ON-SITE TESTING OF JOINT SAND INTERLOCK PROPOSING A NEW STANDARD FOR CONSTRUCTION MONITORING

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ABSTRACT

A new construction test method is introduced for indirectly measuring the consolidation and density of joint sand between concrete pavers. The test method consists of measuring the resistance to torque applied by a torque wrench bit placed in the joints between concrete pavers. The evolution of the test method, the equipment, and testing procedures are presented. Data is presented from 270 sample locations on port and loading dock applications. Tests were primarily conducted on herringbone patterns using rectangular concrete pavers at 80mm and 100mm thick. Based on grouping the data results, recommendations for acceptance or rejection of joint sand consolidation during construction based on allowable joint movement and torque applied. The test method and criteria are proposed to be used with many existing means for inspection by measurement of newly constructed pavements, or to evaluate the performance of existing ones.

1. BACKGROUND

In the late 1990's, engineers at a large US west coast port authority considered concrete pavers among other options for a new 2,000,000m^2 container facility. The author assisted in the preparation of several paving options and recommended pavers over asphalt because of the their life-cycle cost advantage. Pavers were given serious consideration by the port authority because of the obvious success in other ports. Such a project, even when completed in phases, was beyond the size of any project previously done by any contractor in the U.S.

The port authority's construction management staff had no experience with pavers. Therefore the port's engineers were concerned that they did not have a set of construction standards that were enforceable with rigorous quality control/quality assurance testing for all components of the concrete paver assembly. Beyond simple measurements of surface tolerances and joint widths, they wanted quantifiable construction testing procedures that assured interlock and distribution of loads. They wanted to be able to perform such testing on a routine basis during construction. They were not willing to be dependent on the experience of available inspectors and on subjective terms used in past project specifications such as "completely full" or "fully compacted" joints. The design team could not assure the port authority that such tests existed. Therefore, the port authority decided against the use of concrete pavers primarily because they could not have confidence in the quality of the construction.

2. INTRODUCTION

In the concrete paver industry quality assurance has been based almost solely on pre-construction testing of individual elements such as sand, or pavers, and on visual inspection of the installation.

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Competing asphalt and concrete paving systems currently enjoy the competitive advantage of many test methods to insure the quality of the final installation. Project decision makers can have a high level of confidence in detecting problems prior to acceptance of a finished project.

Design elements such as line, grade, surface texture, or color of a pavement are simple to observe or measure. Other elements that affect the service life of a pavement cannot be determined by simple observation. For example, the installed density of asphalt cannot be determined without an in-place test. Practical, repeatable, tests are available for asphalt. Pavers have a similar need regarding joint sand installation. To date no practical test has been available to test in-place joint sand density or measure its consolidation.

The primary testing method for installed asphalt in the U.S. is the nuclear densimeter. It is compact and portable with standard operating procedures. Technicians can be trained to operate it in a short time. One operator can undertake between forty to sixty tests in a typical workday. This leads to a high level of confidence for specifiers in the quality of the finished asphalt product. In order to increase the quality of paver surfaces used in the U.S. market, and perhaps elsewhere, design professionals are demanding a testing system during construction that relates to pavers in the same way that the nuclear densimeter relates to asphalt pavements.

3. PURPOSE

The purpose of this paper is to describe development of a practical, repeatable, low-cost technique that will quantify the functional stability of the surface of a concrete paver installation for factors that not easily observable in the field. Besides evaluating construction results, this technique could be used with other test methods for evaluating functional and structural performance. Such test methods may include measurement of joint width, bond lines (creep), lippage or faulting, surfaces tolerances, rutting, and falling weight deflectometer tests (FWD).

One of the critical factors that affects strength and durability of a paver surface is the proper installation of joint sand. To date, engineers, construction managers, and maintenance planners have had no practical options to determine completeness of joint sand consolidation and therefore cannot confirm compliance with the design intent.

Joint sand consists of particles of various sizes, which must be installed to a sufficient density to achieve design strength and rigidity. The optimum density for granular construction materials is usually defined by a laboratory test in which a quantity of the material in question is prepared and placed into a test cylinder. Energy is applied until the material occupies the smallest volume in the test cylinder. If it is assumed that the particles will not be broken into smaller sizes then the optimum density can be defined as the most efficient packing order of the particles. If all the particles in a container are spherical and of the same size it is easy to predict the volume occupied by the spheres when they are at their most uniform and regular arrangement. Joint sand typically has particles of varying size and shape and the optimum density is hard to predict without laboratory testing.

