CONSTRUCTION MONITORING OF INTERLOCKING CONCRETE PAVER PROJECTS

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SUMMARY

To date installation of interlocking concrete pavers has been treated as a craft. The majority of installations in North America have been residential with low loading where construction monitoring methods were not applied. The increased use of pavers in the municipal, commercial, and industrial markets of North America has resulted in the need for more complete inspection procedures. Cities and others demand quality assurance methods similar to those available for the asphalt and the cast-in-place concrete industries. Yet, specific quality measurements for installation of interlocking concrete pavers have not been available or have not been widely used. This paper discusses various quality assurance techniques specific to unit paving. Determination of average and individual joint widths, variation from line, variation from grade, consistency of pattern, variation in pattern, quality of paver cutting, quality of joint sand installation, direct measurement of joint sand interlock, quality of stabilizer application, measuring dimensional quality of individual pavers, measuring dimensional quality of paver clusters, and other topics are covered.

1. INTRODUCTION

To date most of the interlocking concrete pavers installed in North America have been used on residential driveways and patios. The vast majority of paver installations have been small projects placed by hand. These installations generally had no detailed plans or specifications. If there was an actual Site Plan drawn by an Architect there was often just an arrow pointing to an area with a note calling out a manufacturer, a name of the paver, and a color. If there was no design professional involved, the installer's contract calling out the coverage, paver name, and color was usually all the technical control there was on a project.

It is a very different situation for the competing pavement systems, asphalt and concrete. Each system has been long established with dedicated research agencies, mountains of technical data, standardized specifications and practices available. Every state or province Department of Transportation (DOT) keeps a standard construction manual calling out types of pavements, with complete, tested, and legally vetted details and specifications that control every aspect of a project. These standards are well known and understood by contractors and designers. The contractors know what to, the designer knows the performance characteristics of the asphalt, and the city engineering staff knows how to inspect the work and control the project. There is a high level of confidence.

Sadly, this is not the case for interlocking concrete pavers. Until recently, pavers have been considered an exotic paving system. There were no national standards. Engineers, being conservative by nature, avoided the system. There was, and is a low level of confidence.

The Interlocking Concrete Paver Institute (ICPI) was formed to address these issues. ICPI has published a number of standards and guide specifications that have advanced the industry. For the most part ICPI's efforts have been successful. The market share of pavers is increasing in the commercial, industrial, and municipal sectors. The confidence level of designers and large project owners has increased.

Problems still exist. On several occasions the author has been informed by decision makers on large projects that while they see many advantages to concrete pavers, they are still reluctant to use a system they do not know how to inspect for contract compliance. They are concerned that large general contractors do not know how to manage paver installation subcontractors. Often staff inspectors are looking at their first paver project.
In short, they do not know how to apply the quality assurance procedures they are accustomed to with other paving systems.

In order to be successful in the North American market, pavers must provide similar levels of standardization and confidence. This paper is an attempt to address these problems. It suggests methods to monitor interlocking concrete paver constructions. There may be other methods, as or more effective**.** Improvement will be made as experience in the industry grows. This document should be viewed as a place to start.

This document also assumes the reader has acquainted themselves with the basic concepts of unit paving systems. ICPI is a good source of information. Please refer to ICPI Tech Spec 1 for a glossary of terms used here.

1.1 Quality Control vs. Quality Assurance
As with any paving project, the means and methods are the responsibility of the contractor. Neither the specifications nor the construction monitoring effort should overly restrict the contractor in how they do the work. The contractor is responsible for quality control. Owners should protect themselves by providing good quality assurance via construction monitoring.

1.2 Expectations
The level of craftsmanship required depends on the intended use of the pavement. Architectural pavements are selected for their aesthetic appeal as much as for any other trait. Elements like straightness of line, uniformity of color, uniformity of joint sand depth, and precision of edge paver cuts are of great importance. Industrial paving is concerned primarily with strength, durability, and life-cycle cost. It is not useful to apply architectural standards of appearance to industrial pavements.

