Contractor Focus

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Construction of Bases for Permeable Interlocking Concrete Pavements – Part I

When carefully constructed and regularly maintained, permeable interlocking concrete pavement (PICP) should provide 20 to 25 years of service. Its service life is measured by the ability to store and infiltrate runoff as well as support vehicular traffic with little or no rutting. Regular inspection and maintenance are required to track performance, identify problems and implement solutions. The PICP owner plays a key maintenance role that helps successful long-term PICP performance. However, PICP performance begins with the contractor correctly building the open-graded subbase and base.

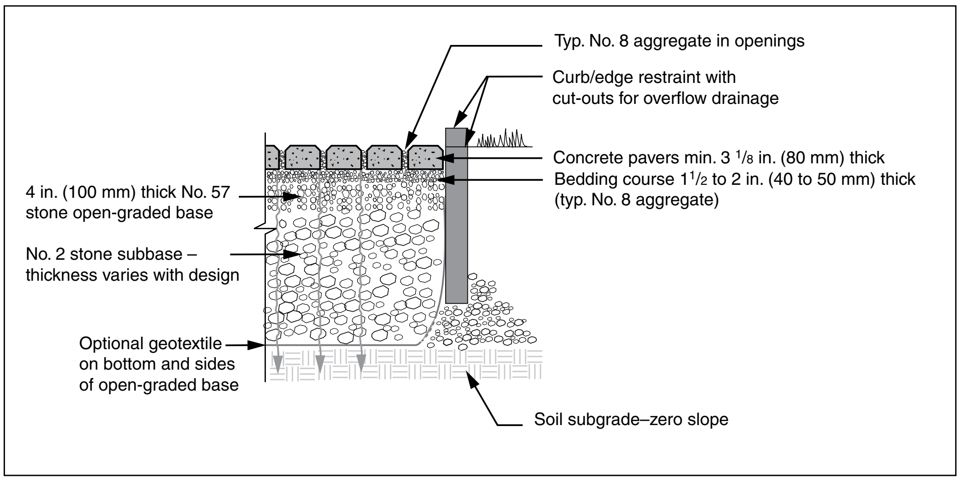

Figure 1. Permeable interlocking concrete pavement (PICP) relies on the water storage capacity of various layers of compacted open-graded stone base.

Subbase, Base and Bedding Materials

ICPI recommends certain ASTM stone gradations for the subbase, base and bedding layers. The gradations for these sizes are identified with numbers. These numbers and gradations are found in ASTM D 448, *Standard Classification for Sizes of Aggregate for Road and Bridge Construction*. ICPI recommends No. 2 stone subbase because it is very stable under construction equipment and has a high water storage capacity (No. 3 also works well). Also recommended are No. 57 stone for the base (over the No. 2) and No. 8 stone for the bedding layer. Figure 1 shows a typical PICP cross section.

ASTM gradations are provided in Table 1. All of these stone products are washed at the quarry which removes most of the dust and fines. Their open gradation (i.e., no smaller particles that fill around the larger stones) allows these materials to store water and infiltrate it back into the base. The absence of fines from washing helps minimize the potential for clogging the soil subgrade while in service.

The No. 2 subbase thickness is typically 6 to 18 in. (150 – 450 mm), depending on the amount of water storage required, as well the amount of traffic and soil type. (See Figure 2.) The water storage capacity of this layer is typically around 40% of the total base volume. The 4 in. (200 mm) thick No. 57 stone layer is used for the base and has a water storage capacity between 30% and 35%. (See Figure 3.) Instead of sand, a 2 in. (50 mm) thick No. 8 stone functions as the bedding layer and jointing material. No. 8 stone has about 20% void space between its particles.

All stone materials should be crushed for the highest interlock and stability during construction and load-spreading capacity during service. There are variations on these ASTM gradations that have been successfully used across North America. Many state and provincial departments of transportation have specifications similar to the ASTM gradations. These are acceptable as long as the bedding layer chokes into the base and the base into the subbase, thereby creating a stable structure for traffic.

