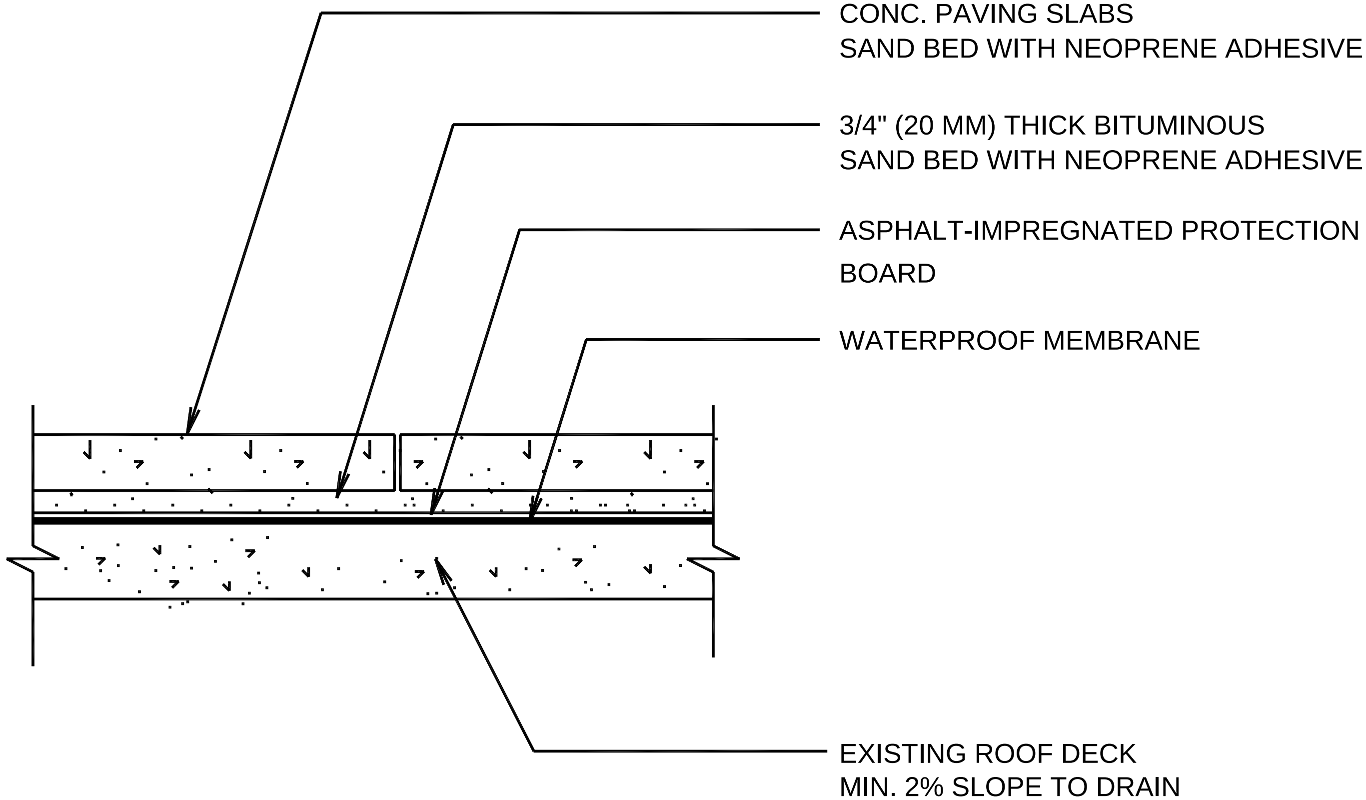
NOTE:

CONSULT WATERPROOF MEMBRANE MANUFACTURER ON NEED
FOR PROTECTION BOARD.

PAVING SLABS FOR ROOF PLAZA DECK

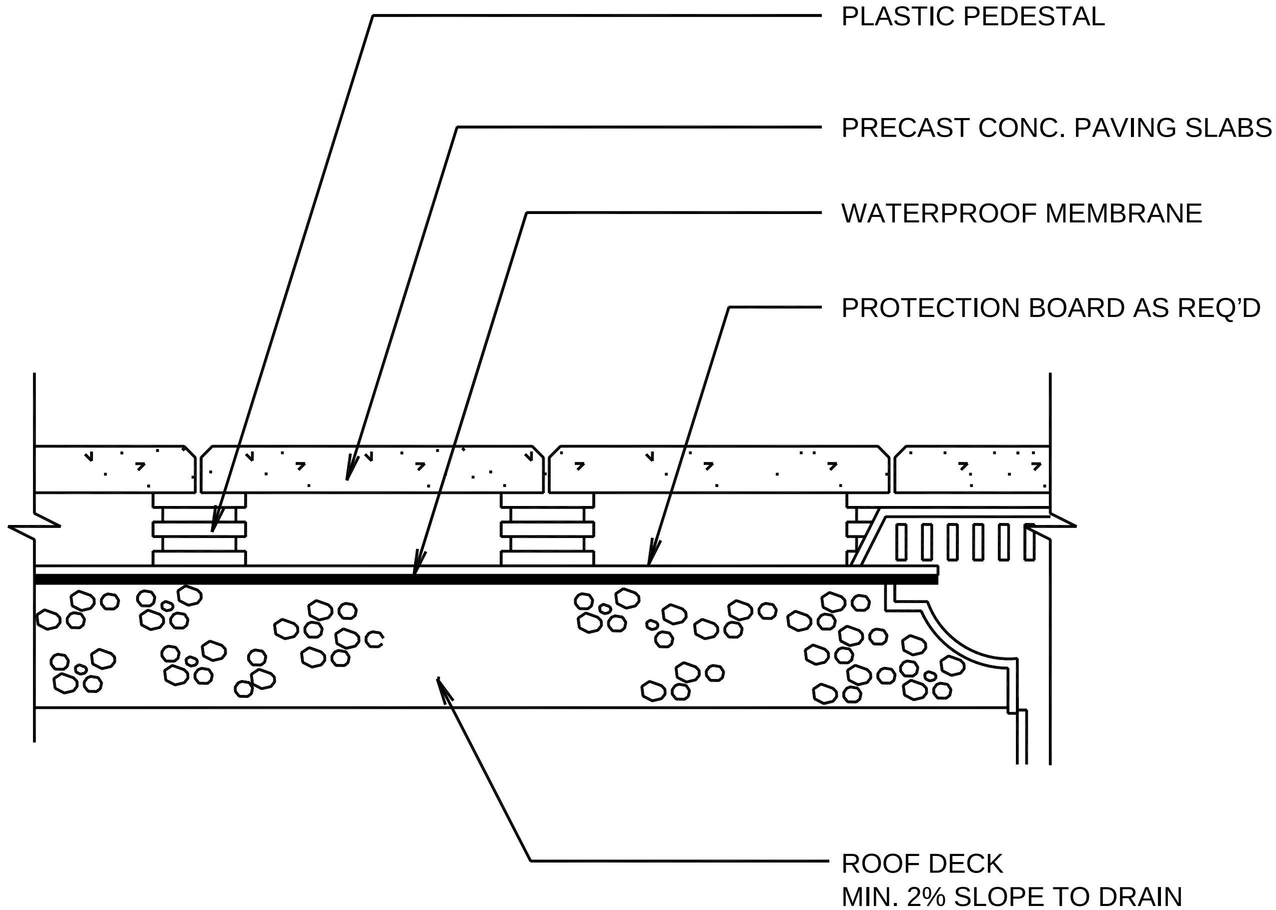
DRAWING NO. ICPI-63

SCALE F.S.