Elements typical to construction monitoring of pavers appear below:

2. CONSTRUCTION ELEMENTS – INTERLOCKING CONCRETE PAVERS

2.1 Elements In Common with Other Paving Systems

2.1.1 Surface Elevations (Grade)
The same techniques for determination of surface elevations that are used for other paving systems apply to paver systems and are addressed well in other publications and by common practice.

2.1.2 Base and Subgrade

The same techniques for approval of base rock and subgrade that are used for other paving systems apply to paver systems and are addressed well in other publications (Check with the local DOT).There is one significant difference. Often on heavy wheel load applications the base is topped with a layer of asphalt or other material. This is sometimes done to provide a running surface for construction for the balance of the project. This layer should be finished to top lift tolerances, not base lift tolerances. Variations in the base topping layer make a quality installation of the pavers more difficult.

2.2 Elements Unique to Unit Paving

2.2.1 Regularity of the Unit Pavers

Traditionally, the general qualities of the unit pavers are controlled using ASTM C 936. This standard is updated from time to time. Insure the latest version is used.

Concrete unit pavers are formed from damp concrete. They are never completely straight or flat. They will not be perfect. They must be square and straight enough that they can be installed in a way that provides good quality pavement. Some of the potential problems with the pavers themselves follow.

2.2.2 Breakage

Concrete pavers are a tough durable product. The majority of pavers today are made on a dedicated paver manufacturing machine. Quality is usually quite good. Occasionally the manufacturer will produce an inferior batch of pavers. This is usually associated with some change in material, or excess water, or a change in the production line. Significant breakage of pavers under compaction indicates a poor quality paver. Significant spalling may indicate a poor quality paver. There will always be some anecdotal breakage and chipping during construction. A very small amount of breakage does not indicate a problem.

2.2.3 Elephant's Foot

Elephant's foot is a solid extension at the bottom of the paver formed as part of the body of the paver typically due to excessive mold wear. Elephant's foot creates significant problems. The extra width makes it very difficult to achieve consolidation of the joint sand and load transfer between the pavers. Such units must be rejected and removed from the jobsite regardless of whatever confidence the installer may have.

2.2.4 Belly or Bulge

A belly is convex sides of a concrete paver often due to excessive water in the concrete mix. Bellied pavers do not generally create a strength issue if properly installed. However, they are more difficult to install correctly. Additionally, bellied pavers will not stay in the clamp of a paving machine. They should be rejected. The author's research indicates that all pavers have a slight curve on the vertical surfaces. If a paver is bellied due to a wet mix the deepest point of the curve will generally be just below the midline, at about 40% of the height of the paver. If the paver is misshapen due to mold wear, the curvature will be in the bottom 15% of the height of the unit. Use a straight edge to determine the location.

2.3.5 Flange

Flange is a small, crust-like edge composed of sand and cement, around the bottom edges of a concrete paving unit typically due to a gap between the mold and the board or platen. Flange is not generally a problem unless it is fairly extreme. If it can be removed with hand or thumb nail pressure it will not create any issue.

2.3.6 Flash
Flash is a thin brittle layer of cement around the bottom edges or at the top edges of a paver typically due to minor leakage of liquid cement between elements of the mold assembly. Flash does not create any real issues for paver installation. It may be an indication of a lower strength paver. Check the rest of the paver for signs of excess moisture.

2.3.7 Efflorescence
Efflorescence is generally a white deposit of soluble salts. The source of the salts is usually from within the concrete. Slightly soluble in water, the materials migrate to the surface through capillary action. Some types will usually dissipate over time due to contact with traffic and can sometimes be removed by stiff brooming. There are a number of commercial efflorescence cleaners. If the efflorescence is not acceptable for the intended use, the paver should be rejected.

