A Working Review of Available Non-Nuclear Equipment for Determining In-Place Density of Asphalt

Problem
The quality of asphalt concrete pavement is determined by its strength, and the density of asphalt is used as a proxy. The greater the density of the asphalt, the fewer the air voids in the mix. Getting maximum performance from asphalt concrete pavement depends on getting the right level of air voids in the mixture.

Density has traditionally measured in one of two ways: by drilling cores and analyzing them in the laboratory, or by using a nuclear density gauge. The laboratory method has the disadvantage that it requires taking a sample from the road, making it a destructive method. The nuclear density gauge uses gamma rays to make the measurement in the field in a nondestructive manner, but requires the handling of radioactive materials and equipment, which is cumbersome and highly regulated. Recently two devices to measure density in the field, the PQI Model 300 and the PaveTracker™. While other researchers had evaluated these devices, their studies were limited by examining asphalt at only one site or by poor statistical designs.

Objectives
This study had two parts, a laboratory part and a field part. The objectives of the laboratory portion were to test the performance of the PaveTracker™ under a variety of factors including surface temperature, surface and internal moisture, size of aggregate, sample area relative to device footprint, and measurement depth. In addition, a statistical analysis of the accuracy of the device was made. The field portion of the study was designed to compare the performance of the PQI Model 300 and the PaveTracker™ against the traditional methods at several construction sites around the state.
Laboratory Study

In order to study the PaveTracker™ under laboratory conditions, 19 mm coarse-graded and 9.5 mm fine-graded mixes were used to create Superpave gyratory compacted samples and slabs. The coarse mix included 30% recycled asphalt pavement but fine mix did had no recycled asphalt pavement. Slabs were created using wooden frames 22.5 in (57 cm) square with depths of 1.5 in (3.8 cm) and 2.15 cm (5.5 cm) to provide a measure of variation in PaveTracker™ results with asphalt depth. The process for making slabs consisted of pouring coarse mix asphalt into the wooden frames and compressing with a 1.5 ton roller. Different density levels of approximately 4% air, 7% air, and 10% air were created by varying the level of gyratory compaction. Similarly, air void levels of 7% and 10% were created in the slabs.

As the samples cooled, the temperature was periodically read with an infrared thermometer and density of the sample was measured with the PaveTracker™ at several locations. Surface moisture was created by adding water to the top of the sample in three different amounts, while internal moisture was created by soaking the samples in water for 24 hours, then drying the surface to remove surface moisture.

To measure the variation with respect to sample area, the 22.5 in (57 cm) square mat was trimmed to 12 in (30 cm) square then to 6 in (15 cm) square, and measurements taken at each step. The mat pieces were then reassembled into larger slabs and measurements retaken.

For each of the factors described above, a correlation coefficient between the PaveTracker™ density reading and the laboratory value was computed. Analysis of Variance (ANOVA) tests were also conducted to examine the behavior under the various levels of temperature and moisture.

Field Study

For the field study, pavements were measured on 24 different projects around the state. The ODOT Engineer on each project identified and marked 10 random sample locations within each lot. The locations varied throughout the pavement to include edges, center, wheel paths, etc. The contractors then performed coring to extract the ten samples and sent them to the ODOT laboratory for analysis. Contractors also performed the field nuclear gauge measurements during both construction seasons and the PQI Model 300 measurements during the first construction season. Ohio University students performed the PaveTracker™ (PT) measurements during both seasons and the PQI Model 300 measurements during the second season. Nuclear density gauge measurements were also made. The PQI instrument is referenced to a test plate made of a controlled composition material prior to making pavement density measurements. Neither the PT nor the PQI instruments were otherwise calibrated in the field or against laboratory core results.

Laboratory and field values for density were compared using statistical analyses, including a regression analysis. The Student’s t test and the Wilcoxon Signed-Rank test were used to determine if the laboratory and field values were significantly different, and the Kolmogorov-Smirnov test used to verify the normality of the sample data. The hypotheses tested concerned the equality of various pairs of measurements, including: the nuclear gauge versus core (laboratory) values, PaveTracker™ versus core, PaveTracker™ versus nuclear, PQI versus core, and PQI versus nuclear.

