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Evaluation of performance characteristics of the heavy vehicle simulator in Florida

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Abstract

The Florida Department of Transportation (FDOT) Materials Office has recently acquired a heavy vehicle simulator (HVS) and constructed an accelerated pavement testing (APT) facility which uses this HVS. An investigation was conducted to evaluate the operational performance of the HVS, and to determine its most effective test configurations for use in evaluating the rutting performance of pavement materials and/or designs under typical Florida traffic and climate conditions. Five trial runs with the HVS used a super single tire with a load of 4082 kg, tire pressure of 793 kPa and a wheel traveling speed of 12.9 km/h. These five trial runs used different combinations of wheel traveling direction (uni-directional or bi-directional), total wheel wander and wander increments. The uni-directional loading was found to be a more efficient mode for evaluation of rutting performance using the HVS. As compared with the bi-directional loading mode, the uni-directional mode produced substantially higher rut depths for the same number of wheel passes and also for the same testing time duration. When the bi-directional loading with no wander was used, imprints of the tire treads were observed on the wheel track. It was found that using a loading mode with wander smoothened out the imprints of the tire treads considerably. The uni-directional loading mode with 10 cm wander using 2.5 cm increments was selected to be used for evaluation of rutting performance based on consideration of testing efficiency and realistic rutting results.

Keywords: Accelerated pavement testing; Superpave; Heavy vehicle simulator; Rutting

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1. Introduction

1.1. Background

FDOT started the use of Superpave mixtures on its highway pavements in 1996. Modified binders have also been used in some of the Superpave mixtures in an effort to increase the cracking and rutting resistance of these mixtures. Due to the short history of these mixtures, it is still too early to assess the long-term performance of these Superpave mixtures and the benefits from the use of the modified binders. There is a need to evaluate the long-term performance of these mixtures and the benefits obtained from the use of modified binders, so that the Superpave technology and the selection of modified binders to be used could be effectively applied.

The FDOT Materials Office has recently acquired a heavy vehicle simulator (HVS) and constructed an accelerated pavement testing (APT) facility which uses this HVS. The HVS can simulate 20 years of interstate traffic on a test pavement within a short period of time. Thus, a research study was started to evaluate the long-term performance of Superpave mixtures and modified Superpave mixtures using the APT facility. This research work is

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being carried out by a cooperative effort between the FDOT and the University of Florida. The main objectives of this study are as follows:

1. To evaluate the operational performance of the HVS, and to determine its most effective test configurations for use in evaluating the rutting performance of pavement materials and/or designs under typical Florida traffic and climate conditions.
2. To evaluate the rutting performance of a typical Superpave mixture used in Florida and that of the same Superpave mixture modified with a SBS polymer.
3. To evaluate the relationship between mixture properties and the rutting performance.
4. To evaluate the difference in rutting performance of a pavement using two lifts of modified mixture versus a pavement using one lift of modified mixture on top of one lift of unmodified mixture.

1.2. Scope

This paper covers the evaluation of the operational performance of the HVS and determination of its most effective test configuration to evaluate the rutting performance of pavement materials under typical Florida traffic and climate conditions.

2. Materials

The two asphalt mixtures which were placed in the test pavements were (1) a Superpave mixture using a PG67-22 asphalt and (2) a Superpave mixture using a PG67-22 asphalt modified with a SBS polymer which had an equivalent grading of PG76-22. Both mixtures were made with the same aggregate blend having the same gradation, and had the same effective asphalt content. The types and gradation of the aggregate blend used were similar to those of an actual Superpave mixture which had recently been placed down in Florida. These mixtures can be classified as 12.5 mm fine Superpave mixes, with a nominal maximum aggregate size of 12.5 mm and the gradation plotted above the restricted zone. The properties of the aggregates used are shown in Table 1.

The designs for these two mixtures were done by the personnel of the Bituminous Section of the FDOT Materials Office. The optimum binder content was determined according to the Superpave mix design procedure and criteria using a design traffic level of $10–30 \times 10^6$ ESALs. The volumetric properties for these two mixtures are shown in Table 2.

