A SPECIFICATION GUIDE FOR MECHANICALLY INSTALLED INTERLOCKING CONCRETE PAVEMENTS

Smith, D.R.

Interlocking Concrete Pavement Institute, 1444 I Street, N.W.: Suite 700
Washington, DC 20005 USA. Tel: (202) 712 9036. Fax: (202) 408 0285.
E-mail: dsmith@bostromdc.com

ABSTRACT

A commitment to coordination and quality paving among the manufacturer, paver installation subcontractor and GC has happened informally on many successful mechanically installed projects in the past. Informally means with little quality control/quality assurance procedures in the project specifications, expressed as method statements for testing paving materials and for their installation. In response to this need, the Interlocking Concrete Pavement Institute has published a specification guide for mechanical installation. This is for designers and potential owners of large paving facilities in North America. It formalizes quality control and quality assurance procedures similar to those found in large-scale asphalt and cast-in-place concrete paving specifications. The North American interlocking concrete pavement industry will compete more effectively against these pavement systems when it uses the same rigor in specifications, testing, and inspection for quality control currently done with asphalt and cast-in-place concrete paving.

The guide follows a common structure for construction specification formats in North America. These formats divide the specification into three parts, Part 1 - General, Part 2 - Products, and Part 3 - Execution. The core of the guide is the Quality Control Plan that requires a high level of planning and detail for executing large-scale paving projects. When refined into a project specification, it can 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 of receiving a durable pavement by owners of large paved facilities.

1. GENERAL

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 subcontractor purchases pavers from a paver manufacturer. The Engineer or employees working for the owner inspect and accept the paving.

Construction specifications in North America follow various formats. A common format is by the Construction Specifications Institute called MasterFormat (CSI, 1995) and this guide is written to fit that format. Division 02, Section 02785 where interlocking concrete pavement is typically specified. CSI should be contacted as major changes are underway for MasterFormat (see www.csinet.org). Sections have three parts, General, Products, and Execution. This guide is divided into these three parts.

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

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11, *Mechanical Installation of Interlocking Concrete Pavements* (ICPI, 1998) should be consulted for additional information on design and construction with this paving method. Other references will include American Society for Testing and Materials (ASTM) and the Canadian Standards Association (CSA) for the concrete pavers, sands, and joint stabilization materials. Other subcontractors or the GC provides the base, drainage, and earthwork.

1.1 Definitions

The following definitions apply:

- *Base*: Layer(s) of material under the wearing 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.
- *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 filling sand*: Sand used to fill spaces between concrete pavers.
- *Joint sand stabilizer*: A stabilizer capable of sufficiently penetrating joint sand prior to polymerization. Joint sand stabilization materials are optional and may be of value if additional stabilization of joint sand is desired. They are liquid penetrating and dry mix additives.
- *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 whose edges are chamfered.

1.2 Submittals

The following is submitted by the GC to the Engineer for review and approval:

- 14 pavers with the date of manufacture marked on each. These can be made available for testing.
- Manufacturer's catalog cut sheets and production mold drawings.
- The stitching pattern for joint clusters when the pavers are placed on the bedding sand.
- 3 kg bedding sand.
- 3 kg joint filling sand.
- Manufacturer's catalog cut sheets of joint stabilization material (if specified).
- 1 liter joint sand stabilizer or joint sand additive (if specified).
- 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 manufactured or processed 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:
- Quality Control organization chart with the names, qualifications, and contact information of responsible personnel, and each individual's area of responsibility and authority.
- A listing of outside testing laboratories employed by the GC and a description of the services provided and the tests performed by GC personnel.
- Preparation and maintenance of a Testing Plan containing a listing of all tests to be performed by the GC and the frequency of testing.
- Procedures for ensuring that tests are conducted according with the Plan including documentation and steps for taking corrective actions if materials do not meet criteria for meeting the standards.
- The paver installation Subcontractor's method statement.

1.3.1 Quality Control Plan Elements

Testing - Independent testing laboratory (ies) 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 should 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 perform the paver installation 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 is 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 prior to manufacture of concrete pavers for this project. This is needed because as delivered production molds may vary in overall cluster size. Mixing pavers from a larger mold with a smaller mold may cause installation problems. 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. A baseline measurement of all mold cavities provides starting point for documenting and planning for mold cavity growth.
3. 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.

