

## 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<sup>3</sup>).

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



*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.*

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.

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

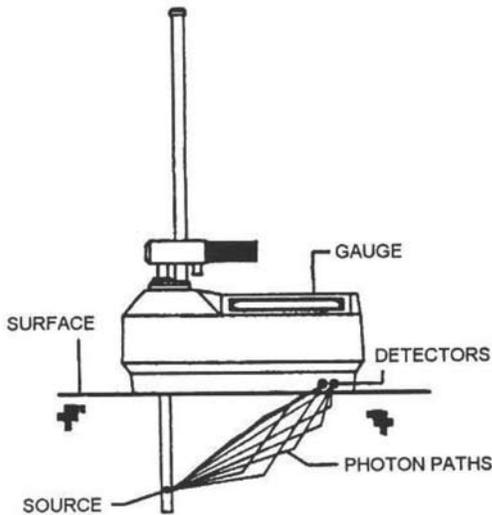


Figure 2. Direct transmission of gamma rays from a nuclear density gauge is detected at the back of the machine. This measurement technique works well in dense-graded bases but not in open-graded bases typical to PICP.

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<sup>2</sup> (500 m<sup>2</sup>). 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

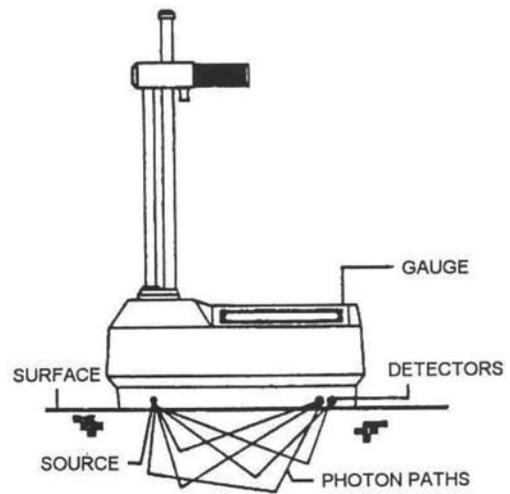


Figure 3. A nuclear density gauge set up for measuring open-graded base density in backscatter mode. Gamma rays are emitted from the end of the probe and are reflected back to the sensor at the back of the gauge. This technique is effective up to 6 in. (150 mm) depth.



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.

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 sub-base 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<sup>3</sup>), 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<sup>3</sup>) 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 contrac-



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.

tor's crew.

Evaluation results from ICPI tests are preliminary, but they indicate that both methods can measure compaction uniformly 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. ❖