EVALUATION OF RUTTING RESISTANCE OF SUPERPAVE MIXTURES WITH AND WITHOUT SBS MODIFICATION BY MEANS OF ACCELERATED PAVEMENT TESTING

Main Objective of Study:

- To evaluate the long-term rutting performance of Superpave mixtures and SBS-modified Superpave mixtures using the Heavy Vehicle Simulator (HVS) at FDOT's Accelerated Pavement Testing (APT) facility

Other Objectives of Study:

- To evaluate the operational characteristics of the Heavy Vehicle Simulator, and to determine its most effective test configurations.
- To compare the rutting performance of a pavement using two lifts of modified mixture with a pavement using one lift of modified mixture on top of one lift of unmodified mixture.
- To evaluate the relationship between mixture properties and rutting performance.

Volumetric Properties of the Mixtures Tested

Mix Type	Asphalt Binder	% Binder	V_a @N_{des}	VMA	VFA	P_{be}	G_{mm}
Superpave Mix	PG67-22	8.2	4.0	14.5	72	4.97	2.276
Modified Superpave Mix	PG76-22	7.9	3.8	14.2	73	4.90	2.273

Test Track Layout

- Total Number of Lanes: 7
- Test Sections per Lane: 3
- Length of Each Test Section: 30 ft
- Width of Each Test Section: 12 ft
- SBS-Modified Mixture: Lanes 1 and 2
- Modified over Unmodified Mixture: Lane 3
- Unmodified Mixture: Lanes 4 through 7

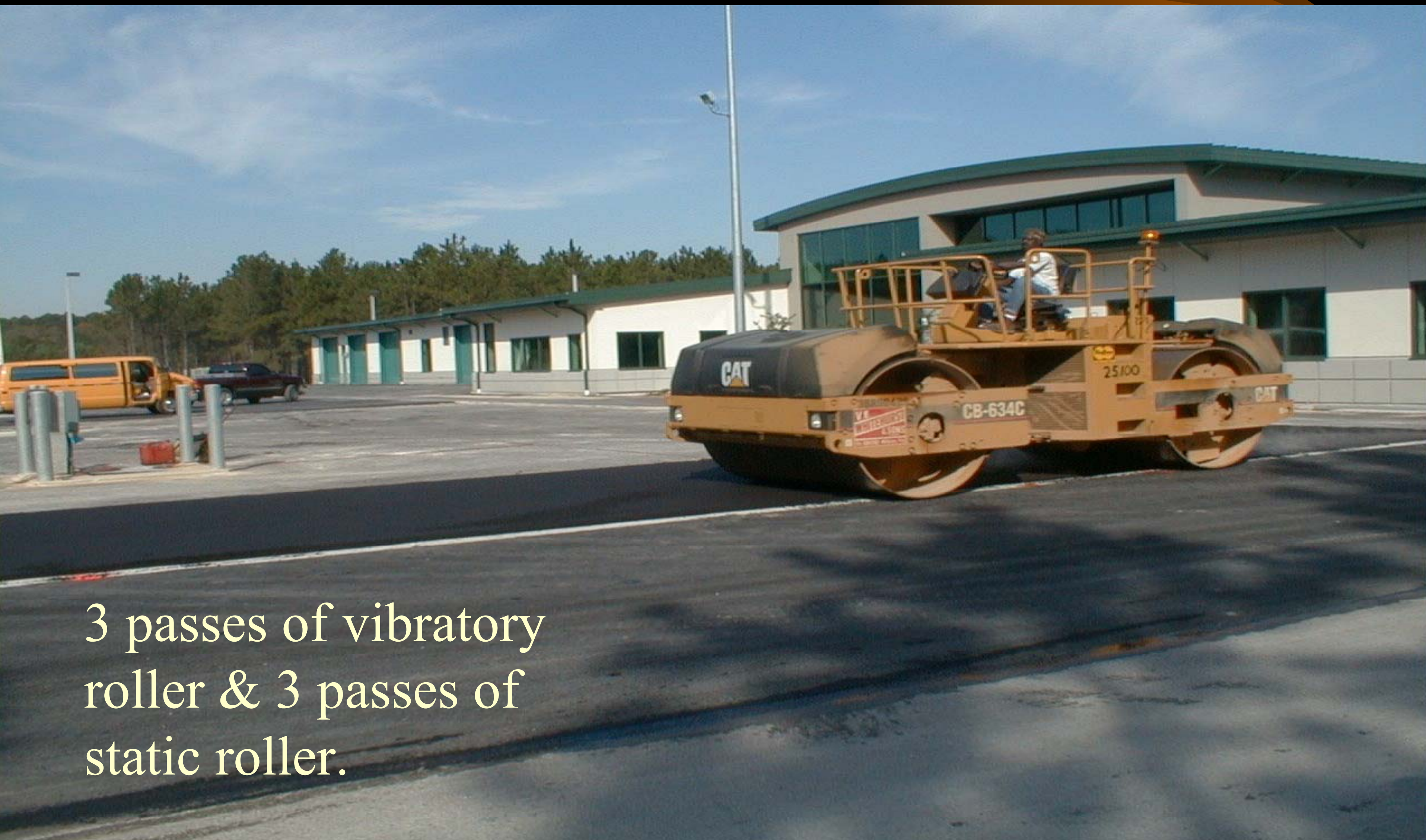
Pavement Structure

- 10.5-inch Limerock Base
- 12-inch Stabilized Subgrade
- Two layers of 2-inch Asphalt Mixture