If large enough, variation in cluster size can reduce mechanized paving productivity, thereby increasing costs and lengthening production schedules. 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 with 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 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:

- Demonstrate past use of mechanical installation by key staff on single projects having a similar application and loads.
- 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.
- List the experience and certification of field personnel and management who will execute the work.
- Provide personnel operating mechanical installation and screeding equipment on job site with prior experience on a job of similar size.
- Report methods for checking slope and surface tolerances for smoothness and elevations.
- Show a means for recording actual daily paving production, including identifying the site location and recording the number of bundles installed each day.
- 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 affect the flow of materials can change throughout the project.
- Provide the number of paver installation machines to be present on the site, and anticipated average daily installation rate in square feet (m^2).
- Provide a diagram, including dimensions, of the typical cluster or layer to be used.
- Provide a diagram of the stitching pattern used to join clusters including a statement about or illustration of the disposition of half-paver, if any.
- The Subcontractor and Manufacturer are encouraged to hold memberships in the Interlocking Concrete Pavement Institute.

1.4 Mock Up

A test area or mock up is necessary to demonstrate competence and efficiency of the paver installation subcontractor, and to serve as an example of compliance with the construction documents. This area is constructed prior to starting full paving activities. The mock-up area should be at least 100 m^2. The mock-up should be retained and used as a standard for judging the remainder of the work. When accepted by the Engineer, the mock-up should remain in an undisturbed condition for periodic referencing against the work in progress. At the time of substantial completion of paving, the mock-up may become part of completed work.

At a minimum, the mock-up should demonstrate the items listed below:

- Efficient, uninterrupted use of all mechanical installation and screeding equipment.
- The quality of workmanship that will be produced for the remainder of the project including cut pavers at edges, paver border courses, paver pattern(s) in the field of pavement, laying face configuration, cluster placement and offsets, stitching of half or full pavers among clusters, pattern direction, typical surcharge and compaction depth of bedding sand and pavers, typical joint widths, joint lines, joints filled with consolidated sand, typical application sand stabilizer, if specified.
- A demonstration of the typical methods for inspection and acceptance of existing site conditions, cleaning of base surfaces in preparation for paving, dimensional control procedures for the clusters, placement of the bedding sand, placement of the pavers, initial compaction of the pavers into the bedding sand, stitching and adjusting of pavers, complete installation of the joint sand and fullness of joints, cleaning of the paver surface, paver cutting, site clean up, end-of-day installation and site conditions, and techniques for protecting materials and work from inclement weather.

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, Contractor, 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. PRODUCTS

2.1 Concrete Pavers

In North America, concrete pavers should meet ASTM C 936 (ASTM, 2001) in the United States or CSA A231.2 (CSA, 1995) 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.

ASTM C 936 includes the following requirements:

- Absorption: 5% average with no individual unit greater than 7% per ASTM C 140 (ASTM, 2001).
- Abrasion resistance: No greater volume loss than 15 cm^3 per 50 cm^2 and average thickness loss shall not exceed 3 mm when tested in accordance with Test Method ASTM C 418 (ASTM, 1998).
- Compressive strength: Average 55 MPa, with no individual unit below 50MPa when tested according to ASTM C 140. If whole pavers are tested, an adjustment factor should be multiplied by the tested compressive strength per Table 1 below to compensate for the height of the unit:

Table 1. Adjustment factors for compressive strength of concrete pavers with various thicknesses.

Nominal Thickness	Multiply Tested Compressive Strength by
3 1/8 in. (80 mm)	1.18
4 in. (100 mm)	1.24
4 ¾ in. (120 mm)	1.33

If cut coupons (half paver) 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:

- Compressive strength: Average 50 MPa at 28 days with no individual unit less than 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.
- Freeze-thaw deicing salt durability: average weight loss not exceeding 200 g/m^2 of surface area after 25 cycles or 500 g/m^2 after 50 cycles. This requirement can be omitted for projects not subject to deicing salts. However, the test method and criteria should be applied to all projects in North America subject to deicing salts, and not just those in Canada.

The CSA freeze-thaw deicing salt test (or freeze-thaw durability test) 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 CSA A231.2. Once this requirement is met, the Engineer should consider obtaining freeze-thaw 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 ±1.6 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 ±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 take the place of any testing required for quality control during production.

For the initial testing frequency, randomly select 14 full-size pavers from initial lots of 2,500 m^2 manufactured for the project, or when any change occurs in the manufacturing process, mix design, cement, aggregate or other materials. 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 12,500 m^2 of pavers, then reduce the testing frequency for each test to one full-sized paver from each 2,500 m^2 manufactured. If any pavers fail any of these tests, then revert to the initial testing frequency.