	Percent Passing		
Sieve Size	No. 2	No. 57	No. 8
3 in. (75 mm)	100		
2.5 in. (63 mm)	90 to 100		
2 in. (50 mm)	35 to 70		
1.5 in. (37 mm)	0 to 15	100	
1 in. (25 mm)		95 to 100	
3/4 in. (19 mm)	0 to 5		
1/2 in. (12.5 mm)		25 to 60	100
3/8 in. (9.5 mm)			85 to 100
No. 4 (4.75 mm)		0 to 10	10 to 30
No. 8 (2.36 mm)		0 to 5	0 to 10
No. 16 (1.16 mm)			0 to 5

Table 1. ASTM Sieve Sizes for No. 2, 57 and 8 Stone Sizes

Estimating Quantities

Quarries supplying crushed stone should be able to provide the bulk density of open-graded aggregate per ASTM C 29 *Standard Test Method for Bulk Density (Unit Weight) and Voids in Aggregate*. If not, the test can be done by a soils testing laboratory. This test approximates the density in pounds per cubic foot or kilograms per cubic meter. For example, a No. 57 stone might have a bulk density of 120 lbs/ft^3 (1,922 kg/m^3). Therefore, a U.S. ton would consist of about 17 ft^3 (0.48 m^3). At 4 in. (200 mm) thick, this would cover about 50 sf (4.6 m^2). Similar calculations can be done on other stone sizes when the bulk density is known. Open-graded stone base materials will cost more than dense-graded base materials since open-graded stone is washed and handled separately from other materials at the quarry.

The Goal: Eliminating Clogging

Preventing and diverting sediment from entering the base and pavement surface during construction must be the highest priority. The best situation is when aggregates can be dumped, spread and compacted when they arrive at the site. This requires close coordination with work crews and the quarry or trucking company delivering the aggregate. If this type of coordination isn't possible, aggregates will need to be stored on piles near the excavated area. This, of course will involve more labor expense with time taken to move the aggregate from piles into the excavation. If aggregates are stored in piles on the site, storing them on hard pavement or on geotextile over soils will help keep them from getting contaminated by soil.

Extra care must be taken to keep sediment completely away from the stone materials and the open excavation. Simple practices such as keeping muddy construction equipment away, installing silt fences, staged excavation, and temporary drainage swales that divert runoff away from the area will make the difference between a pavement that infiltrates well or poorly. A simple practice to minimize mud and sediment transport from getting on the base materials is to place geotextile over the base at the construction entrance and secure it with a thin layer of No. 57 stone. The stone and fabric traps mud deposited by construction equipment and keeps it from getting into the base. The geotextile and stone layer are removed to receive the remaining base or bedding layer.

Moreover, the pavement should not receive runoff until the entire contributing drainage area is stabilized with vegetation. Obviously, vegetation doesn't grow overnight and rain will likely fall right after the pavement is installed. Therefore, erosion control matting can stabilize soil while grass or other vegetation starts to grow. This should be included in the con-

Figure 2. No. 2 subbase stone is spread and eventually compacted over a non-compacted soil subgrade for this large PICP parking lot in Illinois.

Figure 3. Smaller than No. 2 stone, No. 57 aggregate provides a base to receive the bedding material and pavers.

Figure 4. No 8. bedding material and joint material. Finer gradations may be used such as No. 89, 9 or 10. Sand is never used.

struction drawings and specifications.

Sometimes there is a stretch of time between excavation and base installation. The opening will collect water and sediment from rainstorms. One technique for reducing silting and clogging of soil is to excavate the base within 6 in. (150 mm) of the final bottom elevation. Like a temporary detention pond, this area can contain water during storms over the construction period and drain via temporary drain pipes. Sediment is allowed to collect on the surface of the soil subgrade.

Heavy equipment should be kept from this area to prevent compaction. If equipment needs to traverse the bottom of the excavation, tracked vehicles can reduce the risk of soil compaction. As the project progresses and base is ready for placement, sediment and the remaining soil depth can be excavated out to the final grade prior to installing the subbase and base stone. Depending on the project design, this technique might eliminate the need for a separate sediment basin during construction.