3. Experimental design

3.1. Test track layout

The layout of the test track, which was constructed at the FDOT APT facility for this study, is shown in Fig. 1. The test track consists of seven test lanes. Lanes 1 and 2 have two 5 cm lifts of a SBS-modified Superpave mixture. Lane 3 has a 5 cm lift of the SBS-modified Superpave mix over a 5 cm lift of unmodified Superpave mix. Lanes 4–7 have two 5 cm lifts of the unmodified Superpave mix. Each lane is divided into three test sections, designated as A, B and C. The main testing program is to be run on Test Lanes 1–5, with a total of 15 test sections. Test Lane 6 is set aside for additional testing deemed necessary or desirable at the end of the main testing program. Test Lane 7 is to be used for trial runs to evaluate the performance characteristics of the HVS and to determine the most effective test configuration to be used in the testing program.

3.2. Testing configurations

All five trial runs with the HVS used a super single tire with a load of 4082 kg, tire pressure of 793 kPa and a wheel traveling speed of 12.9 km/h. These five trial runs used different combinations of wheel traveling direction (uni-directional or bi-directional), total wheel wander and wander increments as follows:

(1) bi-directional travel with no wander,
(2) uni-directional travel with no wander,
(3) uni-directional travel with 10 cm wander in 5 cm increments,
(4) bi-directional travel with 10 cm wander in 5 cm increments,
(5) uni-directional travel with 10 cm wander in 2.5 cm increments.

Trial Run 1 was run on Test Section 7C. Trial Runs 2 and 3 were run on the western and the eastern sides, respectively, of Test Section 7B, and were designated as 7B-W and 7B-E. The edges of wheel tracks from these two tests were separated by a distance of about 38 cm. Trial Runs 4 and 5 were run on the eastern and western sides, respectively, of Test Section 7C, and were designated as 7A-E and 7A-W. The edges of wheel tracks from these tests were separated by a distance of about 28 cm.

3.3. Temperature measurement

The temperature distribution in each test pavement was monitored by eight thermocouples. For each test section, three thermocouples (#1, 2 and 3) were placed on top of the base course, three (#4, 5 and 6) were placed between the two lifts of asphalt mixture, and two (#7 and 8) were placed on the surface. During each of the trial runs, the temperature readings for the test section were taken every 15 min and recorded by a PC data acquisition system. Table 3 displays (1) the average of the daily minimum temperatures, (2) the average of the daily maximum temperatures, (3) the overall minimum temperature, and (4) the overall maximum temperature as recorded by the three thermocouples between the two lifts of asphalt

Table 1
Temperatures of test pavements as measured by thermocouples placed between the two 5 cm lifts of asphalt mixtures

Section 7C	Bi-directional loading, no wander			
	Thermocouple 4	Thermocouple 5	Thermocouple 6	Average
Avg. daily min. Temp (°C)	20.6	20.4	20.3	20.4
Avg. daily max. Temp (°C)	31.3	31.6	33.3	32.1
Overall min. Temp (°C)	18.9	20.1	18.0	19
Overall max. Temp (°C)	34.2	33.7	37.5	35.1
Section 7B-W	Uni-directional loading, no wander			
Avg. daily min. Temp (°C)	19.2	18.9	19.0	19.0
Avg. daily max. Temp (°C)	33.1	28.4	27.7	29.7
Overall min. Temp (°C)	13.3	12.7	13.1	13
Overall max. Temp (°C)	36.7	31.9	32.4	33.6
Section 7B-E	Uni-directional loading, 10 cm wander with 5 cm step			
Avg. daily min. Temp (°C)	14.5	15.3	14.1	14.6
Avg. daily max. Temp (°C)	16.3	23.0	22.9	20.7
Overall min. Temp (°C)	7.4	8.8	7.0	7.7
Overall max. Temp (°C)	32.2	28.6	28.9	29.9
Section 7A-E	Bi-directional loading, 10 cm wander with 5 cm step			
Avg. daily min. Temp (°C)	9.0	9.4	9.2	9.2
Avg. daily max. Temp (°C)	21.6	19.6	17.9	19.7
Overall min. Temp (°C)	2.9	3.6	2.9	3.1
Overall max. Temp (°C)	30.2	36.1	26.4	30.9
Section 7A-W	Uni-directional loading, 10 cm wander with 2.5 cm step			
Avg. daily min. Temp (°C)	13.1	12.7	13.1	13.0
Avg. daily max. Temp (°C)	25.0	23.1	22.4	23.5
Overall min. Temp (°C)	3.2	3.3	4.3	3.6
Overall max. Temp (°C)	34.6	29.8	34.1	32.8

