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A workability test for slip formed concrete pavements

Marllon Daniel Cook *, M. Tyler Ley, Ashkan Ghaeezadah

Oklahoma State University, Oklahoma, United States

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

* Corresponding author. Address: School of Civil and Environmental Engineering, Oklahoma State University, 207 Engineering South, Stillwater, OK 74078, United States. Tel.: +1 (918) 284 5652.

E-mail address: dcoo@okstate.edu (M.D. Cook).

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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

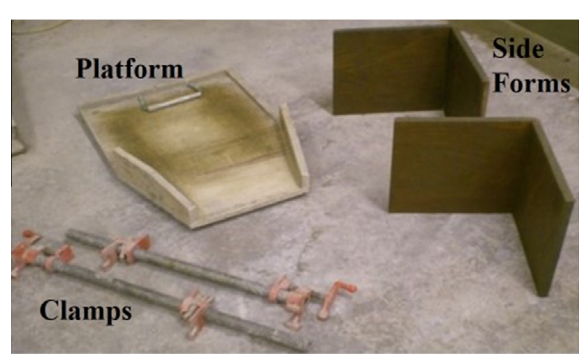

Fig. 1. Each component of the Box Test.

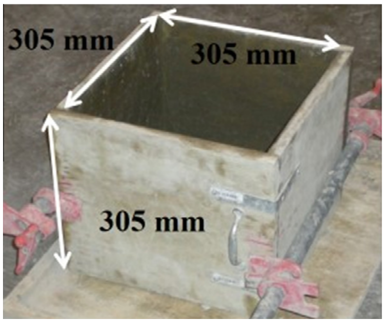

Fig. 2. Assembled components and inside dimensions.

used for this research because increasing the paste content will largely change the volume of the mixture, which is not desirable.

If the paste volume and the ratio of water to cementitious material (w/cm) are held constant while changing other properties of a mixture such as gradation, or aggregate characteristics, the response of the mixture to vibration can be quantified by comparing the amount of WR needed to pass the Box Test. This is achieved by making a concrete mixture and conducting the Box Test. If the mixture did not pass the Box Test, WR was added and remixed until the mixture passed the Box Test. Mixtures requiring smaller amounts of WR performed better than mixtures that needed larger amounts of WR to pass the Box Test.

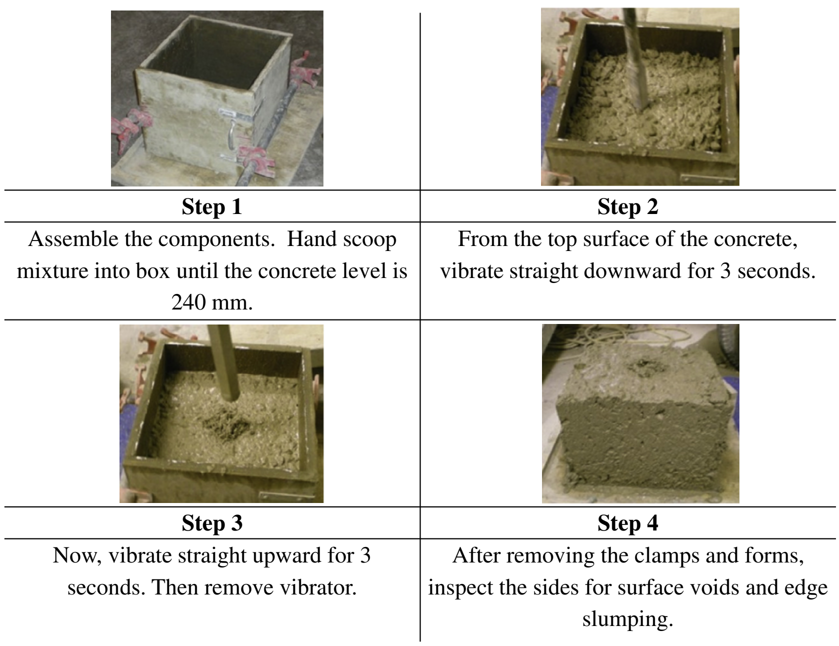

Fig. 3. The four steps of the Box Test.