The hypothesis that the nuclear gauge and laboratory values were equal was accepted, but the others were initially rejected when noncalibrated PaveTracker™ and PQI data were used. A calibration was then performed on the non-nuclear gauge data by using the first reading of the day as a calibration. With this adjustment, the hypotheses that the PQI were equal to the core and the nuclear data were accepted, while for the PaveTracker™, the corresponding hypotheses were still rejected.

Conclusions

Laboratory Study Conclusions:
The performance of the PaveTracker™ was not significantly influenced by HMA mix surface temperature. In general, gauge readings slightly dropped with decreasing mix temperature.

The presence of surface moisture significantly affects gauge readings. With an increase in surface moisture without internal moisture, gauge readings decrease appreciably. But with the introduction of internal moisture without the application of surface moisture, gauge readings increase. The increased amount is far larger than that of core density. The results given by the PaveTracker™ must be interpreted carefully when moisture is present. From the Analysis of Variance, the maximum surface moisture level at which moisture is not a...
significant factor is 0.05 lbs/ft\(^2\) (0.24 kg/m\(^2\)).

The PaveTracker\textsuperscript{TM} performed better with fine mixtures than with coarse mixtures.

The area of the specimen being measured does affect the accuracy of the PaveTracker\textsuperscript{TM}. In this study, the average decrease in gauge density was 2.4 pcf (38 kg/m\(^3\)) while the mat was cut from 12 in. x 12 in. (30 cm x 30 cm) down to 6 in. x 6 in. (15 cm x 15 cm) An increase in mat size from 12 in. x 12 in. (30 cm x 30 cm) to 22.5 in. x 22.5 in. (57.1 cm x 57.1 cm) caused the PaveTracker\textsuperscript{TM} reading to increase by 0.4 pcf (6.4 kg/m\(^3\)) on average.

The relation between measuring (probing) depth of the PaveTracker\textsuperscript{TM} and the thickness of the material being measured is critical to the accuracy. If the measuring depth of the gauge is larger than thickness of the material, the base material would affect the gauge reading, which would be a composite density value of the HMA and the base material. This effect seems to be linearly related to the density of base material.

**Field Study Conclusions:**

Without daily calibration, we found both the PQI and PaveTracker\textsuperscript{TM} results to differ from both laboratory reported core densities and nuclear density results with statistical significance.

Applying a daily mix-specific offset to gauge results as recommended by the manufacturers, hypothesis testing showed that the PaveTracker\textsuperscript{TM} results remained statistically different from both nuclear gauge and laboratory results, but PQI results were not significantly different. In fact, as indicated by the greater P-value for PQI results than for nuclear gauge results, calibrated PQI results agreed better with laboratory core results than did nuclear gauge results.

**Recommendations**

Based on the results of statistical hypothesis testing, we recommend that use of the PQI Model 300 for both QC and QA testing provided the manufacturer’s recommendation to calibrate the device daily by applying a mix-specific offset is followed. We cannot recommend the use of the PQI for QA testing without conducting the recommended calibration.

Even following the manufacturer’s recommended calibration procedure for the PaveTracker\textsuperscript{TM}, we cannot recommend it for QA testing, although contractors may find it useful for QC purposes.

In deciding whether or not to use non-nuclear pavement density gauges, contractors should evaluate the potential cost savings against the risk of receiving underpayment.

Taking a broader view of QA testing, we recommend future research attempting to measure stiffness instead of density. The use of in-place density to indicate pavement quality originated as a surrogate for stiffness, which could not at the time be measured in situ with practicality. However, advances in sensor capability, signal processing technology, and field data processing capability now enable the development of instruments that can determine in situ stiffness practically. Therefore, we recommend that QA standards and practices be adjusted to exploit this capability. The practicality and reliability of measuring stiffness instead of density should be investigated.

**Implementation Potential**

Contractors in the private sector are the ultimate beneficiaries of this research, as non-nuclear devices will allow them to verify asphalt densities without using destructive coring methods or having to handle radioactive materials for nuclear gauges. They will be informed of the results of this project via dissemination of this executive summary and the accompanying report on the ODOT website and through hard copies. The project has already been the subject of a feature article in the Fall 2005 issue of Ohio Asphalt magazine.