Table 2
Properties of aggregates used in the asphalt mixtures

Type material	FDOT code	Producer	Pit no.	Date sampled
1. S-1-A stone	41	Rinker Mat. Corp.	TM-489 87-089	9/11/00
2. S-1-B stone	51	Rinker Mat. Corp.	TM-489 87-089	9/11/00
3. Screenings	20	Anderson Mining Corp.	29-361	9/11/00
4. Local sand		V.E. Whitehurst & Sons, Inc.	Starvation Hill	9/11/00

Percentage by weight total aggregate passing sieves

Blend	12%	25%	48%	15%	JMF	Control Points	Restricted Zone
Number	1	2	3	4			
Sieve size							
19.0 mm	99	100	100	100	100	100	
12.5 mm	45	100	100	100	93	90–100	
9.5 mm	13	99	100	100	89	90	
No.4 (4.75 mm)	5	49	90	100	71		
No.8 (2.36 mm)	4	10	72	100	53	28–58	39.1–39.1
No.16 (1.18 mm)	4	4	54	100	42		25.6–31.6
No.30 (600 μm)	4	3	41	96	35		19.1–23.1
No.50 (300 μm)	4	3	28	52	22		
No.100 (150 μm)	3	2	14	10	9		
No. 200 (75 μm)	2.7	1.9	5.9	2.2	4.5	2–10	
G_{sb}	2.327	2.337	2.299	2.546	2.346		

Table 3
Volumetric properties of the asphalt mixtures

Mix type	Asphalt binder	% Binder	V_a at N_{des}	VMA	VFA	P_{be}	G_{mm}
Superpave mix (compacted at 148 °C)	PG67-22	8.2	4.0	14.5	72	4.97	2.276
Modified Superpave mix (compacted at 163 °C)	PG76-22	7.9	3.8	14.2	73	4.90	2.273

