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A workability test for slip formed concrete pavements

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HIGHLIGHTS

- A novel workability test was developed for slip formed pavements.
- A procedure was developed to compare the workability of mixtures using the test.
- Validations and repeatability data is presented.
- The procedure was used to show gradation impacts on the workability of a concrete mixture.

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ABSTRACT

Evaluating the workability of concrete pavements prior to paving can be challenging. In this paper a novel test was developed using a simplistic and economic approach to measure the response of the concrete to vibration and the ability of the concrete to hold an edge. The variability of the test was evaluated and two comparisons were made to slip formed pavers. Also, a procedure was developed using the test for comparing the workability performance of different mixtures. The procedure was used to briefly investigate the impacts of aggregate gradation on the workability of slip formed paving mixtures.

1. Introduction

Currently, concrete mixtures are designed to meet the necessary strength and durability specifications while also providing sufficient workability for the desired application. Producing a concrete mixture that meets all of these requirements can be allusive and highly iterative [1–6]. Although tests exist to evaluate the strength and durability of a concrete mixture, only a few reliable tests can evaluate the workability of fresh concrete.

The workability of a mixture is a combination of the paste volume and yield stress, aggregate characteristics, and aggregate gradation [7,8]. While each of these variables has been known to be important, no tool exists that allows a quantitative impact of these variables for concrete pavements. When mixtures have insufficient workability, it has been common to increase the cement and water content of the mixture. This can increase cost and decrease the sustainability and durability of the concrete [2].

A concrete mixture for a slip formed pavement must be stiff enough to hold an edge after leaving the paver, but workable enough to be consolidated by vibration. This paper presents a simple and economical test method to evaluate the ability of a mixture to consolidate under vibration and subsequently hold a vertical edge under its weight.

1.1. Current laboratory tests for the workability of concrete

Historically, the workability of a concrete mixture was determined by experience. Multiple laboratory tests have been created to measure workability [2,6,9–12], but none are applicable for slip formed paving. The goal of a workability test should be to provide a standard measurement that evaluates the performance of a mixture in the desired application.

While the Slump Test ASTM C143 [11] has been widely used as a specification to evaluate workability, it is not useful for mixtures with low flowability [2,6]. Shilstone had this to say about the Slump Test, "The highly regarded Slump Test should be recognized

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for what it is: a measure of the ability of a given batch of concrete to sag." [13]. The Remolding Test [6], Vebe Apparatus Test [9] and other similar vibratory tests [9] measures the ability of a mixture to change shapes under vibration. However, transformation of a concrete mixture into a shape may measure the consolidation of a mixture, but promotes mixtures that are too flowable to hold an edge. The vibrating slope apparatus measures the rate of free flow on an angled chute subjected to vibration. While the test was designed to measure the yield stress and plastic viscosity of low slump concrete, it was found to be highly variable and not recommended [9]. The common denominator for these workability tests is the inability to evaluate the workability window required for a slip formed paver. The mixture must be able to be consolidated by vibration, but also stiff enough to hold an edge as it leaves a paver.

1.2. Objectives

A straightforward and inexpensive test was needed to evaluate the ability of a mixture to be placed with a slip form paver. Once this test was developed, it can be used to provide useful tools in quantifying the impacts of many workability variables. It was important to realize not all processes of a slip formed paver can be or should be mimicked for reasons of expense and complexity. Instead, the focus of this work was to simulate the important components of the paving process. This paper aimed to present a new test method to simulate the placing of a concrete mixture for slip formed paving, develop a systematic methodology to use this test to evaluate a mixture, establish the variance of this procedure, and finally show the utility of the test to evaluate different aggregate gradations. These contributions can provide new tools for both practitioners and researchers.

2. Development of the Box Test

A common performance issue for a concrete mixture being placed with a slip formed paver is the unresponsiveness of the mixture to consolidation [3]. Another common performance issue of a fresh concrete pavement is edge slumping, which is an edge deformation after the fresh concrete is placed, consolidated, and extruded from a slip formed paver. However, developing a laboratory test method to evaluate these performance issues would be very complex and expensive due to the variety of the different makes and models of slip formed paving machines and various operating procedures. In order to closely mimic the consolidation of a slip formed paver and provide awareness of possible edge slumping issues, a laboratory test was developed to evaluate the performance of a mixture to a standard amount of vibration and subsequently hold an edge.