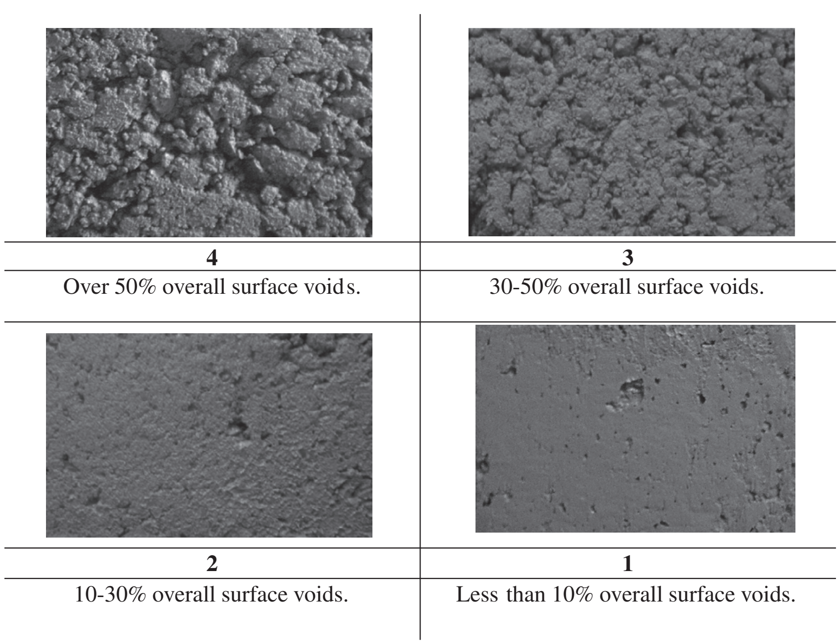

Fig. 4. Percentage and numerical surface void values.

2.2. Detailed description of the Box Test procedure

After a mixture was prepared, the Slump and the Box Test were conducted. If the mixture did not receive a visual rating of 2 as shown in Fig. 4 then the material from the slump and Box Test were placed back into the mixer. The mixer was turned on and a discrete amount of WR was added. After 3 min of mixing, the Slump and Box Test were conducted. This process was continued until the mixture was observed to receive a visual ranking of 2. Typically, WR dosages of 130 mL/100 kg (2 oz/cwt) increments was used. The dosage value varied depending on the amount of voids observed. For example, if the Box Test was conducted and the mixture was found to have close to 50% overall surface voids, the operator may need to add 260 mL/100 kg (4 oz/cwt) before testing again. In Fig. 5, a flow chart shows the procedure for comparing the workability of mixtures using the Box Test. All mixtures were evaluated within a 1 h period in a 22 °C (72 °F) room. If the test was not complete within 1 h, the sample was discarded to ensure initial stiffening did not affect the results.

3. Material and methods

3.1. Materials

The concrete mixtures investigated were prepared using a Type I cement that meets the requirements of ASTM C 150 [14]. All mixtures contained 20% by mass of an ASTM C 618 Class C fly ash [15]. The water reducer (WR) was a lignosulfonate mid-range [16] with the manufacturer's maximum recommended dosage of 782 mL/100 kg of cementitious material (12 oz/cwt). Three different crushed limestones A, B, and C and a river gravel D each have a nominal maximum of 19 mm (0.75 in.) coarse and 9.5 mm (0.375 in.) intermediate. Visually, the crushed limestones are angular while the river rock is rounded. Also, crushed limestone B is visually flatter than crushed limestone A and C. Two different river sands were also used. The gradations of the aggregates used in this study vary. These different materials were included to highlight the applicability of the test to a wide range of materials. More detailed descriptions of the materials and a sieve analysis can be found in another publication [17].

3.2. Mixture design

A slip formed pavement mixture should contain enough paste to allow the concrete to be consolidated, but still keep a stiff edge. Since the aggregate characteristics and gradation can affect the workability, the cementitious material content varied from 192 to 213.4 kg (423 to 470 lbs) with 20% fly ash replacement and a constant w/cm at 0.45. To keep the variables low in this research, air entraining admixtures (AEAs) were typically not used. However, to investigate the effects of AEAs on surface voids, a wood rosin AEA was used on nine different mixtures. Table 1 shows the twenty-eight different mixture designs were used in this paper. The WR doses for each mixture investigation will be presented later.