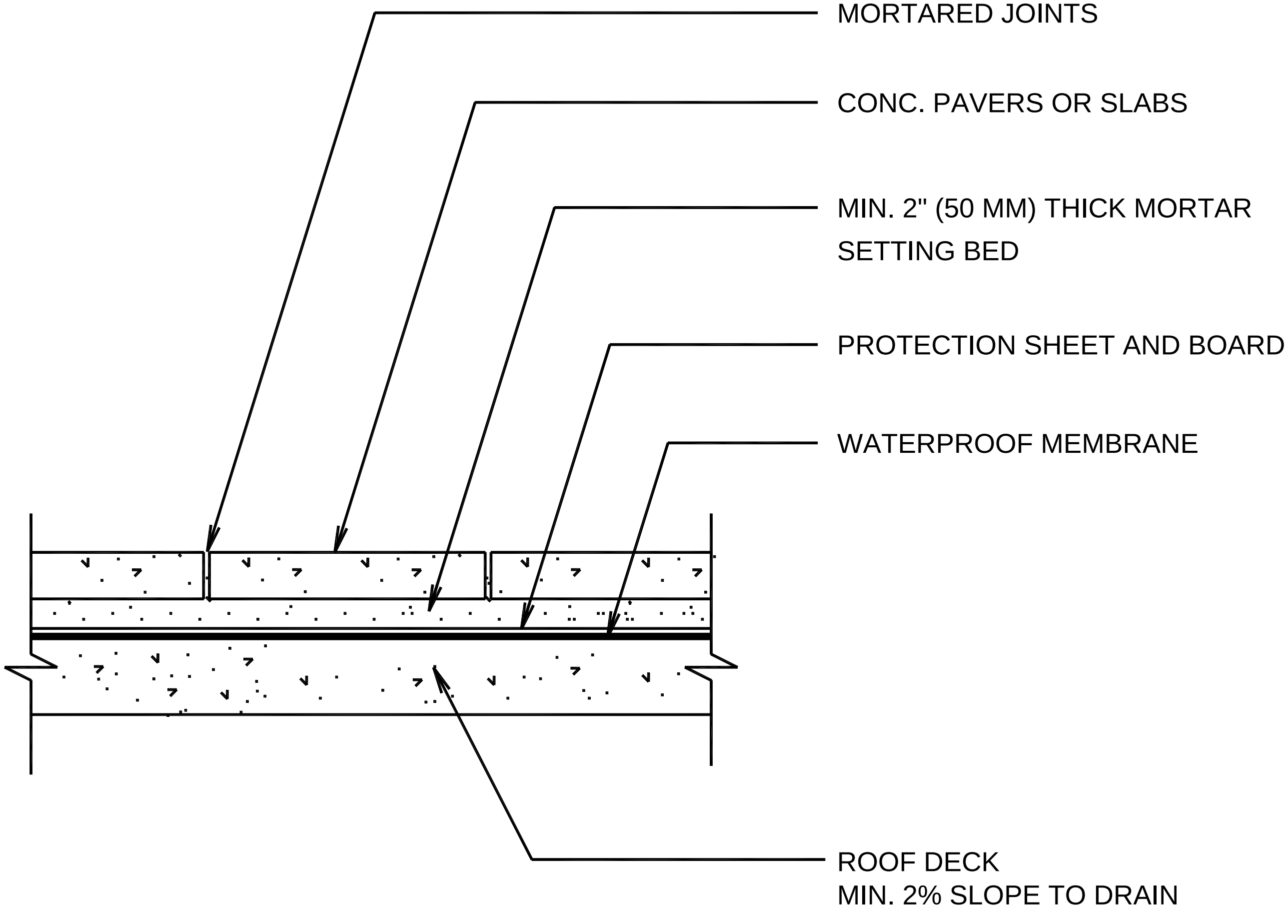
PAVING SLABS BITUMINOUS SET FOR SIDEWALKS

DRAWING NO.	ICPI-65
SCALE	F.S.



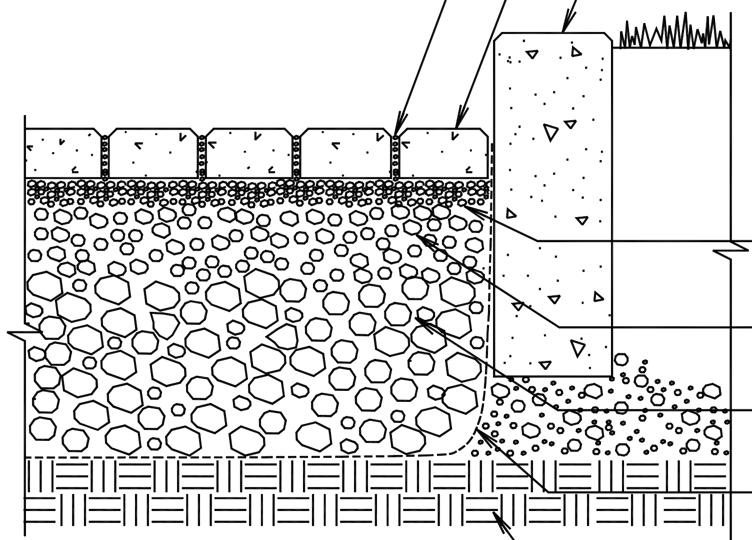
PAVING SLABS FOR ROOF PLAZA DECKS

DRAWING NO.	ICPI-66
SCALE	F.S.



ROOF PLAZA DECK- PAVING SLABS ON MORTAR SETTING BED

DRAWING NO.	ICPI-67
SCALE	F.S.

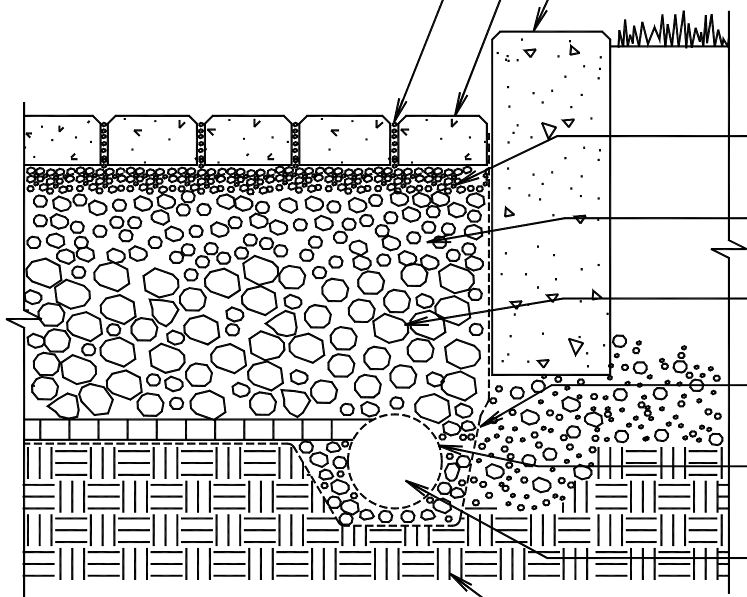


NOTES:

1. 2 3/8" (60 MM) THICK PAVERS MAY BE USED IN PEDESTRIAN APPLICATIONS.
2. NO. 2 STONE SUBBASE THICKNESS VARIES WITH DESIGN.
   CONSULT ICPI PERMEABLE INTERLOCKING CONCRETE PAVEMENT MANUAL.