2.3.8 Nibs, Spacer Bars, or Spacer Lugs
These are small protrusions on each side of the paver, typically 1.5 to 2 mm, that keep them uniformly spaced. The commonly used term “spacer bar” is a misnomer since nibs are usually not as wide as the minimum 2 mm joint called out in most specifications. The nibs should be evenly shaped.

2.4 Elements Related to the Quality of the Work
2.4.1 Bedding Sand
Bedding sand is a layer of coarse, washed sand screeded smooth for bedding the pavers. Bedding sand allows for variation in the height of the pavers and base, provides uniform support, spreads wheel loads, and provides a path for lateral movement of water. Performance of the bedding sand is critical to the success of the paver system. Sand that is useful for other purposes may not be useful under pavers. Gradation, angularity, durability and other qualities should be called out in the specifications or refer to ICPI and paver manufacturer’s data.

Sand is a natural product subject to variation. Sand from one part of a source pit may be fine while sand from a short distance away may not. The pit operator may not notice changes in the material or may not think those changes are important. Most of the characteristics called out are not possible to determine in the field without special equipment. However, it is usually possible to note changes in the quality of the sand. Acquaint yourself with a sample of sand known to meet specifications and approved for the project. Carefully inspect the approved bedding sand under natural light. Visually note color, grain size, translucence of particles, and angularity of the grains. Use of a magnifying lens is helpful. Rub the sand between your hands and note its visual characteristics and roughness. Inspect for contaminates, dirt or odors. Periodically re-inspect the material for any changes. In costal areas where dredge sand can be used, watch for shell content. If there seems to be some variation find out why. The variation may not be important, but it does require explanation and perhaps re-testing.

Precompaction of bedding sand is used in some regions. The practice seems to vary based on installer experience with local materials.

2.4.2 Joint
It is best to think of a joint as the space between the sides of the pavers and the joint sand in that space. A properly constructed joint is necessary for effective surface drainage and lateral load transfer. There are two types of joints; field joints, which are paver to paver joints and edge joints which are in contact with edge restraints and structures located in the field of pavers. Measurement of a joint does not include the nibs.

2.4.3 Joint Sand
Joint sand is the material swept into the openings between the pavers. Joint or "jointing" sand provides the lateral load transfer between paving units, and between pavers and contacts such as edge restraints or utility structures. If the joint sand is not properly installed there is a gap in the paving structure.

2.4.4 Joint Width
The joint width is the space between two adjacent pavers not including the nibs. Contract documents should call out a range of acceptable joint widths. In North America it is usually 2 mm to 5 mm. If joints are too narrow it will be difficult for the installer to completely fill the space with sand. If joints are too wide there is little or no load transfer between pavers or between pavers and edge restraints. Measurement of joint width can be tedious. However, exact measurement is not required.

Joints should be uniform in width, and compliant with the specifications and industry standards. The joint must be narrow enough to insure good lateral load transfer and wide enough to promote complete filling.

Edge joints are subject to the same standards as field joints. Installers sometimes construct edge joints wider than field joints. This is usually done because edge joints are a cut joint and the wider joint is easier to fit. This is not acceptable and must be corrected. If the pavers are installed against an existing batter curb, the pavers should be bevel cut so that the joint is an appropriate width and parallel to the face of the curb.

2.4.5 Joint Sand Consolidation (Joint Filling)
Properly consolidated joint sand is critical to the long term success of unit paving systems. The sand must be good quality, durable, and properly graded. This is called interlock. There are several ways to determine if the joint sand is properly installed into the joint.

Joints must be completely filled with appropriate joint sand that is consolidated into an efficient packing order for transfer of load between the pavers and to the edge restraints. It is possible to fill a joint with unconsolidated jointing sand that makes the joint appear full. Unconsolidated sand does not provide any load transfer and is fairly easily removed by water and cleaning. A fully consolidated joint feels quite firm when tested with a thin probe. The top 10 mm or so will not usually fully consolidate even when the balance of the jointing material is firm. It will remain relatively loose until the joint matures or stabilizer is installed.