Of all the slip formed pavement components, the vibrator contributes to the majority of the energy needed to consolidate concrete. The ability to consolidate fresh concrete is dependent on the workability of the mixture, the dimensions of the section being consolidated, and the speed and power of the vibrator [18]. A slip formed paver uses a hydraulic vibrator to produce the high amplitude, low frequency vibration to consolidate concrete [18]. To minimize the impacts of the air content, it is recommended that a vibrator on a slip formed paver has a frequency range of 5000–8000 vibrations per minute with a speed less than 910 mm (36 in.) per minute [1,3]. These vibrator heads are typically 57 mm (2.25 in.) in size with an average spacing of 300–400 mm (12–16 in.) and placed towards the top surface of the concrete.

However, it was not possible to use a hydraulic vibrator and make this test easy to implement. Instead, a 25 mm (1 in.) square head electric vibrator, which is commonly used in portable consolidation applications, was used. Calculations were utilized to find the energy that a concrete paver imparts to a concrete section when traveling at 910 mm (36 in.) per minute at 400 mm (16 in.) spacing. The concrete dimensions, vibrator frequency, head size, and time of vibration were adjusted to have comparable energy of a hydraulic vibrator on a paver. Also, instead of a single horizontal direction of a vibrator on a slip form paver, the test uses a two-directional vertical path to consolidate the concrete. To still obtain a comparable energy with a two-directional path, the time was adjusted to provide the concrete with similar amounts of consolidation. In Fig. 1, each component of the Box Test is displayed. Fig. 2 shows the 0.028 m^3 (1 ft^3) wooden formed box that consists of a 12.5 mm (0.5 in.) plywood with a length, width, and height of 300 mm (12 in.) with 50 mm (2 in.) L-brackets in two corners. Two pipe clamps with a span of 460 mm (18 in.) were used to hold the other two corners together. Each step of the Box Test is given in Fig. 3. Concrete was uniformly hand scooped into the box up to a height of 240 mm (9.5 in.). A 25 mm (1 in.) square head vibrator at 12,500 vibrations per minute used to consolidate the concrete by inserting it at the center of the box. The vibrator was lowered for 3 s to the bottom of the box and then raised upward for 3 s. Immediately, the clamps were detached from the side wall forms and then both side wall forms were removed.

The response of a mixture to vibration can be assessed by the surface voids observed on the sides of the box using Fig. 4. If a mixture responded well to vibration, the overall surface voids should be minimal because the vibration waves were able to transfer through the concrete and remove these voids [16]. However, if the sides of the concrete mixture had large amounts of surface voids, it did not respond well to vibration. The average surface voids for each of the four sides were estimated with a number ranking using Fig. 4 and an overall average visual ranking was given to each test. The average of four sides with 10–30% surface voids, or a ranking of 2 for a mixture was deemed a good vibration response and an acceptable amount of voids.

Finally, top and bottom edge slumping can be measured to the nearest 5 mm (0.25 in.) by placing a straightedge at a corner and horizontally using a tape measure to find the length of the highest extruding point.

2.1. The Box Test procedure for comparing the workability of mixtures

When a mixture is not workable enough, paste or WR can be added to increase the workability of the mixture. By adding paste or WR, it can reduce the yield stress of a mixture and improve the response to vibration. Using this same concept with the Box Test, when a mixture receives a ranking of a 3 or 4, the response to vibration was poor. Additional WR or paste can be added to achieve the required workability. However, WR will be

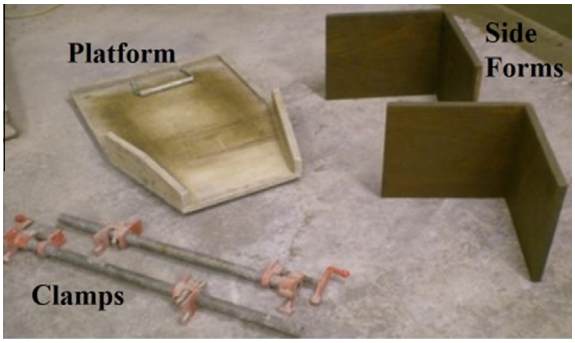

Fig. 1. Each component of the Box Test.