PERMEABLE PAVEMENT WITH FULL EXFILTRATION TO SOIL SUBGRADE

DRAWING NO.	ICPI-68
SCALE	NO SCALE

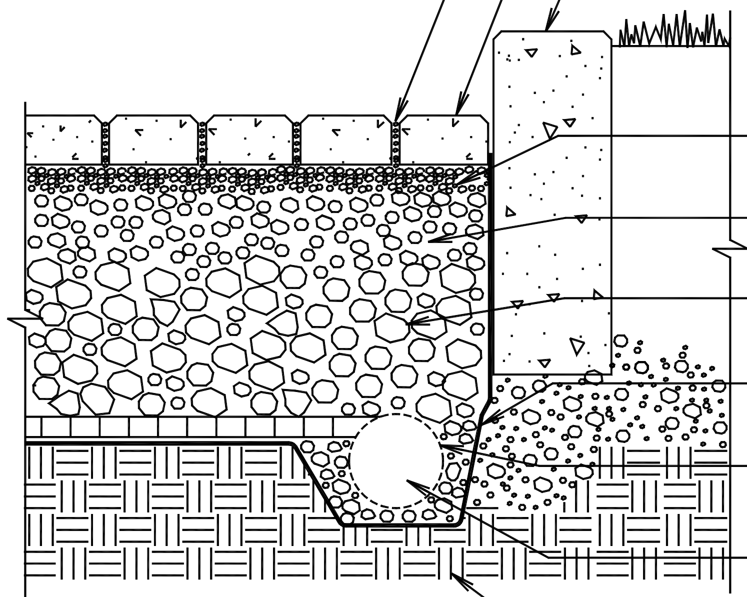


NOTES:

1. 2 3/8" (60 MM) THICK PAVERS MAY BE USED IN PEDESTRIAN APPLICATIONS.
2. NO. 2 STONE SUBBASE THICKNESS VARIES WITH DESIGN.
   CONSULT ICPI PERMEABLE INTERLOCKING CONCRETE PAVEMENT MANUAL.

PERMEABLE PAVEMENT WITH PARTIAL EXFILTRATION TO SOIL SUBGRADE

DRAWING NO.	ICPI-69
SCALE	NO SCALE

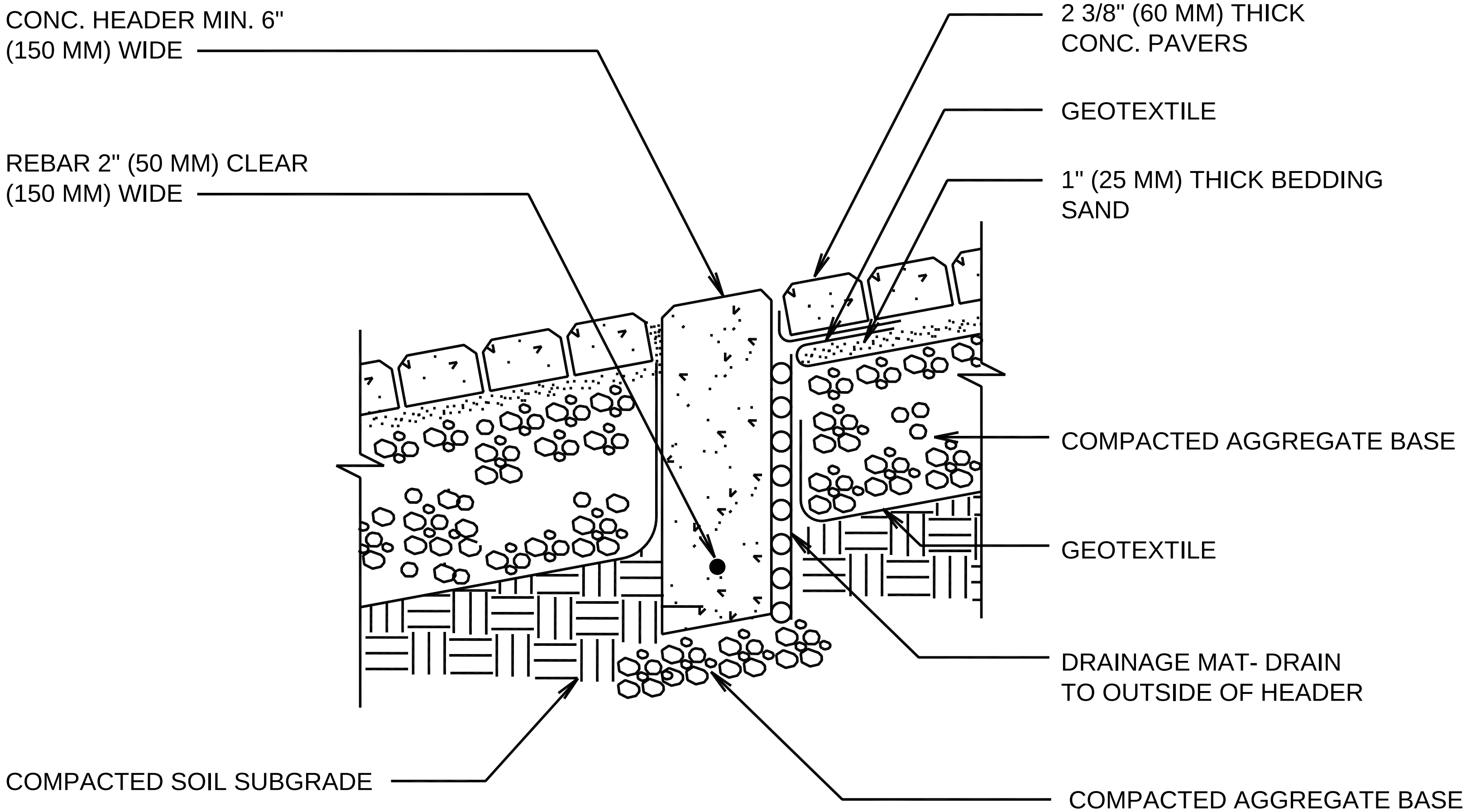


NOTES:

1. 2 3/8" (60 MM) THICK PAVERS MAY BE USED IN PEDESTRIAN APPLICATIONS.
2. NO. 2 STONE SUBBASE THICKNESS VARIES WITH DESIGN.
   CONSULT ICPI PERMEABLE INTERLOCKING CONCRETE PAVEMENT MANUAL.