Soil Compaction

PICP is usually built over native, undisturbed soils. When excavated, native soils have some degree of natural compaction. Their natural, in-place density increases as the excavation depth increases. ICPI doesn't recommend compacting soils under PICP other than grading and trimming them for drainage. Compaction greatly reduces a soil's infiltration capacity. Obviously, there will be equipment passing over the soil subgrade surface and this will bring some compaction. However, compaction incidental to construction equipment is nowhere near the same density or depth brought about by compacting soil with compaction equipment typical to parking lot or road construction.

If the initial, undisturbed soil infiltration can be maintained during excavation and construction, it likely that the base will drain into the soil subgrade as designed. If the soil is inadvertently and repeatedly compacted by equipment during construction, there will be a substantial loss of infiltration. A loss is acceptable if the infiltration rate of the soil when compacted was initially considered during design and in drainage calculations. However, this should be verified at the pre-construction meeting with the design engineer.

In rare situations, compacting low California Bearing Ratio (CBR) (typically clay) soils (<5% CBR) may be necessary. This attains sufficient structural support and minimizes rutting from vehicular traffic. These soils should be compacted to at least 95% of standard Proctor density per ASTM D 698. Nuclear density tests should be performed to verify compaction to this guideline. A network of perforated drain pipes in the open-graded base will likely be required to remove water since compaction will greatly reduce the soil's permeability. Again, compacting soils isn't common to most PICP projects.

Geotextiles

Geotextiles are used in some permeable pavement applications and are optional when using a No. 2 aggregate subbase. No. 2 stone essentially acts as a filter layer while providing additional stability because of the large stones spread stress across the soil subgrade. For vehicular applications, high-quality fabric should be specified that resists the puncturing by coarse, angular aggregate from compaction during construction and from repeated wheel loads during its service life. Bases should have their sides covered in geotextile. If using geotextile over the top of the soil subgrade, ICPI recommends a minimum of 1 ft (0.3 m) overlap in well-drained soils and 2 ft (0.6 m) overlap on poor-draining weaker soils (CBR < 5%).

Open-graded Aggregate Bases

No. 2 subbase material should be spread in minimum 6 in. (150 mm) thick lifts and compacted with a static roller. At least four passes should be made with a minimum 10 ton (9 T) steel drum roller. The roller is often in vibratory mode for the first few passes and then static mode (no vibration) for the final passes. This compaction method applies to the No. 2 and No. 57 layers.

Figure 5 shows a dual drum roller compacting the open graded aggregate. The No. 57 base layer can be spread and compacted as one 4 in. (100 mm) lift. Figure 5 shows the No. 57 aggregate spread over the No. 2 stone and being compacted with a heavy plate compactor. This equipment is also effective in compacting No. 57 stone. Compacting will

Figure 5. A dual drum roller compacts the open-graded base first in vibratory then in static mode. This particular machine is a 12-ton roller.

Figure 6. A 13,500 (60 kN) reversible plate compactor is also effective in compacting No. 57 stone.

Figure 7. Mechanical screeding of the bedding material speeds construction on larger projects.

be made a bit easier when all stone surfaces are moist. This enables the particles to slide and move into their tightest fitting figuration more easily.

When riding on the No. 2 subbase and the No. 57 base, equipment drivers should avoid rapid acceleration, hard braking, or sharp turning on the compacted layers. Tracked equipment is recommended. If the base surfaces are disturbed, they should be re-leveled and re-compacted.

A test section or trial area of the base should be constructed and closely monitored during compaction. The section will indicate settlement of the base, and indicate when excessive compaction crushes the aggregate. This should be avoided as crushing generates fines that can clog the soil subgrade and reduce PICP effectiveness in infiltration water. The test section can be used to train construction personnel on these and related aspects. The work crew objective is to have no visible movement in the stone during the last compactor pass and no crushing of the stone.