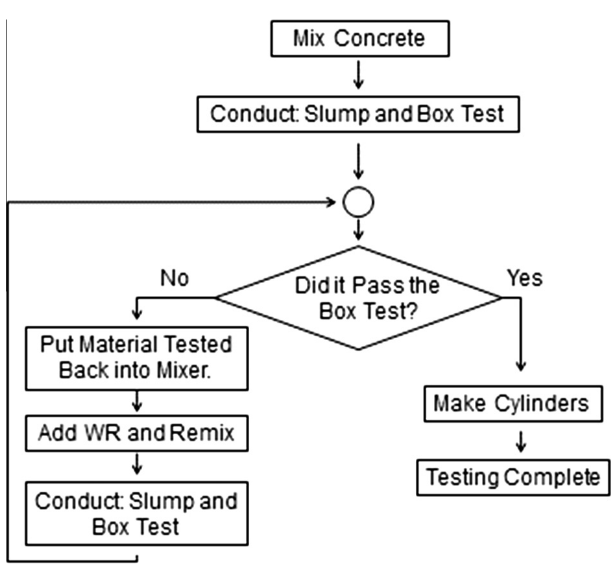

Fig. 5. Flow chart of the Box Test procedure for comparing the workability of mixtures.

3.3. Mixing and testing procedure

Aggregates are collected from outside storage piles, and brought into a temperature-controlled laboratory room at 22 °C for at least 24-h before mixing. Aggregates were placed in a mixing drum and spun. Then a representative sample was taken for a moisture correction.

At the time of mixing all aggregates were loaded into the mixer along with approximately two-thirds of the mixing water. This combination was mixed for 3 min to allow the aggregates to approach the saturated surface dry (SSD) condition and ensure the aggregates were evenly distributed. Next, the cementitious material and the remaining water was added and mixed for 3 min. The resulting mixture rested for 2 min while the sides of the mixing drum were scraped. After the rest period, the mixer was turned on and mixed for 3 min. The initial testing of the mixture included Slump and the novel test method called the Box Test, whose aim is to examine the response to vibration.

4. Results

A number of variables were investigated to validate the Box Test and the procedure for comparing the workability of mixtures. These variables included: effects of sequential dosage, repeatability of a mixture by single and multiple operators, and comparison of visual rankings from multiple operators. A limited number of tests were also completed in the field with a side-by-side comparison to a slip formed paver.

4.1. Validating the Box Test

4.1.1. Multiple evaluators

Three different evaluators used the visual number ranking scale to evaluate the void range amount of eleven different mixtures. Ten out of eleven evaluations had the same average ranking from the three evaluators. The single inconsistent evaluation was composed of two evaluators ranking the mixture as a three while the other evaluator gave the mixture a ranking of two. This suggests that the area of surface voids was close-to the boundary between a two and three.

4.1.2. Measuring edge slumping

The twenty-eight mixtures investigated displayed straight edges and differed by less than 6.35 mm (0.25 in.). This suggests the mixtures would have satisfactory performance in the field.

4.1.3. The effects of air entrainment on visual ratings

A series of nine mixtures without any additional air entrainment were conducted using the Box Test. Next the mixtures were replicated with various amounts of air entrainment. Using three different evaluators to visually rank the surface voids, the results showed the visual ranking was the same whether AEA was used or not. It was observed the addition of AEA slightly lowered the surface voids. This may be due to the AEA increasing the workability of the mixture. However, the AEA did not change the visual ranking.

4.1.4. Comparison to a slip formed paver

Comparisons between the Box Test and two different slip formed pavers on two different job sites were completed. On both jobsites, three different truckloads of fresh concrete were adequately placed and consolidated with a slip formed paver. After a test sample was taken from each truckload, the Box Test was performed. Each sample had a consistent satisfactory visual ranking of a two and no edge slumping.

Table 1
Summary of the mixture designs.

Mix	Quarry	Sand source	Coarse (kg)	Int. (kg)	Sand (kg)	Cement (kg)	Fly ash (kg)	Water (kg)
1	A	A	920	301	751	223	56	126
2	A	A	997	328	649	223	56	126
3	A	A	1189	0	773	223	56	126
4	B	A	976	244	719	223	56	126
5	B	A	738	453	750	223	56	126
6	A	B	1189	0	779	223	56	126
7	A	B	953	241	765	223	56	126
8	C	A	740	569	773	201	50	113
9	C	A	802	618	667	201	50	113
10	C	A	1268	0	782	201	50	113
11	C	A	888	535	669	201	50	113
12	C	A	975	452	670	201	50	113
13	C	A	865	505	718	201	50	113
14	D	A	565	662	757	201	50	113
15	D	A	612	726	643	201	50	113
16	D	A	659	790	529	201	50	113
17	C	A	1288	170	656	201	50	113
18	C	A	1201	265	644	201	50	113
19	C	A	1112	359	631	201	50	113
20	C	A	1025	454	619	201	50	113
21	C	A	937	550	607	201	50	113
22	C	A	849	646	595	201	50	113
23	C	A	761	743	584	201	50	113
24	C	A	672	840	572	201	50	113
25	C	A	1196	389	524	201	50	113
26	C	A	1029	329	740	201	50	113
27	C	A	942	298	848	201	50	113
28	C	A	857	267	959	201	50	113