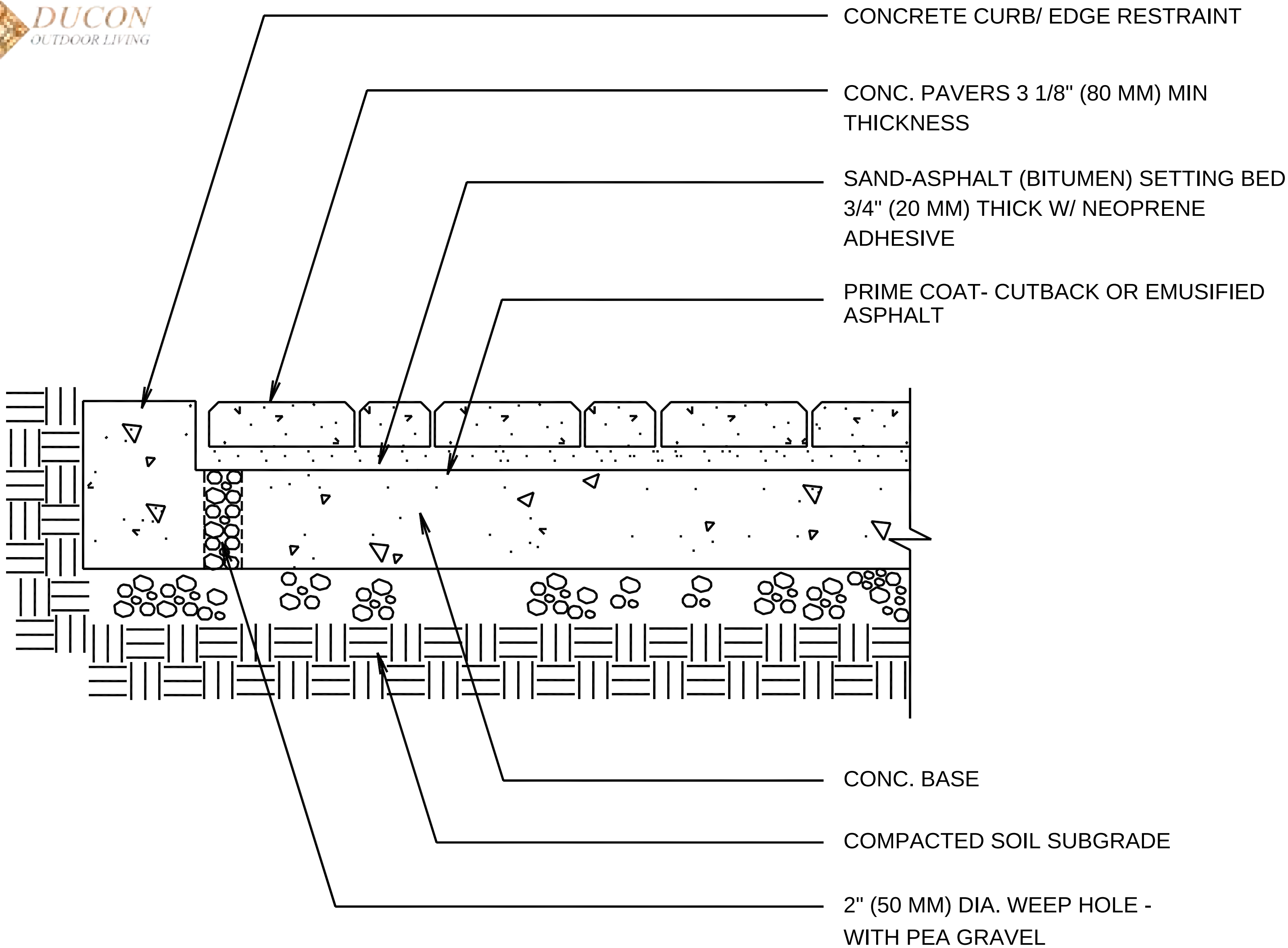
PERMEABLE PAVEMENT WITH NO EXFILTRATION TO SOIL SUBGRADE

DRAWING NO.	ICPI-70
SCALE	NO SCALE



HEADER FOR HIGH SLOPE WALK/ RESIDENTIAL DRIVEWAY

DRAWING NO.	ICPI-71
SCALE	F.S.



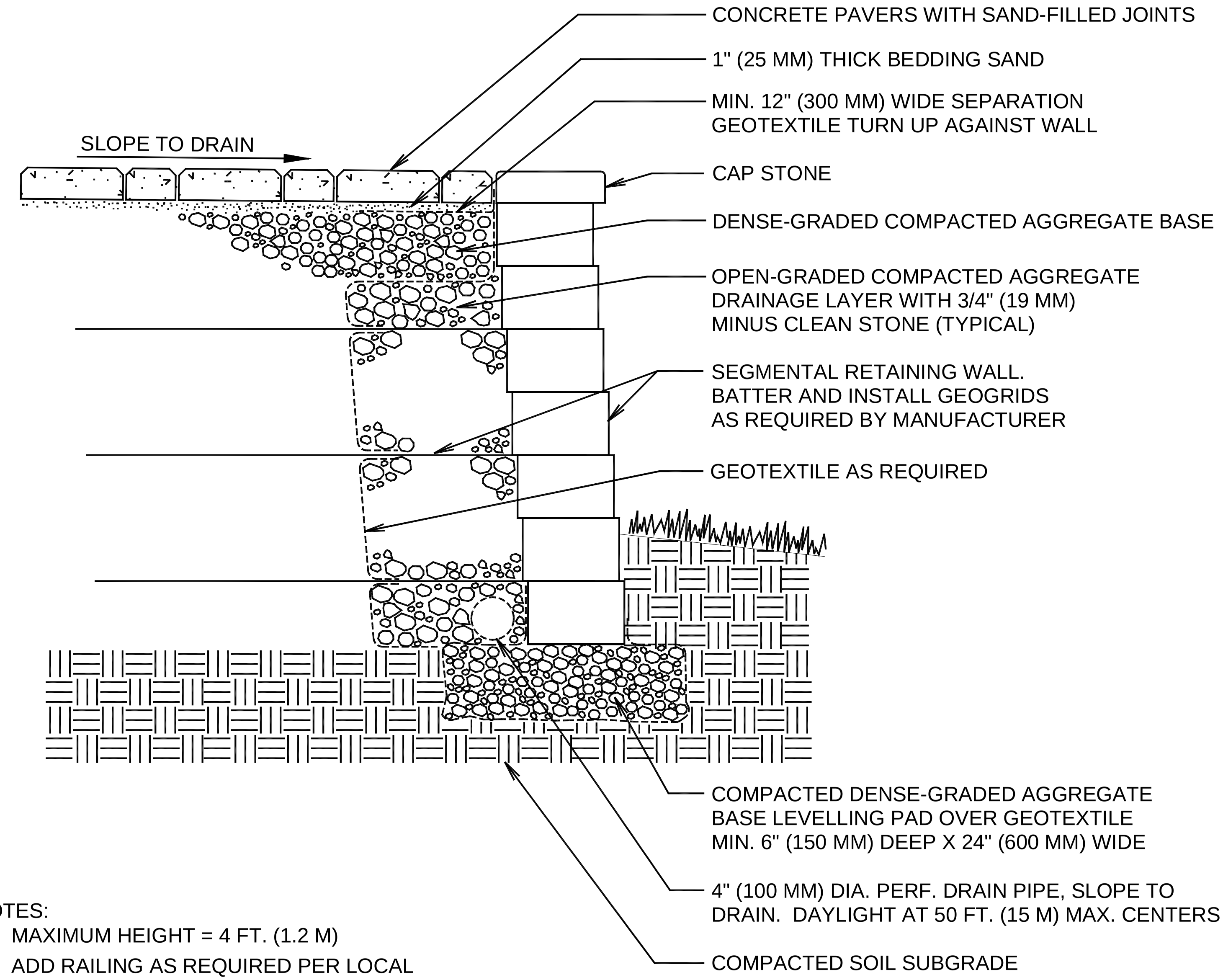
NOTES:

1. DO NOT COVER WEEP HOLES WITH SAND-ASPHALT SETTING BED.
2. 2 3/8 IN. (60 MM) THICK PAVERS MAY BE USED FOR PEDESTRIAN APPLICATIONS.