Several technologies are available to test the in-place density of compacted sand or aggregate surfaces. All of these require access to the top surface of the compacted material. Joint sand is contained in a small confined space with no access. Therefore, no practical method exists to measure the density of in-place joint sand.

It is possible to take an indirect approach by measuring the resistance to movement of the joint that is the result of reaching the optimum density of the in-place joint sand.

Installers and project engineers often decide if pavers are properly installed by prying the pavers apart with a screwdriver or similar tool. Based on their experience and the response of the movement of the concrete pavers, a determination is made whether the units are properly fixed in place. This response is based on the extent of consolidation of the joint sand. This paper proposes a test method that applies measurable values to this common intuitive approach.

The method proposed here is based on the following assumptions:

- The greatest interlock and support between individual pavers occurs when the joint sand is at optimum density.
- Optimum density (consolidation) can be defined as occurring when the sand particles are at their most efficient packing order and occupying the least space in the joint, within the limits of normal construction practices.
- Considered individually, sand particles are essentially incompressible and will not fracture under the loads imposed by the testing apparatus. Therefore, any apparent compressibility in a joint is due to rearrangement of the particles. Rearrangement of the particles under moderate forces is indicative of less than optimum density in the joint sand.
- The amount of force required to displace two pavers relative to one another varies in response to the density of the sand in the joints surrounding the pavers
- There is a measurable difference in the amount of force required to move pavers relative to one another when the joint are sufficiently filled with completely consolidated joint sand versus joint sand that has not been completely consolidated.

Based on the above assumptions and keeping in mind practicality, repeatability, and low-cost, the following test method was developed to determine the relative density or consolidation of joint sand, and therefore interlock, by a force applied with a lever.

4. EQUIPMENT

The equipment consists of a small continuous reading torque wrench, calibrated to 22.6Nm (200 inch-pounds), with a 0.8mm (0.031”) thick by 19 mm (0.75”) wide flat steel bit attached, a dial indicator calibrated to 0.025mm (0.001”) increments, the dial indicator’s base, and a small suitable anvil. A clipboard was used to hold a reporting form.

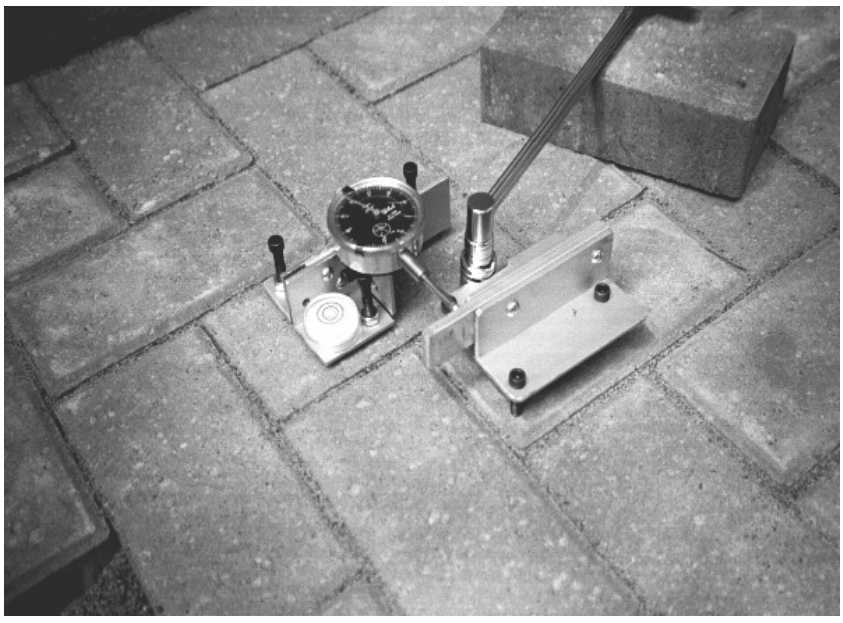

Figure 1. Equipment used.