4.2. Validating the procedure for comparing the workability of mixtures

4.2.1. Effects of sequential dosage

To investigate the impacts of sequential WR dosages of the test procedure over time, nine replicate mixtures were evaluated where a single dosage of WR was added during the initial mixing procedure instead of the sequential dosages used in the test procedure over time. Table 2 shows the results of the Slump and the Box Test were found to be very similar between replicate mixtures.

4.2.2. Repeatability of a mixture by single and multiple operators

The result for the repeatability of WR dosage for a single operator is shown in Table 3. Ten mixtures were blindly replicated to compare the fresh properties. For each mixture, the WR dosage added was enough to receive a 2 ranking. The average percent difference was 16.1% with a standard deviation of 13.5%. The absolute difference in WR was 80 mL/100 kg with a standard deviation of 49.9 mL/100 kg. In Table 4, five different mixtures were repeated with three different operators. This allowed ten different comparisons to be made. Each operator added enough WR for a mixture to have a two visual ranking. For each mixture the average WR value and the absolute difference, which was the absolute value difference between the two WR values, was given. The percent difference was the absolute difference divided by the average WR expressed in percent.

Table 2
Comparison of single and multiple dosages.

Mix	WR (mL/100 kg)	Multiple dosage		Single dosage	
		Rank	Slump (mm)	Rank	Slump (mm)
1	540	2	40	2	40
6	1178	2	50	2	50
4	872	2	50	2	50
8	358	2	10	2	10
9	378	2	30	2	30
10	944	2	30	2	30
11	221	2	25	2	10
12	404	2	10	2	10
13	879	2	50	2	50

4.2.3. Evaluating gradations using the Box Test

With the w/cm and paste content held constant, the Box Test was used on a variety of mixtures to show the ability of the Box Test to make quantitative comparisons between different gradations. The combined gradations were plotted on the individual percent retained chart. Fig. 6 holds the sand amount constant and varies the amounts of coarse to intermediate. Fig. 7 holds the coarse to intermediate ratio constant and varies the amounts of sand. In each figure, the WR dosage required to pass the Box Test is given in the legend.

5. Discussion

5.1. The Box Test

The Box Test was a useful and consistent tool in evaluating the response of a concrete mixture to vibration and simultaneously holding an edge. It was important to note the majority of mixtures investigated had less than a 5 mm (0.25 in.) edge slump and therefore edge slumping could not be thoroughly evaluated. It seemed that the visual ranking scale was a useful indication to how the concrete responded to vibration. Also, it should be noted that a consistent slump value did not corresponded to a passing Box Test value. This will be discussed in more detail later, but this was a significant observation that is prevalent in all results.

5.2. Procedure for comparing the workability of different mixtures using the Box Test

5.2.1. Effects of sequential dosage

Nine different mixtures were investigated to compare the response consistency in multiple and single dosages. Whether a

Table 3
Single operator repeatability.

Mix	Operator	WR (mL/100 kg)	Slump (mm)	Average WR (mL/100 kg)	Absolute difference (mL/100 kg)	Percent difference (%)
1	A	540	40	579	78	13.5
		618	30			
2	A	944	50	912	65	7.1
		879	40			
3	A	456	50	375	163	43.5
		293	50			
4	A	977	40	970	14	1.4
		963	40			
5	A	1139	50	1084	110	10.1
		1029	50			
8	A	358	15	436	156	35.8
		514	15			
9	A	378	30	414	71	17.2
		449	25			
10	A	944	30	967	46	4.8
		990	25			
11	A	475	15	440	71	16.2
		404	15			
12	A	247	25	234	26	11.1
		221	15			
Average					80	16.1
Standard deviation					49.9	13.5

Table 4
Multiple operator repeatability.