SAND-ASPHALT SET CONCRETE PAVERS FOR PEDESTRIANS & VEHICLES

DRAWING NO. ICPI-72

SCALE F.S.



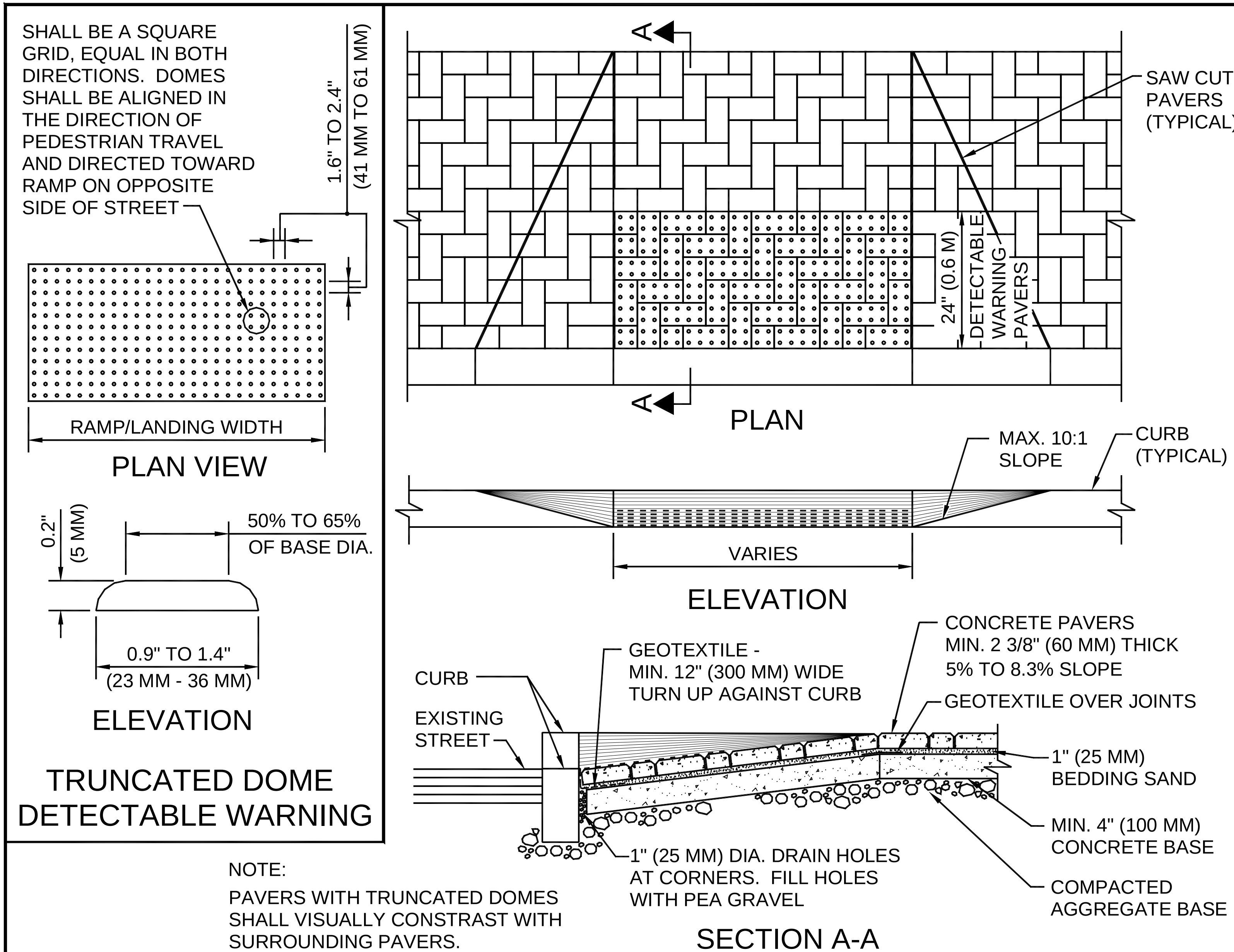
NOTES:

1. MAXIMUM HEIGHT = 4 FT. (1.2 M)
2. ADD RAILING AS REQUIRED PER LOCAL BUILDING CODE.

RAISED PATIO

DRAWING NO. ICPI-73

SCALE: NO SCALE



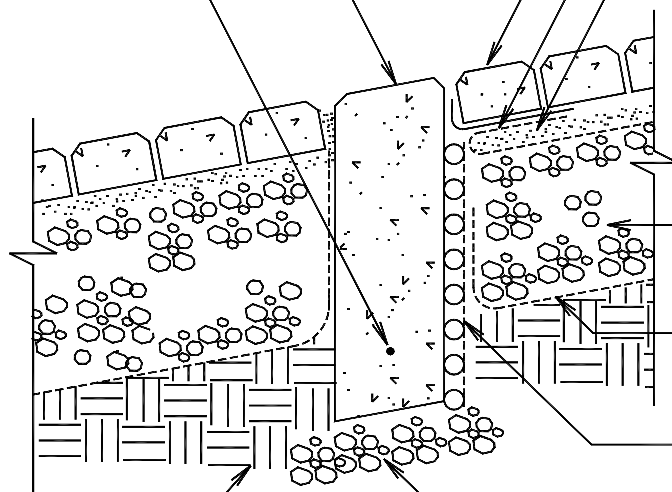
NOTE:
PAVERS WITH TRUNCATED DOMES SHALL VISUALLY CONSTRAST WITH SURROUNDING PAVERS.

CURB RAMP WITH DETECTABLE WARNINGS

DRAWING NO. ICPI-75

SCALE NO SCALE

DUCON OUTDOOR LIVING



HEADER FOR HIGH SLOPE WALK/ RESIDENTIAL DRIVEWAY

DRAWING NO.	ICPI-76
SCALE	NO SCALE

Construction Tolerances and Recommendations for Interlocking Concrete Pavements

Note: This guide does not apply to permeable interlocking concrete pavements

icpi
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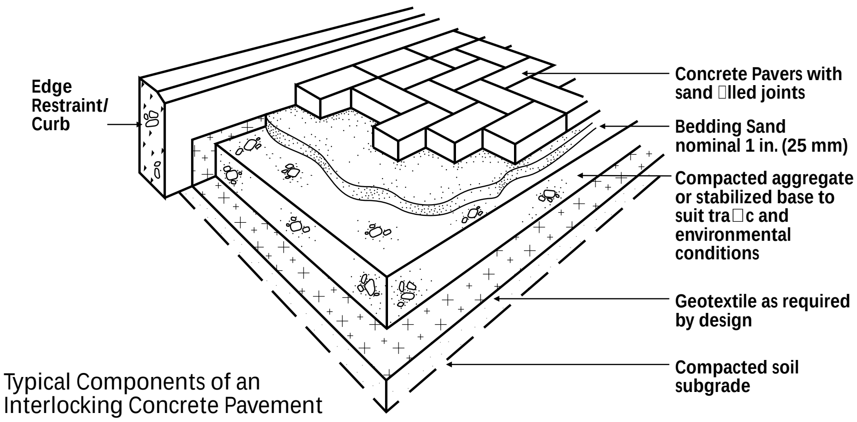
These are the basic guidelines. Review related Tech Specs for specific details. These tolerance and recommendations are applicable to most products, but allowances may be required for tumbled, embossed or other unique products. Consult manufactures recommendations.