When all lifts are compacted the surface should then be covered with a 2 in. (50 mm) thick layer of moist No. 8 crushed stone. This layer of finer crushed stone is screeded and leveled ver the No. 57 base. The No. 8 should be moist to facilitate movement into the No. 57. Larger projects typically use mechanical screeds as shown in Figure 7. No. 8 stone is not compacted. The surface tolerance of the screeded No. 8 material should be $\pm^1/_2$ in. over 10 ft. (±13 mm over 3 m). Construction equipment and foot traffic should be kept off the screeded layer.

Concrete pavers should be placed immediately after the No. 8 base bedding is placed and screeded. Mechanical installation appears to be used more often as most PICP projects are large and require efficiency from these machines. After placement, the paver joints are filled with No. 8 stone and compacted with a minimum 5,000 lbf (22 kN) plate compactor. The compactor force on the pavers pushes the No. 8 stone into the upper portion of the No. 57 stone base.

In conclusion, key considerations in constructing a PICP base is keeping it free from sediment and fines. These materials come from equipment or from eroding surfaces near them. They also come from crushing stones during compaction. These situations require constant inspection on the part of the contractor to help ensure long-term PICP infiltration. In the November issue, measuring base density will be covered.

ICPI has a number of resources available to assist with your next project. *Permeable Interlocking Concrete Pavements – Selection, Design, Construction and Maintenance* provides guidance for design professionals and contractors. ICPI has a continuing education program entitled Construction of Permeable Pavements as part of the new ICPI Level II Concrete Paver Installer Certification program. ICPI has begun development of a separate certification program for PICP contractors. The program is expected to have a classroom and hands-on components. This magazine will report on these developments in the coming months. ❖

Contractor Focus

by David R. Smith, ICPI Technical Director

Construction of Bases for Permeable Interlocking Concrete Pavements – Part II

Part I in the August 2007 issue provided an overview of subbase, base and bedding materials for permeable interlocking concrete pavement (PICP). Careful selection and installation of these materials are critical for long-term PICP water storage and infiltration. Part I covered typical base material gradations, water storage capacity, estimating quantities and handling these crushed stone materials on the site to minimize sediment contamination. The article also covered why soils under PICP aren't compacted (to preserve water infiltration) and the optional use of geotextiles. Compaction, the most important aspect of base construction, was briefly described. The most challenging part of compaction is measuring density. Part II below provides additional insights into density measurements and ICPI research in this area.

Measuring Density

Density measurements ensure structural stability and long-term pavement performance for any type of aggregate or stabilized base construction. Specifications should call for density measurements to ensure that optimum density has been achieved to minimize rutting during pavement life. From the contractor's perspective, density measurements indicate completed compaction. Under-compaction can lead to rutting (and costly callbacks) and over-compaction wastes time and money, and in extreme cases can crush and damage some base materials.

Dense-graded bases (those with fines used for roads) are typically tested with a nuclear density gauge. The small box brought to a site by a technician consists of a testing probe typically driven into the base (usually up to 12 in. or 300 mm) for residential driveways, parking lots and municipal road projects. Figure 1 shows a nuclear density gauge and Figure 2 shows what happens when measurements are taken. Gamma rays are directly transmitted from the probe into the open-graded base. A detector on the machine bottom measures the returned rays as they pass through the base materials. Some of the rays are absorbed by the base. The denser the base, the fewer the rays return to sensors on the gauge bottom. The gauge rapidly translates returning rays into a density expressed in pounds per cubic foot (pcf) or kilograms per cubic meter (kg/m^3).

Unfortunately, open-graded stone bases for permeable pavements don't make use of the density gauge probe in them. The probe can't be driven into these materials without damage. Therefore, another testing approach called backscatter is used. This test method measures density of open-graded bases and is a common density test for freshly compacted asphalt (typically 2 in. or 50 mm thick). The gauge (with the probe withdrawn) emits gamma rays directly into the base. The sensors on the gauge bottom measure the extent to which rays work their way through the void spaces between the stones and back to the sensors. Figure 3 shows how the backscatter test method works.