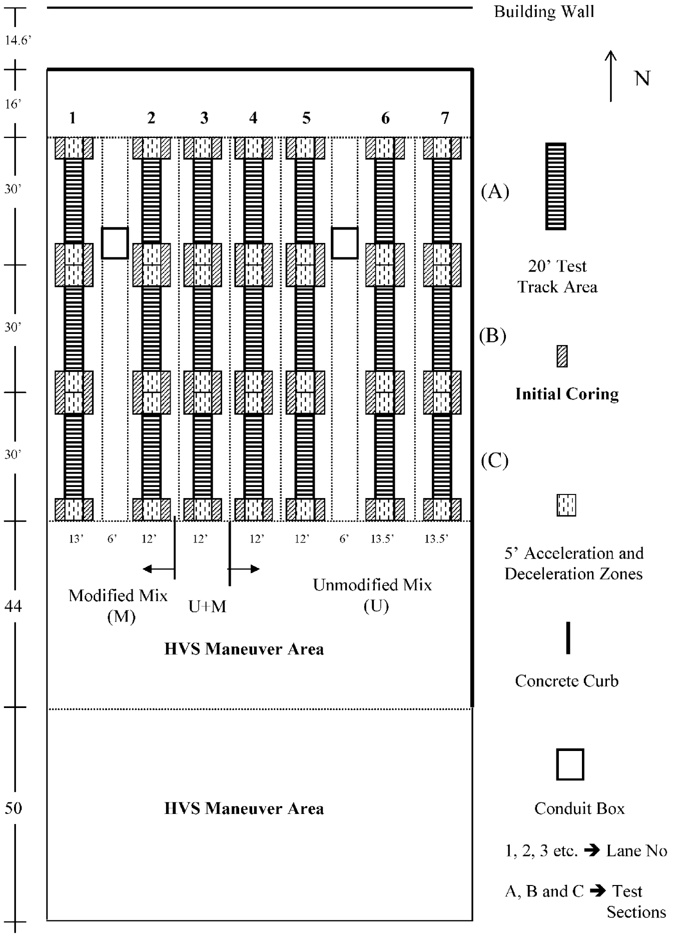

Fig. 1. APT test track layout (plan view).

mixtures for each test. The averages of the values from the three thermocouples are also given in the table.

3.4. Rut measurement

For each test pavement, five transverse profiles were measured on a daily basis by means of a straight edge placed across the pavement at five fixed locations evenly spaced across the test section. A ruler was used to measure the relative elevation (or profile) of the pavement surface with respect to the straight edge. Fig. 2 shows how this measurement was done.

Rut depths were determined by two different methods. In the first method, the initial surface profile of the pavement before the test was subtracted from the measured surface profile at specified times to give the "differential surface deformations." This method is termed the "Differential Surface Deformation Method" in this paper.

In the second method, the measured profile was plotted, and a straight line was drawn on the plot such that it touched the highest point on each side of the wheel track. The maximum distance between the straight line and the measured profile was determined as the rut depth. This procedure is similar to how rut depths are usually determined in the field. Fig. 3 illustrates how this was done. This method is termed the "Surface Profile Method" in this report.

Fig. 2. Photo of straight edge used for measuring rut depth.

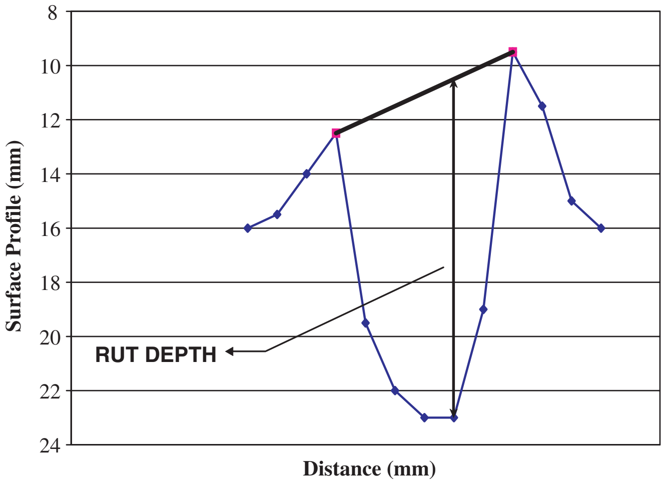

Fig. 3. Rut depth in the surface profile method.

4. Test results and discussion

4.1. Comparison between bi-directional and uni-directional loading with no wander

Trial Test No. 1 (bi-directional loading with no wander, Test Section 7C) was run for 12 days with a total of 315,299 wheel passes. Fig. 4 shows a picture of the rutted pavement at the end of the test. With this mode of loading, the wheel appeared to travel along the exact tire print as it moved back and forth without lifting itself off the ground. As a result, imprints of the tire treads could be clearly seen on the wheel track. This is not representative of pavement rutting in the field.

Trial Test No. 2 (uni-directional loading with no wander, Test Section 7B-W) was run for 8 days with a total of 101,414 passes. Fig. 5 shows a picture of the rutted pavement at the end of the test. It can be seen that the imprints of the tire treads were smoothen out considerably in this loading mode. However, continuous ridges were observed along the wheel track. Although the observed rutted pavement surface represents an improvement over that observed in the bi-directional loading case, it is still not representative of pavement rutting in the field.