Typical Components of an Interlocking Concrete Pavement

Paver and bedding layer

Attribute	Tolerance*
Paver joint width	1/16 in. (2 mm) to max 3/16 in. (5 mm)
Paver surface flatness	±3/8 in.(10 mm) in 10 ft. (3 m) (non cum.)
Lippage at catch basins/drains	1/8 in. to 3/8 in. (3 to 10 mm) (non ADA)
Lippage between individual pavers	maximum 1/8 in. (3 mm) for pedestrian access routes

Attribute	ICPI recommendation
Paver aspect ratio (l:t) (length divided by thickness)	max. 4:1 for pedestrian & driveways max. 3:1 for street/parking
Joint fill depth	max. depth of 1/4 in. measured from the bottom of the chamfer or the top surface of the paver if there is no chamfer at the time of final inspection
Bond lines[1]	±1/2 in. (13 mm) max. over 50 ft. (16 m)
Slope for drainage	min. 2%
Cut pavers[5]	No less than 1/3 for vehicular application No less than 3/8 in. (10 mm) for all other applications
Paver laying pattern[2]	Acceptable for application
Minimum paver thickness	3 1/8 in. (8 cm) for street/parking 2 3/8 in. (6 cm) for pedestrian & driveways
Bedding layer thickness	1 in. (25 mm) nominal
Joint sand gradation	ASTM C144 or C33 CSA A23.1 FA1 or CSA A179
Bedding sand gradation	ASTM C33 or CSA A23.1 FA1

Base and subbase layer

Attribute	Tolerance*
Top of base surface variation	± 3/8 in. (10 mm) over 10 ft. (3 m) (non cumulative)

Attribute	ICPI recommendation
Base thickness variation[3]	+ 3/4 in. to -1/2 in. (+20 mm to -13 mm)
Compaction	min. 98% standard Proctor
Base Extensions	see table below
Geotextile	as needed

Base Thickness in. (mm)	Base Extension in. (mm)
Up to 6 (150)	6 (150)
6 to 10 (150 to 250)	equals base thickness
10 to 20 (200 to 500)	10 (250)
20 (500) or greater	1/2 base thickness

Minimum base thickness[4]

Sidewalks, patios, pedestrian	4 in. (100 mm)
Residential driveways	6 in. (150 mm)
Parking lot/residential street	8 in. (200 mm)

Edge restraint/curb edge

Attribute	ICPI recommendation
No movement	firmly in place
Proper restraint	acceptable for application (see "Guide References" on reverse)

Notes:

[1] Bond lines: Unless it is deemed that the pavement is not adequately restrained at the edges the bond line tolerance is considered cosmetic

[2] Paving layer pattern: ICPI recommends herringbone laying pattern for all vehicular applications

[3] Base thickness variation: An example of an acceptable variation is 7 1/2 in. to 8 3/4 in. (190 to 220 mm) for an 8 in. (200 mm) required total base thickness. The excavated cut should have the same slope and contouring as the final surface profile.

[4] Minimum base thickness: These are for well drained soils. Increase thickness in colder climates or weak soils.

[5] The contractor should have the discretion on cuts less than 1/3 paver size. Sometimes it is not possible to adjust the cuts to 1/3 paver size without adjusting laying pattern, and sometimes it is not possible to adjust laying pattern with certain shapes.

*See reverse for tolerance measurement guidance

Interlocking Concrete Pavement Institute • 14801 Murdock Street, Suite 230 • Chantilly, VA 20151
Tel: (703) 657-6900 • Fax: (703) 657-6901 • Email: icpi@icpi.org • Web: icpi.org

Guide References

Specification and design references

ASCE 58-16 Structural Design of Interlocking Concrete Pavements for Municipal Streets and Roadways

ICPI Tech Spec 4–Structural Design of Interlocking Concrete Pavement for Roads and Parking Lots

ICPI Tech Spec 9–Guide Specification for the Construction of Interlocking Concrete Pavement

Pavement system references

ASTM C936 Standard Specification for Solid Interlocking Concrete Paving Units

CSA A231.2 Precast Concrete Pavers

ICPI Tech Spec 1–Glossary of Terms for Segmental Concrete Pavement

ICPI Tech Spec 2–Construction of Interlocking Concrete Paveme

ICPI Tech Spec 4–Structural Design of Interlocking Concrete Pav for Roads and Parking Lots

ICPI Tech Spec 5–Cleaning, Sealing and Joint Sand Stabilization Interlocking Concrete Pavement

Bedding and joint sand references

ASTM C33 Standard Specification for Concrete Aggregates

CSA A23.1 Concrete Materials and Methods of Construction

ASTM C144 Standard Specification for Aggregate for Masonry M

CSA A179 Mortar and Grout for Unit Masonry

ICPI Tech Spec 17–Bedding Sand Selection for Interlocking Conc Pavements in Vehicular Applications

Base, subbase and subgrade layer references

ASTM D 2940 Standard Specification for Graded Aggregate Material For Bases or Subbases for Highways or Airports

ICPI Tech Spec 2–Construction of Interlocking Concrete Pavements

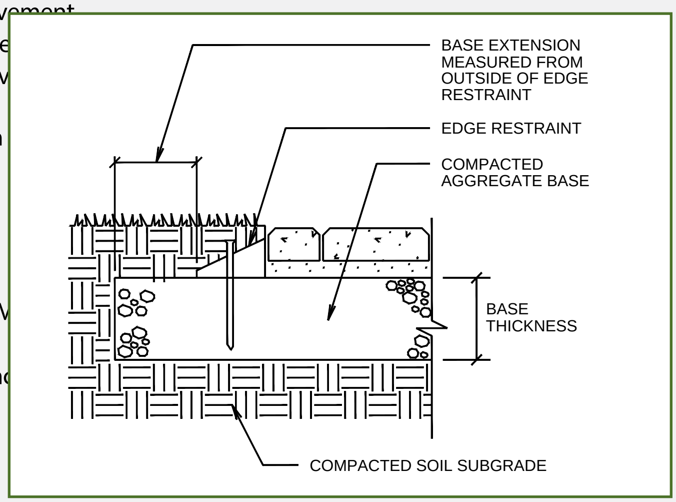
ASTM D698 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort

Edge restraint references

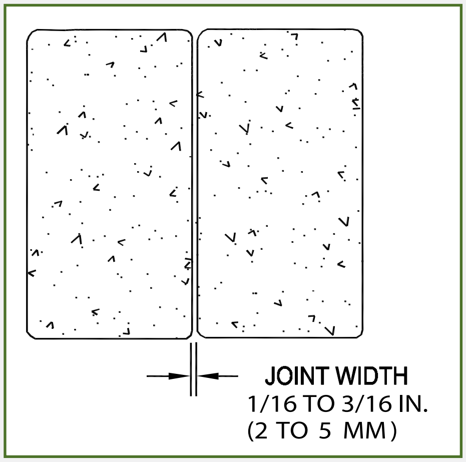
ICPI Tech Spec 3–Edge Restraints for Interlocking Concrete Pavements