2.4.6 Paver Cutting
All cuts should be made with a dry or wet masonry saw. Cut paver faces should meet the same requirements as the manufactured face. In fact, because pavers are pressed from damp concrete a properly cut face is likely to be flatter than manufactured faces. Cuts with a shelf or bevel should typically be rejected.

Specifications usually require that no paver be cut to less than 1/3 of its original size. In practice this is based on one cut 100mm x 200mm rectangular unit or 66 sq cm (10.5 sq in). Cut pieces should not be long and thin. If the pavement is intended for use under vehicles, modify the pattern by inserting half or 2/3 sized pavers to increase the area at the edge contact allowing a larger cut paver.

Cutting pavers with a splitter is not acceptable. Splitters should be used only on residential projects where there is no possibility of vehicle traffic and a rustic look is desired.

2.4.7 Line and Squareness of Pattern
Specifications usually callout tolerances to deviation from line. If not, consult with ICPI documents or the paver manufacturer's literature for standards. Pavements selected in part for their visual appeal require a high standard of uniformity of pattern. While desirable, uniformity of pattern is not as important for industrial pavement.

2.4.8 Holdover at Contacts
Pavers should be installed slightly above grade at edge contacts such as at flush curbs and utility structures. The base sand will consolidate slightly under traffic and the elements even after appropriate use of compaction equipment. The amount of this additional consolidation will vary with local materials. Typically the holdover required is on the order of 5 mm.

2.4.9 Pre-installation Conditions
Inspect the project area prior to the placement of bedding sand. Satisfy yourself that the base is properly prepared, curbs and other edge restraints are at the proper line and grade, and lids on utility structures are properly secured.

2.4.10 Joint Sand Stabilizer
This is liquid penetrating or dry mix applied materials that provide early stabilization of joint sand. Joint sand stabilizers should be installed in accordance with the manufacturer's instructions. The primary concern is penetration of the stabilizer into the joint sand. A 1/2 inch of actual penetration should be considered minimum.

2.4.11 Lippage
Lippage is the difference in vertical distance between the surface of one paving unit and an adjacent unit. Lippage can result from excessive preconsolidation of the bedding course, incomplete setting of the pavers into the bedding course, or from unit pavers which vary in height. In extreme cases it can be a safety issue.

2.4.12 Fish Scale
This is unevenness of the surface corresponding to the shape of machine installed clusters or to individual pavers) Fish scale can result from excessive preconsolidation of the bedding course, incomplete setting of the pavers into the bedding course or in the case of machine installation poor laying practices. Under heavy wheel loads the condition will be self healing over time. If the surface is for pedestrian use only, it will not self repair and must be fixed.

2.4.13 Spall
A spall is a fragment, usually in the shape of a flake, detached from the edge or surface of a paver by a blow or sudden force, the action of weather, or pressure from adjacent pavers. Spalls indicate a problem either with the manufacture of the paver or the installation.

If the pavers are spalling under the vibrating plate or early under traffic, and the joints are adequate, then the pavers are likely substandard. Test samples of the on-site pavers as per ASTM 936, latest addition.

If the pavers are spalling because of direct paver-to-paver contact, then the joint is not adequate. Check that the joint is solidly and completely filled with sand and that there is adequate width. Determine if the base sand is performing properly and not failing in some way.

3. ON-SITE TESTING METHODS

3.1 Proof Rolling

Proof rolling is called for in some specifications as a testing method. The intent is to knead the paver with a piece of equipment capable of greater loading than a vibrating plate compactor or even a loaded dump truck. In theory, this kneading should cause any voids in the joint sand to collapse and the level of sand in the joint to fall. More joint sand is installed to repair the low areas. Proof rolling is an effective tool. However, in practice, a dedicated proof roller is rarely on site for any other purpose and is rarely easily available. The testing has a significant impact on the project. A requirement for proof rolling can significantly delay opening finished areas. It precludes opening small finished areas until it is practical and cost effective to bring in a proof roller for a large area. Proof rolling also delays installation of joint sand stabilizers. It may not be a practical testing method on some projects due to the cost and smaller size of the installation.