Mix	Operator	WR (mL/100 kg)	Slump (mm)	Average WR (mL/100 kg)	Absolute difference (mL/100 kg)	Percent difference (%)
3	A	456	50	345	228	66.7
	B	228	50			
3	A	456	50	397	124	31.5
	C	332	50			
8	A	514	15	436	156	35.8
	B	358	25			
8	A	514	15	423	182	43.0
	C	332	25			
9	A	449	25	378	143	37.9
	B	306	30			
9	A	449	25	462	20	4.4
	C	469	30			
10	A	990	25	1009	32	3.2
	B	1022	25			
10	A	990	25	990	0	0.0
	C	990	25			
11	A	475	15	417	117	28.1
	B	358	15			
11	A	475	15	534	117	21.9
	C	592	15			
Average					111.9	27.2
Standard deviation					73.7	20.8

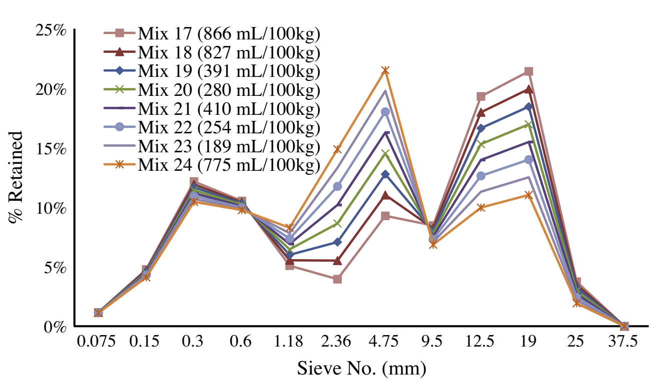

Fig. 6. The Box Test measuring the gradation changes of intermediate to coarse aggregate with a fairly constant sand amount.

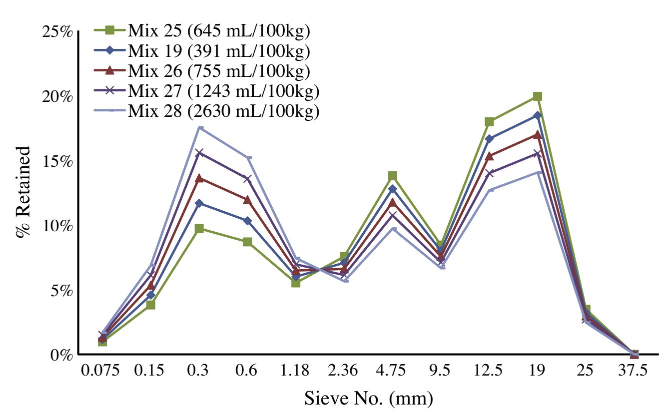

Fig. 7. The Box Test measuring the gradation changes of sand to coarse aggregate.

single or multiple dosage of WR was used, the slump value varied while the Box Test value stayed consistent. This makes logical sense due to the concrete being in the induction stage of hydration.

5.2.2. Repeatability of a mixture by single and multiple operators

In Table 4, ten different mixtures were blindly replicated by a single operator. From those mixtures the largest difference in WR to pass the Box Test ranking scale was 163 mL/100 kg (2.5 oz/cwt) with an average absolute difference of 78 mL/100 kg (1.2 oz/cwt) and a standard deviation of 50 mL/100 kg (0.77 oz/cwt). This suggests a single user can complete the test to 179 mL/100 kg (2.74 oz/cwt) with a 95% confidence interval. Since this was close-to the same size of a single dosage of WR in this testing, it was considered to be satisfactory.

The repeatability of multiple operators was shown in Table 3. The maximum difference in WR dosage was 228 mL/100 kg (3.6 oz/cwt) with an average value of 112 mL/100 kg (1.7 oz/cwt) and a standard deviation of 73.7 mL/100 kg (1 oz/cwt). These values were higher than values obtained from a single operator. The results were to be expected since some variance in replicating the same concrete mixture, subjectivity in the dosage of WR, and the visual ranking. However, these values were not extreme and still provide a useful comparison method between mixtures. With a 95% confidence interval, two tests from multiple operators should be repeatable to 254 mL/100 kg (3.9 oz/cwt) or about the size of two separate dosages of WR for this testing. The slump of each replicated mixture varied by 12.5 mm (0.5 in.) or less, but a consistent value of slump was not shown with the Box Test results.