Fig. 4. Photo of Section 7C (bi-directional loading with no wander).

Fig. 5. Photo of Section 7B-W (uni-directional loading with no wander).

It was also observed that the loading wheel experienced more wear when run in the uni-directional mode. Accumulation of rubber, which was rubbed off from the tire, was observed on the surface of the wheel track, and mostly at the starting location.

Fig. 6 shows the comparison of rut depths as measured by the differential surface deformation method as a function of number of wheel passes between these two modes of loading. Fig. 7 shows similar comparison of rut depths as measured by the surface profile method. It can be seen from both figures that for the same number of wheel passes, the uni-directional loading produced substantially higher rut depths than those by the bi-directional loading. In the uni-directional loading mode, the asphalt mixture was pushed (or shoved) in one direction, and the amount of shoving would just keep on building up (with no compensating effects). In the bi-directional loading mode, the asphalt mixture was pushed in one direction and then in the opposite direction. The deformation in one direction can compensate for the deformation in the other direction.

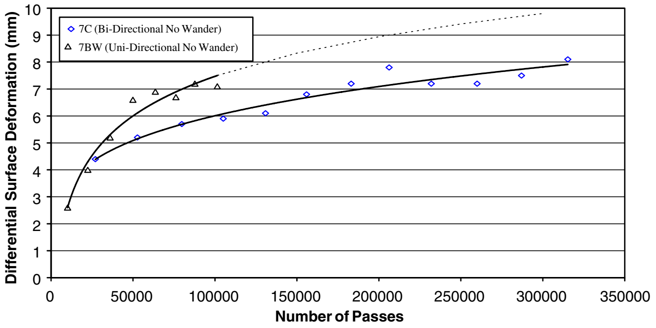

Fig. 6. Comparison of differential surface deformation vs. number of passes between bi-directional and uni-directional loading with no wander.

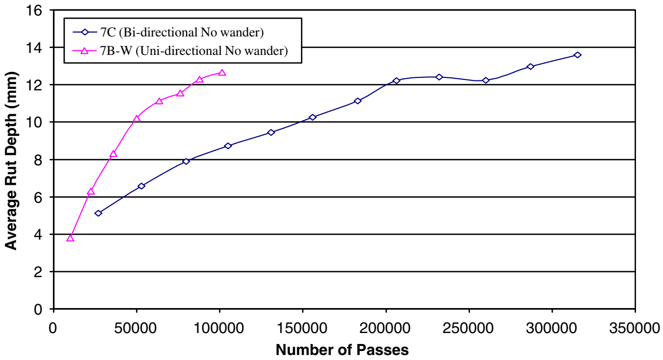

Fig. 7. Comparison of average rut depth as measured by the surface profile method vs. number of passes between bi-directional and uni-directional loading.

As a result the observed rut depth in the bi-directional mode was much lower.

Figs. 8 and 9 show the comparisons of rut depths versus testing time between these two modes of loading, using the differential surface deformation method and surface profile method, respectively. Although the bi-directional mode can apply almost twice the number of wheel passes per day as compared with the uni-directional mode, the uni-directional mode of loading still produced slightly higher rut depths for the same testing duration.

A comparison between the recorded pavement temperatures for these two tests show that both the average daily maximum temperature and the overall maximum temperature during the bi-directional test were higher than those during the uni-directional test. Although the pavement temperature was relatively lower during the uni-directional test, rutting was still observed to be higher. Thus, it can be concluded that the uni-directional loading is a more efficient mode for evaluation of rutting performance using the HVS.