3.2 Water Testing Joints

It has long been known that joint sand sometimes falls during the first heavy rain if sand stabilizer has not been applied. It is often thought that the sand has been washed away. This is usually not the case unless there is evidence of significant loose sand downstream. Generally, poorly installed joint sand has consolidated in the joint lowering the sand level in the joint. This effect is also observed after the application of liquid joint sand stabilizers on poorly installed sand. Water testing should be done with a gentle covering that will not scour away the joint sand. Normal gravity flows are generally OK. The intent is to find sand that is not properly consolidated. This method may not find deeper voids in the joint. After water testing the surface, an exposed joint must be completely dry before the reinstallation of joint sand.

3.3 Joint Interlock Testing

To insure maximum performance of an interlocking unit paver system, it is important that the surface behave in an elastic, rather than plastic, manner. Elastic behavior indicates good lateral load transfer between units. The Binkelman beam, Falling Weight Deflectometer and other methods can test the overall resilience of the pavement system. They do not determine if the surface itself is behaving elastically.

The author uses a torque wrench and anvil set up to determine expansion and rebound of joints (a description appears in the Notes on Tools section below). Other methods may also work.

4. CONSTRUCTION MONITORING TOOLS

There are no dedicated tool kits for construction monitoring of paver installation. However most are easy to find or make. Tools discussion follows:

4.1 Joint Probe

A thin probe is useful in identifying poorly consolidated joint sand and voids. It consists of a stiff piece of metal about 1.5 mm in diameter and a handle to protect the hand. A 1.5 mm or similar T-handle hex wrench works well. Traditionally the proper consolidation of joint sand has been by observation of the sand under the vibrating plate or by using a putty knife. Neither method provides a good indication of the completeness of joint sand consolidation. A thin probe can be pushed into the joint sand at the corners of pavers and along the sides. If the tool can be pushed deep into the joint with moderate side-

to-side motion, the joint sand is not properly consolidated. Additional vibration and sand are required. Twisting a probe to bore into the joint does not provide a useful indicator. It is usually possible to push the probe a short distance into properly installed sand. However, boring with the probe can defeat even the best joint sand.

4.2 T-Handle Hex Wrenches and Probes

Hex wrenches can be purchased in sizes appropriate to check joint widths. Bedding sand depth can be checked by placing a piece of tape one inch above the tip of the wrench so a reading can be made when it is pushed into the bedding sand. Be careful that the hex rod is turned so that the sides are parallel to the joint. It may be useful to grind down a 5 mm hex drive to produce a tool that that is 5 mm in one direction and 2 mm in the other.

4.3 Calipers

Calipers are useful to measure many elements of the installation and the unit pavers including changes in paver size, actual joint widths, thickness of bedding sand, depth of sand in joints, elephant's foot, nib height, size of spalls, or chips. The stem of the caliper can be used as a straight edge when inspecting individual pavers. Because pavers are formed of a damp concrete and will always have some variation, machinist quality calipers are not required in the field, lightweight plastic dial calipers are adequate. Check the contact surfaces to insure that they have not been damaged by repeated contact with the rough concrete. Protect the tool from excessive contamination by sand.

4.4 String Line

A line can be used to check alignment of the pattern. Use thin metal rods such as nails or probes to anchor the string at corners of pavers in the pattern. Alternately, the string can be anchored by tying it around pavers or other heavy objects. Make sure the string is tight enough to avoid sag and excessive movement due to wind. Align the string along paver edges or corners. Inspect and/or measure the pattern for deviation from the string line. The same technique can be used to measure relative movement of pavers over time or to quantify any later deterioration.