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 nonconformance of 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, 1995) as appropriate with modifications as noted in Table 2. Supply washed, natural or manufactured, angular sand.

Table 2. Grading requirements for bedding sand.

ASTM C 33		**CSA A23.1-FA1**	
Sieve Size	**Percent Passing**	**Sieve Size**	**Percent Passing**
3/8 in. (9.5 mm)	100	10 mm	100
No. 4 (4.75 mm)	95 to 100	5 mm	95 to 100
No. 8 (2.36 mm)	85 to 100	2.5 mm	80 to 100
No. 16 (1.18 mm)	50 to 85	1.25 mm	50 to 90
No. 30 (0.600 mm)	25 to 60	0.630 mm	25 to 65
No. 50 (0.300 mm)	10 to 30	0.315 mm	10 to 35
No. 100 (0.150 mm)	2 to 10	0.160 mm	2 to 10
No. 200 (0.075 mm)	0 to 0.5	0.075 mm	0 to 0.5

At the start of the project, conduct gradation tests per ASTM C 136 (ASTM, 2001) or CSA A23.2A (CSA, 2000) for every 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 Lilley-Dowson (Lilley, 1988) sand degradation test should be conducted to assess the durability of the bedding sand. The test method is as follows. Obtain a representative sand sample weighing 1.5 kg. The sample is dried for 24 hours or to a constant weight in a thermostatically controlled oven at a temperature of 115-120° C. Obtain three sub-samples each weighing 0.5 kg by passing the main sample several times through a riffle box. Conduct a sieve analysis test in accordance with ASTM C 136 on each sample. Remix each sub-sample and place in a 125 mm diameter liter nominal capacity porcelain jar together with two 25 mm diameter steel ball bearings each with a mass of 75 ±5 g. Place each jar on a bottle roller to rotate at 50 rpm for a period of six hours. Repeat the sieve analysis on each sub-sample. Report the individual and mean sieve analysis. The samples shall comply if the maximum average increase in the percentages passing each sieve and the maximum individual percent passing are as follows:

Sieve Size	Max. Increase	Max. % Passing
No. 200 (0.075 mm)	2%	2%
No. 100 (0.150 mm)	5%	15%
No. 50 (0.300 mm)	5%	35%

Repeat the test for every 25,000 m^2 of bedding sand or when there is a change in sand source.

2.3 Joint Filling 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.

Table 3. Grading requirements for joint filling sand.

ASTM C 144		**CSA A179**	
Sieve Size	**Percent Passing**	**Percent Sieve Size**	**Passing**
No. 4 (4.75 mm)	100	5 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 (0.600 mm)	40 to 75	0.630 mm	65 to 95
No. 50 (0.300 mm)	10 to 35	0.315 mm	15 to 80
No. 100 (0.150 mm)	2 to 15	0.160 mm	0 to 35
No. 200 (0.075 mm)	0 to 1	0.075 mm	0 to 1

At the start of the project, conduct gradation test per for every 2,500 m^2 of concrete paver wearing course. Testing intervals may be increased upon written approval by the Engineer when 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 mix 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 13 mm prior to polymerization. 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.

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:

- Subgrade preparation, compacted density and elevations conform to specified requirements.
- Geotextiles or geogrids, if applicable, placed according to drawings and specifications.
- 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.

Larger or heavy wheel load paving will often have high strength base material such as cement stabilized base, concrete slabs, or asphalt. Even though these materials are being 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 are not as tightly controlled for grade as variations can be made up by the top lift of asphalt. When the top layer is pavers and bedding sand, compensation for variations in base 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 where 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 fill 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 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 25 mm thickness. Maintain a uniform thickness within a tolerance of ±6 mm. Allow for surcharge due to compaction of the pavers, typically 5 mm. For example, if the pavers are 80 mm thick, the elevations of the base surface should be 100 mm below the finish elevation of the pavement. The exact amount of surcharge 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 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.

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 pry bars. If the cluster pattern is shipped to the site with half-sized paver units, adjust 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. If such contact occurs, remove and replace the affected materials.

Cut pavers 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.

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 0.2 m^2 that transmits a force of not less than 0.1 MPa at 75 to 100 Hz. After initial compaction, remove cracked or broken pavers, and replace with whole units. Initial compaction should occur within 2 m of all unrestrained edges at the end of each day.