5. METHOD

Most of the testing was done on a standard herringbone pattern with rectangular pavers. For rectangular pavers, it was performed on two parallel pavers touching along half their length. The testing equipment was set up with the dial indicator centered on the long side of one paver. The arm of the indicator extended over the long side of that paver at the midpoint, and directly over the joint normal to the midpoint. The anvil was placed at the center point of the end of the abutting paver. The plunger of the dial indicator was placed in contact with the anvil and the indicator set to zero. The flat bit of the torque wrench was inserted into the joint at the midpoint of the contact between the pavers. In this way the testing equipment could always be set in the same configuration. The exact measurement of the initial distance between pavers is not important to the measurement of interlock from joint sand consolidation. Relative movement during the test was the primary interest. A geometric analysis determined that any normal variation caused by "eye ball" registration of the equipment would not significantly affect accuracy.

Several test runs of the equipment were made to determine possible configurations of the flat bit and the appropriate energy range for the torque wrench. Other configurations, which required application of more energy, often resulted in crushing or chipping of the concrete at the point of contact with the flat bit. A torque wrench and flat bit combination was determined to be appropriate.

A small amount of the joint sand was gently removed with a hooked knife in order to make room for the flat bit. The flat bit was inserted into the joint and steadily increasing force was applied with the torque wrench. Readings were taken from the torque wrench at initial movement of the joint, and at 0.13mm (0.005"), 0.25mm (0.010"), 0.51mm (0.020"), 0.64mm (0.025"), 0.76mm (0.030"), 1.02mm (0.040") and 1.25mm (0.050"). The series was deemed complete if the reading on the torque wrench reached 22.6 Nm (200 inch-pounds) or if there was a movement greater than 1.25mm (0.050"). Information was recorded manually.

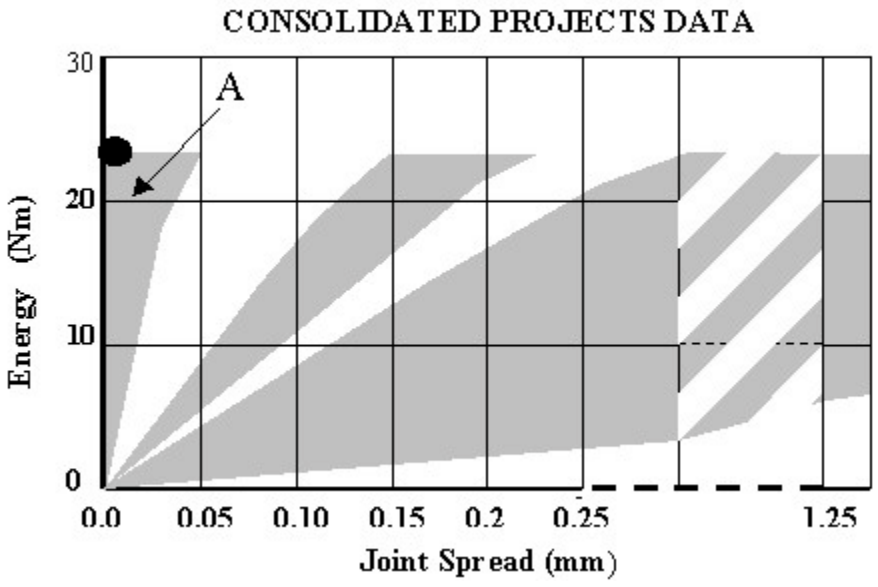

Figure 2. Chart of results.

6. RESULTS

Readings have been taken from several hundred sampling locations and a variety of paver patterns and shapes to date. The results presented here are from only 100mm x 200mm rectangular pavers both 100mm and 80mm thick laid in a herring bone pattern. They represent 210 sampling locations from several projects and include approximately 3500 individual measurements. The samples

included areas which had received passes from container handling equipment (design axle load 90,000kg) for a period of six months, abutting areas which had received little or no loading, and areas which had received only truck loading. The number of vehicle passes was not possible to determine. A generalized chart of the results is shown in Figure 2.

Approximately 50% of the test locations are in the area labeled "A" at the left hand portion of the chart. These locations had a total movement of less that 0.05mm. Most of these showed no measurable movement and are indicated as a dot in the top left portion of the graph. This data was taken from projects where known problems existed. It includes a very high proportion of joints with unconsolidated or incomplete joint sand. Data taken from projects where no problems existed had essentially all joints indicating less than 0.05mm movement. Data was taken to up to 1.25mm movement but not included on this chart for purpose of clarity.