4.5 Interlock Tester

The equipment consists of a small continuous reading torque wrench, calibrated to 22.6 Nm, with a 0.8 mm thick by 19 mm wide flat steel bit attached, a dial indicator calibrated to 0.025 mm increments, the dial indicator's base, and a small suitable anvil. The testing equipment is set up with the dial indicator on a paver and the anvil on an abutting unit. It is important that the testing equipment always be set in the same configuration. The plunger of the dial indicator is placed in contact with the anvil and the indicator set to zero. The flat bit of the torque wrench is inserted into the joint between the pavers and force is applied to determine the relative spreading of the joint. Relative movement and rebound during the test are the primary indicators; the exact measurement of the initial distance between pavers is not important to the measurement of interlock from joint sand consolidation.

Document the movement at several levels of torque. No exact numeric indicators are standardized at this time. However, maximum movement should be on the order of one or two thousandths of an inch and the return of the joint to its original width should be nearly 100%.

5. OTHER/ADDITIONAL CONSIDERATIONS

5.1 Frozen Materials

Frozen sand, even if friable, cannot be fully consolidated. Work must cease until the materials are thawed and dried. Alternately a tent or other warming system can be placed over a work area and the materials. This is not usually practical except for small projects or small labor intensive portions of larger projects like a logo or other intricate design.

5.2 Contamination

Contaminated areas must be removed. Concrete dust from cutting operations, dirt from surrounding construction activities, and petroleum spills are the most common contaminates. All of them will affect the ultimate performance of the system.

5.3 Finishing the Pavement at the End of the Work Day

Sometimes installers may want to leave the working face unfinished at the end of the day. ICPI standards and best practices require that the pavers be sanded and vibrated into place to within 3 feet of the working face. Unfinished surfaces are vulnerable to damage by wind and rain. If the surface is left with open joints, the base can become saturated making proper consolidation very difficult and effective consolidation of the joint sand impossible. Once the base sand is dry these problems go away. Drying of the base sand may take many days, especially if additional rain is expected. Construction schedules can be severely impacted.

5.4 Protecting the Work

Until the surface is completed and released for traffic, it should be protected from other construction activities, the elements, and contamination. Premature wheel loads pre-consolidate the base sand, push pavers out of alignment, tilt pavers, and damage joint sand stabilizer.

5.5 Pay Items

Payment should be based on unit area of completed paver system including all fill-ins of pavers at edge contacts, and other structures, edge restraints, and fully consolidated joint sand. The only exception to this maybe the installation of stabilizer if it occurs somewhat after the rest of the construction. Any other arrangements, such as an extended weather break, should be clearly understood and documented by both parties.

6. CONCLUSIONS

The increased use of pavers in the municipal, commercial, and industrial markets of North America has resulted in the need for more complete inspection procedures. Specific values for the measurement of the installation of interlocking concrete pavers are not yet well established. However, good construction monitoring and quality assurance procedures are possible. Average and individual joint widths, variation from line, variation from grade, consistency of pattern, quality of paver cutting, quality of joint sand installation, direct measurement of joint sand interlock, quality of stabilizer application, and dimensional quality of individual pavers are all traits that should be reviewed while construction is in progress.

7. REFERENCES

Tech Spec Number 1 Glossary of Terms used in the Production, Design, and Construction of Interlocking Concrete Pavement, ICPI

Tech Spec Number 2 Construction of Interlocking Concrete Pavements, ICPI

Tech Spec Number 3 Edge restraints for Interlocking Concrete Pavements, ICPI

Tech Spec Number 6 Reinstatement of Interlocking Concrete Pavements, ICPI

Tech Spec Number 9 Guide Specification for the Construction of Interlocking Concrete Pavements, ICPI

Tech Spec Number 11 Mechanical Installation of Interlocking Concrete Pavements, ICPI

Tech Spec Number 14 Concrete Paving Units for Roof Decks, ICPI

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