After initial compaction of the pavers, sweep and vibrate joint sand into the joints until all are completely filled with consolidated joint sand. The number of passes and effort required to produce completely filled joints will vary based on many factors. Some of these include moisture, sand gradation, sand 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 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 in completed to within 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 best practice. The surface should be placed to specified tolerances, 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 and 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 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 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 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 Proofing for Consolidation of Joint Sand
After the final compaction of the joints in the sand, 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 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 putty knife into the joint and pressing down. The knife should not penetrate more than 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 26 kN. Higher force compactors will be required on pavers thicker than 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 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 2 mm. The maximum joint width depends on the paver shape and thickness. Generally, thicker pavers thicker than 80 mm with more than four sides (dentated) will require slightly larger joints, as much as 6 mm.

Recommended tolerances are as follows:

- *Joint widths*: This depends on the paver thickness. For 80 and 100 mm thick pavers, 2 to 5 mm is acceptable. No more than 10% of the joints shall exceed 5 mm for the purposes of maintaining straight joint lines. For 120 mm thick dentated pavers, the maximum joint spacing can be increased to 6 mm with no more than 10% of the joints exceeding 6 mm for the purposes of maintaining straight joint lines.
- *Surface tolerances*: ±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 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 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.
- *Bond or joint lines*: ±15 mm within a 15 m string line.

3.4 Protection and Clean Up

The GC should insure that no vehicles other than those from 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.

4. CONCLUSION

Mechanical installation requires a high level of quality control for the paving units, sands, and their placement. This specification guide is intended to increase the awareness of many technical issues around quality control important to the design engineer/specifier, GC, paving installation subcontractor, and paver manufacturer. Increased awareness comes from joint development of a Quality Control Plan by these participants. The Plan includes a method statement covering considers standards and procedures for quality control/quality assurance for many aspects. Joint development of the Plan can increase a commitment to it and to a high quality result.

This specification guide should be modified to specific project conditions and the contractual relationships within each project. Whatever those relationships, this guide can be used to address technical issues before they arise during construction of mechanically installed interlocking concrete pavement projects. Addressing these issues prior to paving should result in a high quality installation for the owner. The result for the GC, paver installation contractor, and paver manufacturer will be a reduction of wasted time and money through a reduction or elimination of lost productivity.

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A SPECIFICATION GUIDE FOR MECHANICALLY INSTALLED INTERLOCKING CONCRETE PAVEMENTS

Smith, D.R.

Interlocking Concrete Pavement Institute, 1444 I Street, N.W.: Suite 700
Washington, DC 20005 USA. Tel: (202) 712 9036. Fax: (202) 408 0285.
E-mail: dsmith@bostromdc.com

Biography

David R. Smith, MUPRL, ASCE, CSI, ASLA

With an architecture, engineering, and environmental planning background, David R. Smith has been involved with segmental concrete pavement since 1977. He has been working in the industry and for institutionalization of segmental concrete paving in North America since 1987. With many companies, he launched the Interlocking Concrete Pavement Institute (ICPI) in 1993. He has authored scores of magazine articles, brochures, and technical bulletins, technical papers, and promotional brochures for the ICPI.

His work includes co-authorship of ICPI technical manuals, *Port and Industrial Pavement Design with Concrete Pavements* and *Airfield Pavement Design with Concrete Pavers*. He has authored the *ICPI Concrete Paver Installation Contractor Certification Course* and *Permeable Interlocking Concrete Pavements*. David R. Smith is editor of *the Interlocking Concrete Pavement Magazine*, a quarterly publication featuring unique projects that circulates to thousands of designers and contractors. He also authored the design idea book, *Patio, Driveway and Plazas—The Pattern Language of Concrete Pavers*.

As a leading authority in North America on concrete segmental paving, Mr. Smith regularly speaks at national and international conferences. He is secretary-treasurer of the Small Element Paving Technologists. He is an active member of ASTM Committee C 27.20 on Architectural Precast Products, having written and revised product several standards on segmental concrete paving products for that organization. He is participates as a member in the American Society of Civil Engineers, American Public Works Association, Construction Specifications Institute, and the American Society of Landscape Architects. Mr. Smith has contributed continuing education programs to the American Society of Landscape Architects and to the American Institute of Architects.

His education includes a bachelor of Architecture and a masters of Urban and Regional Planning (environmental concentration) from Virginia Tech in Blacksburg, Virginia. As ICPI's Technical Director, he works daily with design professionals, contractors, and homeowners on the design, specification, construction, and maintenance of segmental concrete pavements.