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Tech Spec 15

icpi
Interlocking Concrete
Pavement Institute

A Guide for the Specification of Mechanically Installed Interlocking Concrete Pavements

Introduction

This guide assists 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 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 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 consulted for additional

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.

information on design and construction with this paving method. Other references include American Society for Testing and Materials or the Canadian Standards Association for the concrete pavers, sands, and joint stabilization materials, if specified. Placement of the base, drainage and related earthwork should be detailed in another specification section and may be performed by another subcontractor or the GC.

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 paver 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.

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 written project references and contact information 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 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 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 wear 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 production machine cycles. Production records for each bundle should show the date of manufacture, a mix design designation, mold number, mold cycles and sequential bundle numbers.

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.

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 reduces the risk of clusters that will not fit easily against 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 present on the site, and anticipated average daily installation rate in square feet (m^2).
9. Submit the paver manufacturer's pallet configuration 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 work day.

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 paving products or materials 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 2012.) 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.

ASTM C 936 includes the following requirements:

1. Absorption: 5% average with no individual unit greater than 7% per ASTM C 140 (ASTM 2012).
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.
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.
2. Freeze-thaw deicing salt durability: average weight loss not exceeding 225 g/m2 of surface area after 28 cycles or 500 g/m2 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 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

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.

±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. Independent laboratory 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 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.

One paver manufacturing machine can produce approximately 125,000 sf (12,500 m^2) in five days. 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 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

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 1. 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 2. Gradation for Joint Sand

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 1. 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 3 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 (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 2. 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

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 3. Recommended Laboratory Material Properties for Bedding and Joint Sands in Vehicular Applications

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.

Figure 7. Maintaining an angular laying face that resembles a saw-tooth pattern facilitates installation of paver clusters.

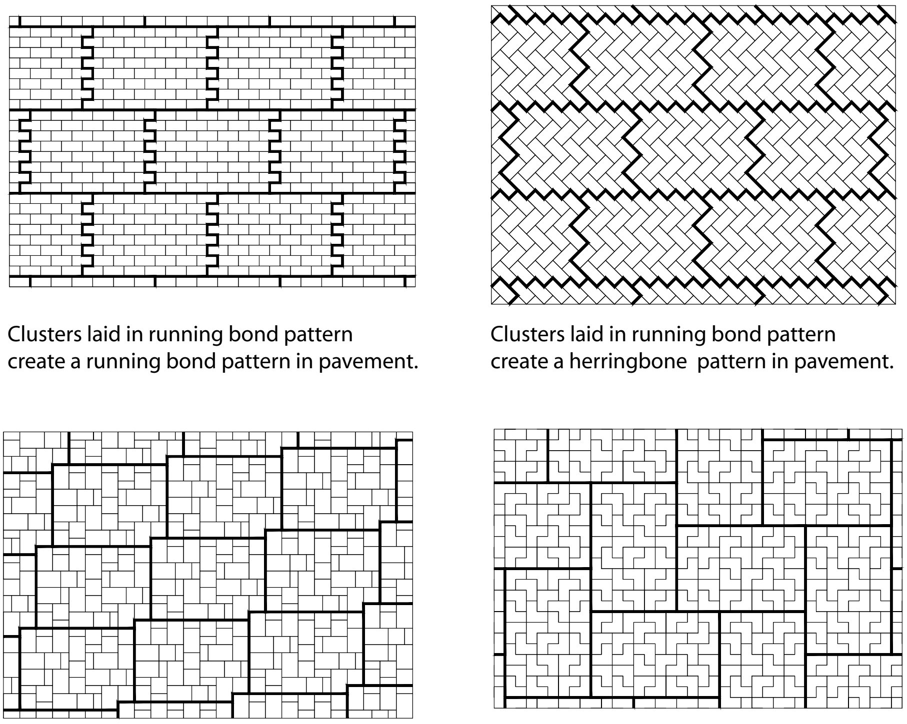
Variations in the surface of the base must be repaired prior to installation of the bedding sand. The screeded bedding course should not be exposed to foot or vehicular traffic. Fill voids created by removal of screed rails or other equipment with sand as the bedding proceeds. The screeded bedding sand 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. Maximizing interlock among clusters and throughout the pavement surface is assisted by the placement pattern of the clusters. To help maximize the interlock between clusters, installations should avoid straight, continuous bond lines throughout the pavement surface. Rotating clamps on mechanical placement equipment facilitate easier clusters placement in patterns that do not create continuous joint lines.

Paver cluster configuration determines stitching as well as possible cluster placement. Some pavers clusters created with dentated paving units mesh into each other and do not require stitching. If the cluster pattern has half-sized paver units, offset their locations when placing clusters or maintain their alignment, remove and fill openings with full-sized pavers, thereby stitching and interlocking each cluster with its neighbors. Just as the paving pattern can affect the pavement strength and stability under vehicular traffic, so can the placement pattern of clusters. Clusters placed in herringbone patterns offer increased stability over clusters placed in a running bond patterns. This supports the recommended use of herringbone patterns in vehicular areas.



Clusters laid in running bond pattern create a running bond pattern in pavement.

Clusters laid in running bond pattern create a herringbone pattern in pavement.

Notched clusters create horizontal and vertical shifts in the cluster pattern that minimize long continuous bond lines.

Rectangular clusters laid in a herringbone pattern minimize long continuous bond lines.

Figure 8. Cluster patterns

Figure 9. Edge pavers are saw cut to fit against a drainage inlet.

Figure 10. Initial compaction sets the concrete pavers into the bedding sand.

Figure 11. During initial compaction, cracked pavers are removed and immediately replaced with whole units.

Different laying and cluster patterns are shown in Figure 8. The need to maximize interlock among clusters with stitching depends on expected vehicular loads. For lower load applications, stitching may not be needed. In some cases stitching is done more for aesthetic reasons. For higher load applications, herringbone patterns or stitching clusters together may be required. The cluster configuration pattern and stitching (if required) 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 9 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 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 10). After initial compaction, remove cracked or broken pavers, and replace with whole units. Figure 11 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 12 and 13). The number of passes and effort required to produce completely filled joints depends 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

Figure 12. Sweeping jointing sand across the pavers is done after the initial compaction of the concrete pavers.

Figure 13. Final compaction should consolidate the sand in the joints of the concrete pavers.

Figure 14. A simple test with a putty knife checks consolidation of the joint sand.

sweeping and vibration so it can enter the joints readily. Vibrate and fill 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 and final compaction. Inspection should keep up with the paving so as to not delay its progress. There may be the occasional case where the 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 subcontractor, inspection schedules, and weather. Therefore, the engineer may establish a maximum distance from the laying 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 condition makes the bedding course impossible to compact.

3.2.1 Joint Sand Consolidation

After the final compaction of the sand in the joints, 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 measurements of joint sand depth and consolidation. Take measurements by inserting a thin, rigid putty knife into the joint and pressing down. See Figure 14. 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.

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 possible 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 pavers until completion of paving. This requires close coordination 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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Figure 14. The Port of Oakland, California, is the largest mechanically installed project in the western hemisphere at 4.7 million sf (470,000 m^2).

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