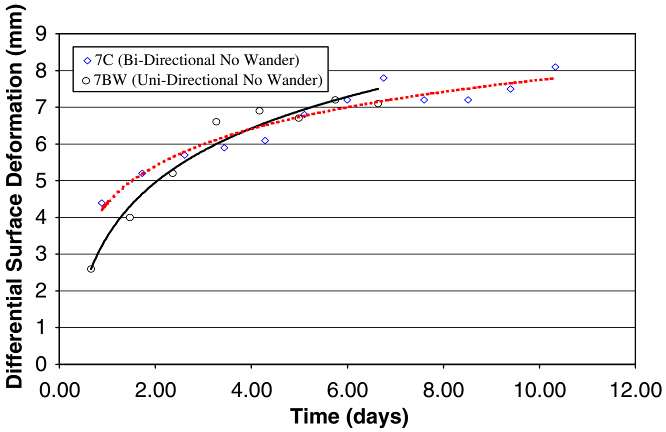

Fig. 8. Comparison of differential surface deformation vs. time between bi-directional and uni-directional loading.

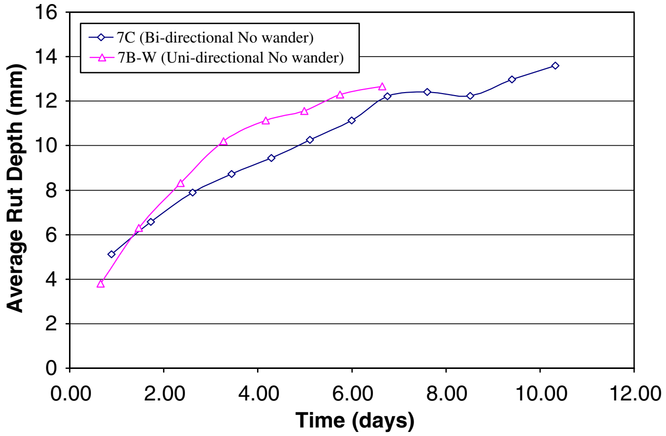

Fig. 9. Comparison of average rut depth as measured by the surface profile method vs. time between bi-directional and uni-directional loading with no wander.

4.2. Comparison between bi-directional and uni-directional loading with 10 cm wander

Trial Test No. 3 (uni-directional loading with 10 cm wander in 5 cm increments, Test Section 7B-E) was run for 25 days with a total of 310,620 wheel passes. Fig. 10 shows a picture of the rutted pavement at the end of the test. Trial Test No. 4 (bi-directional loading with 10 cm wander in 5 cm increments, Test Section 7A-E) was run for 33 days with a total of 843,151 passes. Fig. 11 shows a picture of

Fig. 10. Photo of Section 7B-E (uni-directional loading with 10 cm wander in 5 cm increments).

Fig. 11. Photo of Section 7A-E (bi-directional loading with 10 cm wander in 5 cm increments).

the rutted pavement at the end of the test. In both cases, the rutted wheel tracks were observed to be much smoother than those in Trial Tests 1 and 2 (with no wander). However, continuous ridges were still observed along the wheel track. Accumulation of rubber on the surface of the wheel track was also observed in Trial Test 3 (with uni-directional loading).

Fig. 12 shows the comparison of rut depths as measured by the differential surface deformation method as a function of number of wheel passes between these two modes of loading. Fig. 13 shows similar comparison of rut depths as measured by the surface profile method. It can be seen from both figures that for the same number of wheel passes, the uni-directional loading produced substantially higher rut depths than those by the bi-directional loading.

Figs. 14 and 15 show the comparisons of rut depths versus testing time between these two modes of loading, using the differential surface deformation method and surface profile method, respectively. It can be seen that for the same testing time, the uni-directional loading produced higher rut depths than those by the bi-directional loading.

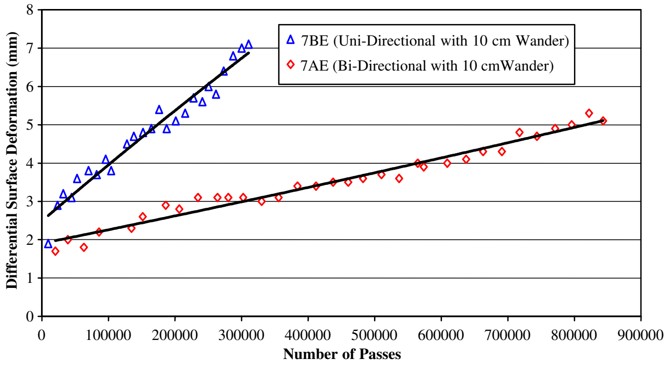

Fig. 12. Comparison of differential surface deformation vs. number of passes between uni-directional and bi-directional loading with 10 cm wander.