5.2.3. Using the Box Test to compare the workability of different mixtures

Both Figs. 6 and 7 use the WR dosage required to achieve a pass ranking in the Box Test to compare the performance of aggregate gradations with fixed paste content. The gradations requiring a higher dosage of WR are less desirable than a gradation requiring a lower WR dosage. Both figures have a range of gradations requiring a low amount of WR and would be expected to perform well. Gradations outside of this range seemed to require significantly higher amounts of WR with only small changes in gradation. While the amount of coarse and intermediate varied largely with only little differences in WR dosage, a change in the amount of sand had a greater impact on the workability of the mixture. This data was useful as these comparisons were not possible with previous testing methods and will be discussed further in future publications.

5.3. Slump and Box Test measurements

Even though the slump values were consistent between all repeated mixtures, a single slump value did not correspond with a passing performance in the Box Test. When a mixture passed the Box Test, the slump value was within the typical range for a concrete pavement mixture (ranging between 0 and 50 mm) (0–2 in.)) [1]. This is a critical observation supports the idea that the Slump Test does not provide a consistent measuring tool for concrete used in slip formed paving. It further suggests the Box Test was more sensitive to these mixtures.

5.4. Improvements to the Box Test

While the Box Test was a useful test to evaluate the workability of a mixture for a slip formed pavement, improvements could still be made to the Box Test and the procedure for comparing mixtures.

The primary variability of the test comes from the dosage of WR added by the operator. If a more systematic WR dosage procedure was used then this may reduce the variability between users. However, the variability of the test was found to be within acceptable ranges to make comparisons between concrete mixtures. This was especially true for single operators.

Although the visual ranking scale was found to be very consistent, it could still be improved if a systematic point count method was used to quantify the amount of voids on the surface similar to the hardened air void analysis. An image analysis technique or a simple transparent overlay could be placed on the concrete and individual points could be counted and compared to the total area, which was the same technique used in ASTM C 457 and other work [19,20].

Additional work could be completed to determine the sensitivity level of the test for different mixing and consolidation procedures. Further evaluation with field concrete and the Box Test would also be beneficial. Edge slumping measurements could also be further investigated by determining the impacts of different sample heights to real edge slumping measurements in the field.

5.5. Practical implications

The Box Test was designed to be a simple and inexpensive test using common equipment available in the concrete industry. It was important to realize the Box Test was designed to evaluate the response of a concrete mixture to vibration while simultaneously holding an edge and not necessarily to correlate with the exact performance of a slip formed paver.

The procedure for comparing the workability of mixtures was able to quickly and easily evaluate mixtures in a useful and quantitative process. By using this procedure, it can make valuable assessments of different mixture proportions to improve the concrete mixture design process for slip form paving. However, the WR dosage required to achieve the desired response to vibration was likely higher than field requirements.

6. Conclusion

An outline for the Box Test and the procedure for comparing the workability of mixtures using the Box Test was given and the variability of the test was investigated. The results show the Box Test and the procedure for comparing mixtures are both useful and repeatable tools to evaluating different mixtures for slip formed paving.

The following points were made:

- This work shows the Box Test provides a simple and quantitative tool to evaluate the impact of different mixture variables for slip formed pavement mixtures.
- The consistency of multiple evaluators to visually measure surface voids was shown to be over 90%.
- In two different field comparisons, the Box Test performed comparably the same as a slip formed paving machine.
- No difference was found between mixtures evaluated with a single or multiple dosage of water reducer for the Box Test.
- The repeatability of a single operator adding WR dosage had a maximum expected difference of 163 mL/100 kg (2.5 oz/cwt) and an average absolute difference of 80 mL/100 kg (1.2 oz/cwt).
- Multiple operators adding WR dosage had an average absolute difference of 112 mL/100 kg (1.7 oz/cwt) and a maximum expected difference of 254 mL/100 kg (3.9 oz/cwt).
- The procedure using the Box Test was able to provide a quantitative comparison of the mixture proportions for coarse, intermediate, and fine aggregate on the response to vibration.

These findings will be useful to help guide design a concrete mixture for slip formed paving. Work is ongoing to use the Box Test to make a quantitative comparison between a number of mixture design variables that were not previously possible. Results will be provided in future publications.

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