Geosynthetics reference

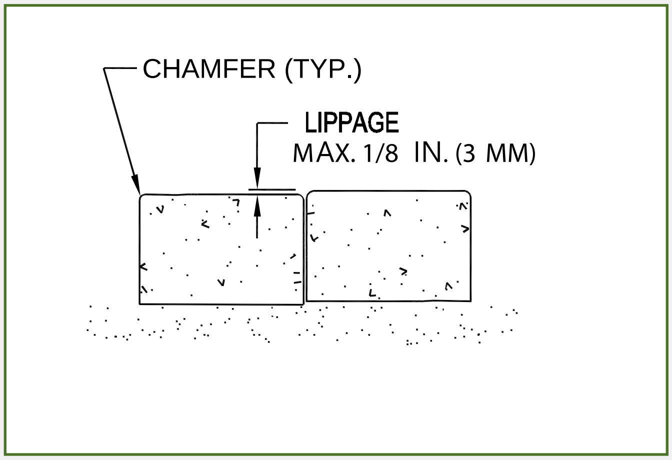
Tech Spec 22 –Geosynthetics for Segmental Concrete Pavements



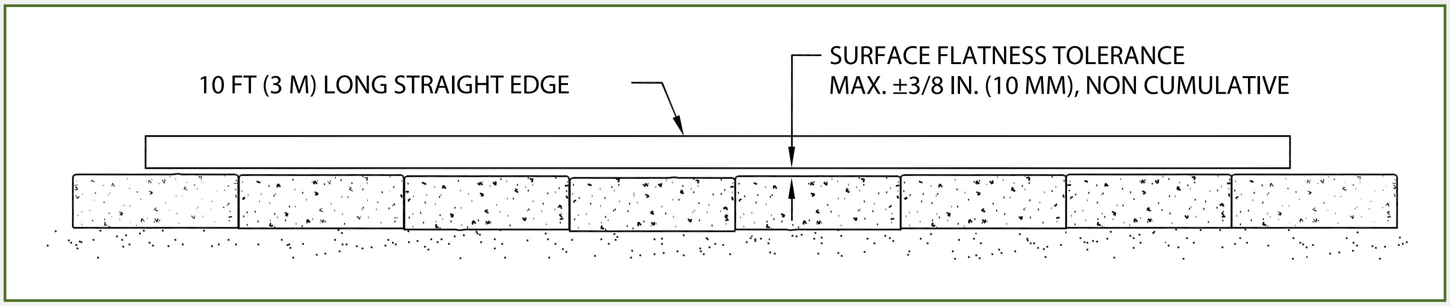
Tolerance Measurement Guidance



Joint widths are measured with a ruler from inside edge of paver to inside edge paver between adjacent pavers



Lippage is measured from the top of a paver to the top of the adjacent paver



Paver surface flatness and top of base surface variation are measured with a straight edge for simple slopes and complex contours

Recommended Construction Tolerances for Permeable Interlocking Concrete Pavements

Permeable interlocking concrete pavements comprise a system of unique components providing durable pedestrian and vehicular surfaces in all climates. This document provides achievable construction tolerances that contribute to structural and hydrologic performance that support stormwater management objectives.

Note: This guide does not apply to standard interlocking concrete pavements

Rev. 2021-09

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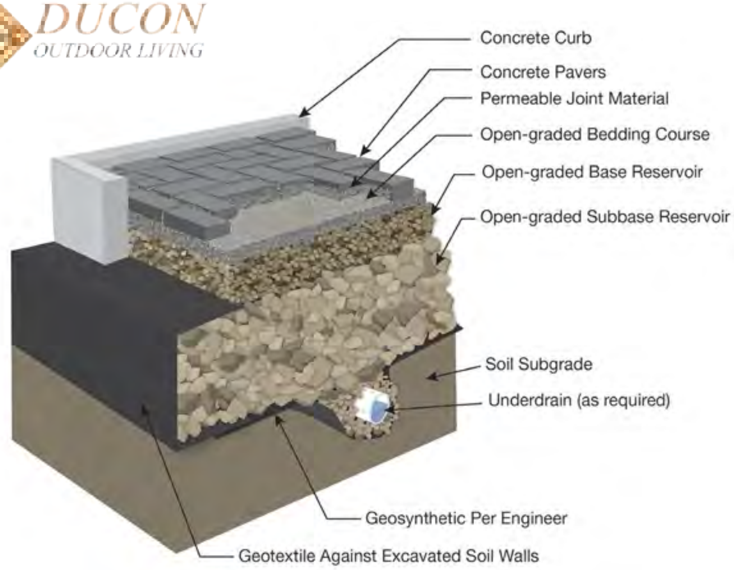


The following are basic guidelines for permeable interlocking concrete pavement (PICP) installations. Review related ICPI Tech Specs for **specific details. These tolerances and** recommendations are applicable to most PICP products, but allowances may be required for tumbled, embossed or other unique products. Consult manufacturer's recommendations.

Minimum offsets

Attribute	ICPI recommendation
Wells and surface water	100 ft. (30 m)
Foundations	10 ft. (3 m) unless protected by waterproofing and underdrains
Water table and bedrock	24 in. (600 mm)

Paver and bedding layer

Attribute	Tolerance (see page 4 detail)
Paver joint width	Min. 3/16 in. (4.5 mm) to max. 1/2 in. (13 mm)
Paver surface flatness	±3/8 in. (10 mm) over a 10 ft. (3 m) straight edge (non cumulative)
Lippage at catch basins/drains	Min. 1/8 in. (3 mm) to max. 1/4 in. (6 mm) for ADA compliance or max. 3/8 in. (10 mm) for non-ADA
Lippage between individual pavers	Max. 1/8 in. (3 mm)
Top of bedding surface variation	± 3/8 in. (10 mm) over 10 ft. (3 m)

Attribute	ICPI recommendation
Paver aspect ratio (length : thickness)	Max. 3:1 for streets, parking and driveways Max. 4:1 for pedestrian
Paver thickness	Min. 3 1/8 in. (80 mm) for streets, parking & driveways Min. 2 3/8 in. (60 mm) for pedestrian
Bond lines	Max. ±1/2 in. (13 mm) over a 50 ft. (16 m) taut stringline
Surface Slope	Typically 0% to 5%
Cut pavers[1]	Min. 1/3 of full-size unit for vehicular application Min. 2 in. (50 mm) long for all other applications
Paver laying pattern[2]	Acceptable for application
Joint fill depth	Max. depth of 1/4 in. (6 mm) measured from the bottom of the chamfer, or the top surface of the paver if no chamfer, at the time of final inspection
Joint aggregate gradation	Washed ASTM No. 8, 89 or 9 stone or CSA Group II 10-5 or 5-2.5 Coarse Aggregate
Bedding layer thickness	2 in. (50 mm) nominal
Bedding aggregate gradation	Washed ASTM No. 8 stone or CSA Group II 10-5 Coarse Aggregate
Infiltration rate	Minimum 100 in./hr (2,540 mm/hr) at the time of final inspection per ASTM C1781

[1] The contractor should have the discretion on making cuts less than 1/3 paver size. Sometimes it is not possible to adjust the cuts to less than 1/3 paver size without adjusting laying pattern, and sometimes it is not possible to adjust laying pattern with certain shapes.
[2] Paving layer pattern: ICPI recommends herringbone laying patterns for all vehicular applications.