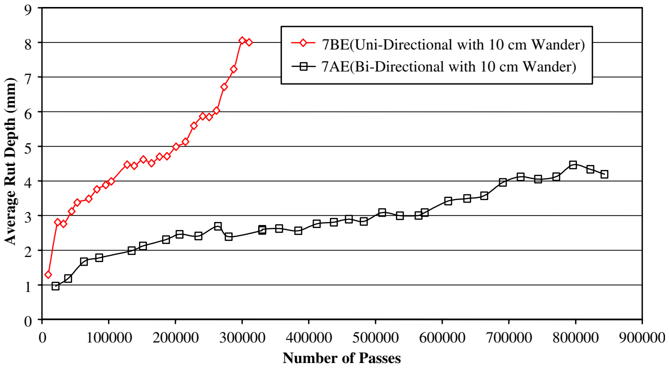

Fig. 13. Comparison of average rut depth by profile method vs. number of passes between uni-directional and bi-directional loading with 10 cm wander.

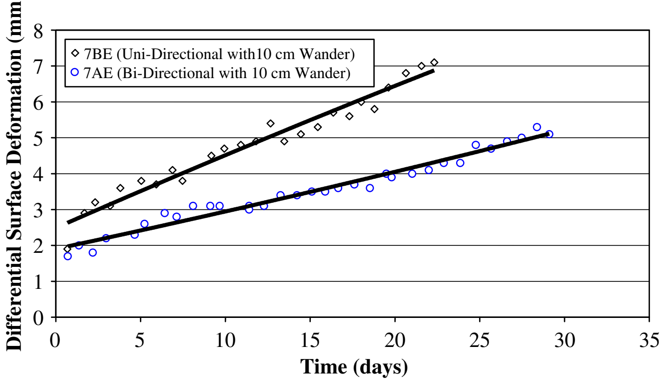

Fig. 14. Comparison of differential surface deformation vs. time between uni-directional and bi-directional loading with 10 cm wander.

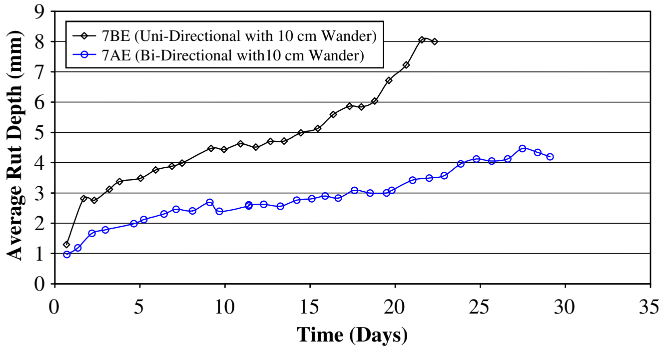

Fig. 15. Comparison of average rut depth by the profile method vs. time between uni-directional and bi-directional with 10 cm wander.

4.3. Comparison between uni-directional loading with 10 cm wander in 5 cm increments and uni-directional loading with 10 cm wander in 2.5 cm increments

Trial Test No. 5 (uni-directional loading with 10 cm wander in 2.5 cm increments, Test Section 7A-W) was run for 39 days with a total of 443,489 wheel passes. Fig. 16 shows a picture of the rutted pavement at the end of the test. The rutted wheel track was observed to be much smoother than those in Trial Tests 3 and 4 (with 10 cm wander in 5 cm increments). Accumulation of rubber on the surface of the wheel track was also observed in this test as in the other tests using uni-directional loading.