ICPI is evaluating test methods for measuring density and stiffness of PICP open-graded bases using the classic vibratory roller shown here and large plate compactors.

Obviously, the stones (or asphalt) cause some rays to scatter and decay, hence, the term backscatter. This test method produces highly variable results and doesn't provide reliable measurements on base thicknesses over 6 in. (150 mm). Many measurements are usually taken and averaged to find a density range rather than measure to an exact minimum density. According to technical support staff at Troxler Labs (density gauge producers), open-graded density can be

Figure 1. A common site on pavement construction: a technician reads a nuclear density gauge on and PICP project.

compared to compacted densities of the same material in a laboratory. The test methods for determining the laboratory density of open-graded base are ASTM D 4253 *Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table* and ASTM D 4254 *Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density*. These test methods essentially determine the optimum compacted density of open-graded base in the laboratory and field measurements are compared to them. However, staff noted that field measuring of open-graded base density can be subject to wide variability.

ICPI Base Testing Evaluations

Current ICPI recommendations for PICP open-graded base compaction specifications state that at least four passes are needed with a 10-ton roller. The first few passes are done in vibratory mode with the last few passes in static mode. The acceptance criterion is no visible movement in the base during the final static roll. In addition to using vibratory roller, contractors have reported acceptable results using large (over 13,500 lbf or 60 kN) plate compactors. While the visual method for accepting base has worked without problems, engineers and experienced PICP contractors have asked for more quantifiable means for testing open-graded base density.

In response to these inquiries, ICPI is evaluating various density test methods under a vibratory roller and a plate compactor. One method is the backscatter test as previously described. A proposed guide specification has been developed for evaluation. This consists of constructing a control or test area with base materials on the job site (which can be incorporated into the project). The specifications provide designers and contractors with quality assurance testing and acceptance criteria for density. The draft test procedure is aimed at developing a target density for compaction equipment to achieve and testing the No. 57 stone base layer. Measuring density of large size ASTM No. 2 stone subbase under No. 57 is almost impossible. However, this railroad ballast material likely reaches optimum density when placed and compacted.

To establish a target density, a control strip is constructed no larger than 5,000 ft^2 (500 m^2). During its construction, aggregate should be kept moist during compaction. This enables the particles to move more easily and into their tightest packing arrangement. After initial placement of the

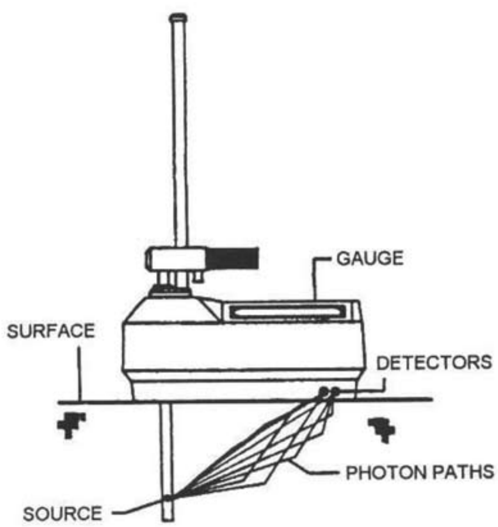

Figure 2. Direct transmission of gamma rays from a nuclear density gauge is detected at the back of the machine. This measurement technique works well in dense-graded bases but not in open-graded bases typical to PICP.

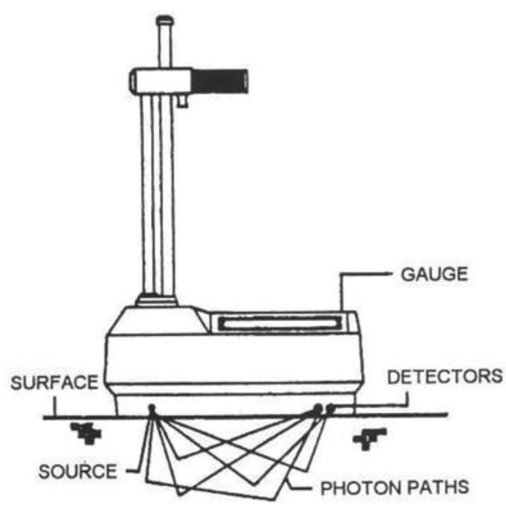

Figure 3. A nuclear density gauge set up for measuring open-graded base density in backscatter mode. Gamma rays are emitted from the end of the probe and are reflected back to the sensor at the back of the gauge. This technique is effective up to 6 in. (150 mm) depth.