Base and subbase layer

Attribute	Tolerance (see page 4 detail)	
Top of base surface variation	± 1/2 in. (13 mm) over 10 ft. (3 m)	
Top of subbase surface variation	± 2 in. (50 mm) over 10 ft. (3 m)	

Attribute	ICPI recommendation	
Base layer thickness	4 in. (100 mm) used in vehicular applications except residential drives	
Base aggregate gradation	Washed ASTM No. 57 stone or CSA Group II 28-14 Coarse Aggregate	
Base thickness variation[3]	+ 3/4 in. to -1/2 in. (+20 mm to –13 mm)	
Compaction	Max. 0.5 mm deflection measured with LWD per ASTM E2835	
Base Extensions	Base Thickness	Base Extension
	12 in. (300 mm) or less	6 in. (150 mm)
	Greater than 12 in. (300 mm)	1/2 base thickness
Subbase layer thickness[4]	Minimum 6 in. (150 mm)	
Subbase aggregate gradation	Washed ASTM No. 2, 3 or 4 stone or CSA Group II 80-40, 56-28, 40-20 coarse aggregate	
Geosynthetics	Geotextile, geocells, geogrids or geomembrane as specified	

Subgrade

Attribute	ICPI recommendation
Subgrade compaction	As specified
Subgrade slope	0% to 2% without check dams. 2% to 5% may require check dams. Greater than 5% requires check dams.

Edge restraint/curb

Attribute	ICPI recommendation
No movement	Firmly secured in place to resist anticipated loads
Proper restraint	Acceptable for application (see "Guide References" on reverse)

Site Details

Surrounding Area	Stabilize soil and prevent washing onto PICP
Signage	As specified

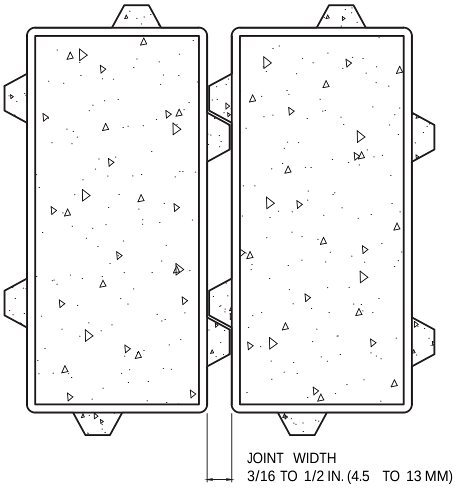
Maintenance

Attribute	ICPI recommendation
Routine Maintenance	To prevent clogging. See ICPI Tech Spec 23 on PICP Maintenance
Restorative Maintenance	Restore clogged surfaces. See ICPI Tech Spec 23 on PICP Maintenance
Other Surface Distresses	See ICPI Tech Spec 23 on PICP Maintenance

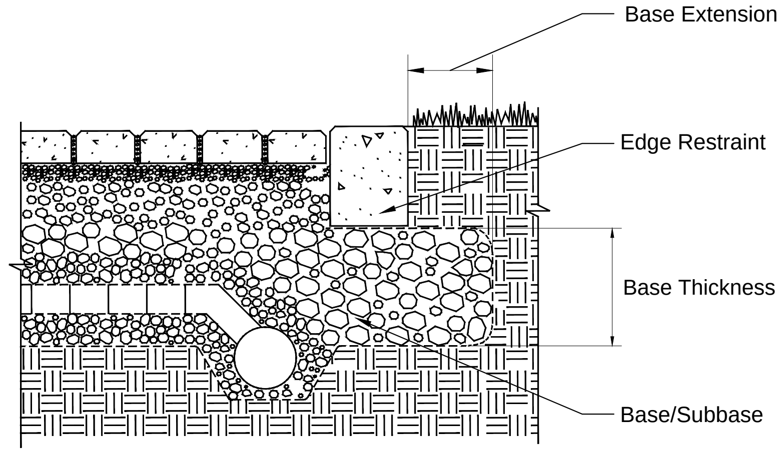
[3] Base thickness variation: An example of an acceptable variation is 3 1/2 in. to 4 3/4 in. (90 to 120 mm) for a 4 in. (100 mm) required base thickness. The surface of the excavated soil subgrade should have the same slope and contouring as the final surface profile.

[4] Subbase thickness: Structural and hydrologic analysis may require thicker subbases for weaker soils or greater storage volumes.

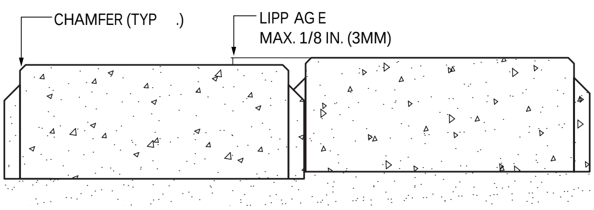
Tolerance Measurement Guidance



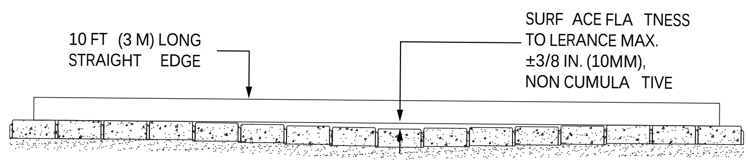
Joint widths are measured with a ruler from inside edge of paver to inside edge paver between adjacent pavers



Base extension is measured from the outside of the edge restraint to the edge of the base/subbase



Lippage is measured from the top of a paver to the top of the adjacent paver



Paver surface flatness and top of base surface variation are measured with a straight edge for simple slopes and with a transit for complex contours

Guide References

Specification and design references

ASCE 68-18 Design, Construction and Maintenance of Permeable Interlocking Concrete Pavement

ICPI Permeable Interlocking Concrete Pavements (5th Edition): Design, Specifications, Construction, Maintenance

Pavement system references

ASTM C936 *Standard Specification for Solid Interlocking Concrete Paving Units*

ASTM C1781 *Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems*

CSA A231.2 Precast Concrete Pavers

ICPI Tech Spec 1—Glossary of Terms for Segmental Concrete Pavement

ICPI Tech Spec 18—Construction of Permeable Interlocking Concrete Pavement

ICPI Tech Spec 23—Maintenance Guide for Permeable Interlocking Concrete Pavements

Base, subbase, bedding and joint aggregate references

ASTM D448 *Standard Classification for Sizes of Aggregate for Road* and Bridge Construction

(Note: Gradations in AASHTO M-43 *Sizes of Aggregate for Road and* Bridge Construction are identical to ASTM D448.)

ASTM E2835 *Standard Test Method for Measuring Deflections using* a Portable Impulse Plate Load Test Device

CSA 23.1/23.2 Concrete materials and methods of concrete construction / Test methods and standard practices for concrete

Edge restraint references

ICPI Permeable Interlocking Concrete Pavements (5th Edition): Design, Specifications, Construction, Maintenance

Geosynthetics references

AASHTO M-288—*Standard Specification for Geosynthetic Specification for Highway Applications*

Tech Spec 22—Geosynthetics for Segmental Concrete Pavements

BOD Approved: 2020-08