Fig. 17 shows the comparison of rut depths as measured by the differential surface deformation method as a function of number of wheel passes between uni-directional loading with 10 cm wander in 5 cm increments and uni-directional loading with 10 cm wander in 2.5 cm increments. It can be seen that for the same number of wheel passes, the loading with wander in 5 cm increments gave slightly higher differential deformations than those by the loading with wander in 2.5 cm increments. Fig. 18 shows similar comparison of rut depths as measured by the surface profile method. In this comparison, the case using 2.5 cm increments appears to give slightly higher rut depths

Fig. 16. Photo of Section 7A-W (uni-directional loading with 10 cm wander in 2.5 cm increments).

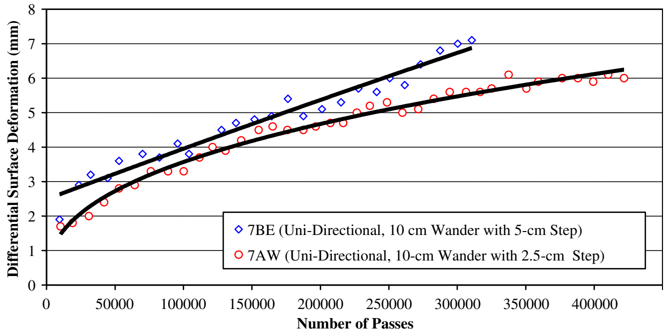

Fig. 17. Comparison of differential surface deformation vs. number of passes between loading with wander in 5 cm increments and 2.5 cm increments.

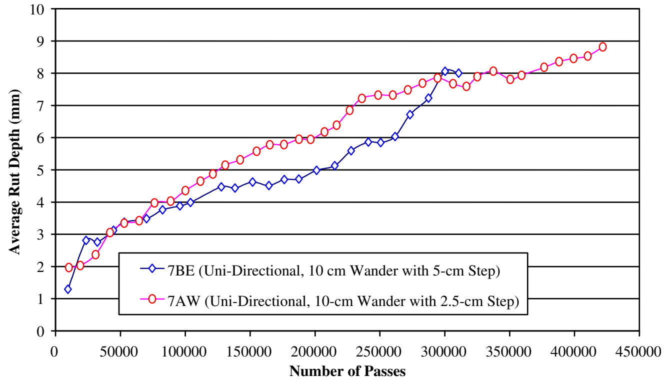

Fig. 18. Comparison of average rut depth by the profile method vs. number of passes between loading with wander in 5 cm increments and 2.5 cm increments.

than those in the case using 5 cm increments. This may be explained by the fact that the case using 2.5 cm increments produced more heaving at the edge of the wheel track and thus resulted in higher rut depths as measured by the surface profile method.

5. Summary

The main findings from the evaluation of the performance characteristics of the HVS in this study can be summarized as follows:

(1) The uni-directional loading is a more efficient mode for evaluation of rutting performance using the HVS. As compared with the bi-directional loading mode, the uni-directional mode produced substantially higher rut depths for the same number of wheel passes and also for the same testing time duration.
(2) When the bi-directional loading with no wander was used, the wheel appeared to travel along the exact tire print as it moved back and forth without lifting itself off the ground. As a result, imprints of the tire treads could be clearly seen on the wheel track. This was not representative of pavement rutting in the field.
(3) The uni-directional loading mode was seen to cause substantially more severe wearing of the tire, as compared with the bi-directional loading mode. Accumulation of rubber, which was rubbed off from the tire, was observed on the surface of the wheel track when the uni-directional loading mode was used.
(4) When loading with wander was used, the imprints of the tire treads were smoothened out considerably as compared with the case with no wander. Loading with wander produced rutting which was more representative of field conditions.
(5) The loading mode with wander using 2.5 cm increments appeared to produce slightly higher rut depths than those in the case using 5 cm increments.
(6) The uni-directional loading mode with 10 cm wander using 2.5 cm increments was selected to be used for evaluation of rutting performance based on consideration of testing efficiency and realistic rutting results.

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