Figure 4. In contrast to a nuclear density gauge, the Geogauge device measures base stiffness which can indicate when compaction is complete. Unlike a nuclear density gauge, operating this device does not require certification.

Figure 5. A 13,500 lbf (60 kN) plate compactor includes a device that indicates when no further compaction is needed on the area being compacted. This can reduce compaction time and increase assurance that the PICP open-graded base is compacted.

aggregate, compaction equipment makes two passes over the entire surface of the control strip. Using the backscatter/indirect method, densities are determined at five randomly selected locations at least 15 ft (5 m) apart. The average of these is used as the initial target value. As previously noted, the maximum compacted thickness of the No. 57 aggregate layer measured for density is 6 in. (150 mm). ICPI recommends a 4 in. (100 mm) thick No. 57 base layer over the No. 2 subbase layer, so most base layers should meet this limitation.

After this measurement, compaction equipment then makes two additional passes over the entire surface of the control strip. At least three separate, random field density measurements are taken using the backscatter/indirect method. If each density exceeds the previous value by more than 1.2 pcf (20 kg/m^3), then the compaction equipment makes two additional passes. If the new average dry density does not exceed the previous value by more than 1.2 pcf (20 kg/m^3) then compaction of the control strip is considered satisfactory and complete.

Measuring Stiffness

Another approach to evaluating compaction results is by measuring stiffness (vertical movement under a test loads) of the base rather than density. Figure 4 shows a device called a Geogauge which measures base stiffness using an electro-mechanical method. This equipment is also being evaluated by ICPI using the same protocol described earlier. According to the manufacturer, Humboldt, the Geogauge works by "applying steady state sinusoidal loadings on to the soils surface and measuring the resulting displacement." The ASTM test method for this device is ASTM D 6758-02 *Measuring Stiffness and Apparent Modulus of Soil and Soil-Aggregate In-Place by an Electro-Mechanical Method*. Unlike a nuclear density gauge, this device doesn't require a certified technician from a testing laboratory to operate it. The Geogauge is a portable device available for contractor purchase and tests can be performed easily by the contractor's crew.

Evaluation results from ICPI tests are preliminary, but they indicate that both methods can measure compaction uniformity on a job site. ICPI will provide an update of the results for several construction sites in a future article.

Compaction Equipment Sensors

ICPI compaction testing evaluations also included a large plate compactor for open-graded bases. Figure 5 shows a 13,500 lbf (60 kN) plate compactor under evaluation. Manufactured by Weber MT, the compactor is fitted with sensors that light up to indicate full compaction. Preliminary test results show this plate compactor achieved as stiff of a base compaction as a 10 ton (12 T) dual drum roller. More testing will be done this Fall to validate the test results.

Conclusion

Decades of research and experience in road building have resulted in standardized methods for dense-graded base thickness design and density testing. These test methods are expressed through ASTM and AASHTO standards. While open-graded bases have supporting test methods, their application isn't as common. Therefore, the experience and research behind them is small compared to that on dense-graded bases. For now, ICPI offers a visual method for verifying completed compaction. Density or stiffness testing offer alternative methods for designers and contractors who want numeric values reached on the job site. In addition, plate compactor manufacturers are providing compaction sensors on their equipment to guide operators. Real-time compaction information can save contractor time and money and it appears that this approach correlates well with density and stiffness testing. In the meantime, ICPI is investigating the advantages of each test method and hopes to offer additional testing recommendations and amended guide specifications in the near future. ❖