Clusters of measurements fell into one of three basic groups:

- Movement was 0.05mm or less - There was little or no movement of the joint. The joint returned to its original position at the end of the test. The joint felt hard and unyielding.
- Movement was between 0.05mm and 0.25mm – The joint rebounded to 94% or more from its greatest width during the test. The joint felt very firm to firm during the test.
- Movement was greater than 0.25mm – The joint permanently expanded because result of the test. Some began as firm feeling and yielded to soft as force was applied, and others were soft and moved easily even at relatively low applied force.

It was important to note that the there were no final measurements between 0.05mm and 0.15mm and only a few results between 0.15mm and 0.20mm.

Additionally, four series of measurements were taken between individual passes of a vibrating plate compactor under optimum conditions. The results were consistent with those presented above.

7. CONCLUSIONS

Based on this data and observations of the condition of the pavers at the individual test locations, it is possible to quantify the consolidation of the joint sand. We have defined the following performance characteristics for rectangular pavers, 100mm x 200mm in plan either 80mm or 100mm thick, with typical joint widths from 1.7mm to 3mm and the configuration of the testing equipment used:

- Joints with a total movement of less than 0.05mm at 20Nm are adequately consolidated. Additional consolidation of the joint sand under traffic or by plate vibration will not result in any additional measurable increase in the strength of the joint.
- Joints with an initial joint movement of 0.25mm at less than 2.8Nm are not, at the time of measurement, completely consolidated or are not sufficiently filled. These joints may, depending on the amount of joint sand present, increase to a full strength joint under traffic or by additional plate vibration. However, the top level of the sand will be below the chamfer, and the life of the pavement may be reduced due to the effect of that lower joint sand.
- Joints with initial joint movement at less than 2.8Nm and an overall movement of greater than 0.2mm are unacceptable for vehicular service and must be re-sanded and re-consolidated with a plate compactor.
- Joints do not need to be filled completely to the top to achieve complete interlock. Fully consolidated joints, filled to 85% of the height of the joint, can demonstrate the same strength as joints that are 100% full.

The lever interlock test method works well to define relative high and low quality joint sand consolidation on a specific site. As the database expands it will be possible to propose typical, acceptable, values for the industry based on paver geometry and standardized equipment.

The equipment is inexpensive and hand portable. Technicians with only moderate specialized knowledge can perform the field measurements. Office analysis produces strength curves for the test points. Data can be usefully presented as tables and/or mapped.

8. DISCUSSION

We believe that with standardization of equipment configuration, this method will increase the confidence level for designers and specifiers for the world market in general and the North American market in particular.

The method has been used successfully on approximately 185,000 m^2 (2,000,000 ft^2) of 100mm thick concrete pavers in marine terminals and commercial properties in the U.S.

Applications for new construction could include verification of compactive effort required to achieve optimum consolidation of joint sands, determination of the presence of damage due to weather or other causes, and reference as acceptance criteria for finished pavement. Applications for existing pavements include mapping the extent of low strength areas, determining the result of repair efforts, measuring the changes in the strength of the paver surface in heavy use areas, and maintenance planning. With additional data collection it may be possible to predict remaining life in a paver surface.

Other data was taken that may also indicate the strength of the joint. One example is the movement curves taken at known problem locations. Some of these demonstrated elastic deformation of the joint followed by plastic deformation. This is to be expected for any material. However this information may ultimately provide a more complete indicator of the condition of the joint and a predictor of the future service life of the joint.

Another indicator may be the rebound of the joint after the test was complete. Stable joints returned to their original width. Less consolidated joints rebounded less and had wider measurements after the test. Since the initial joint width was not generally measured definitive results are not available. However, it may be practical to devise a test that measures the rebound on the joint after application of a known force. Such a test may be simple to perform and offer a standard for acceptance or rejection of an installation.

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Biography

P.E. Gille Wilbanks
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Mr. Wilbanks has been involved in Civil Engineering for over fifteen years. Professional experience includes civil design of marine terminals, commercial and industrial building sites, and remediation projects, Prior to working in civil engineering Mr. Wilbanks was employed as a geologist specializing in geophysical survey methods for discovery and exploitation of geothermal energy. To date he has been involved to the design or investigation of more than 8,000,000 m^2 of commercial and industrial pavements in North and South America and Asia, including approximately 1,000,00 m^2 of pavers. He graduated from Southern Oregon College, Ashland, Oregon, USA, with additional studies at Portland State University, Oregon, USA, and Universidad de Guanajuato, Gto., Mexico.