Limerock Base of Test Pavement

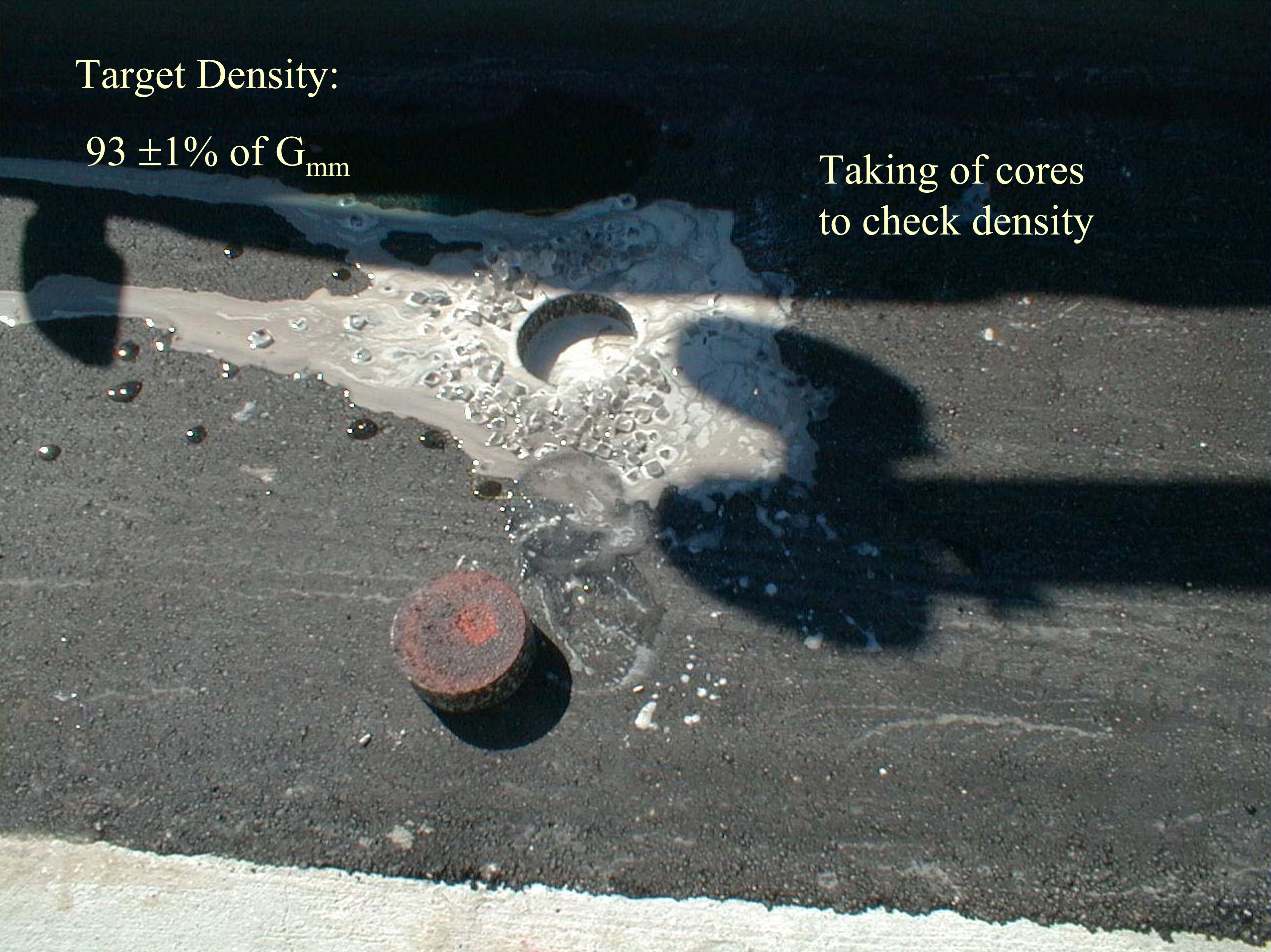

October 17, 2000
Construction of Test Sections

Picture of 25,000-pound Roller used in Compaction of Test Pavements

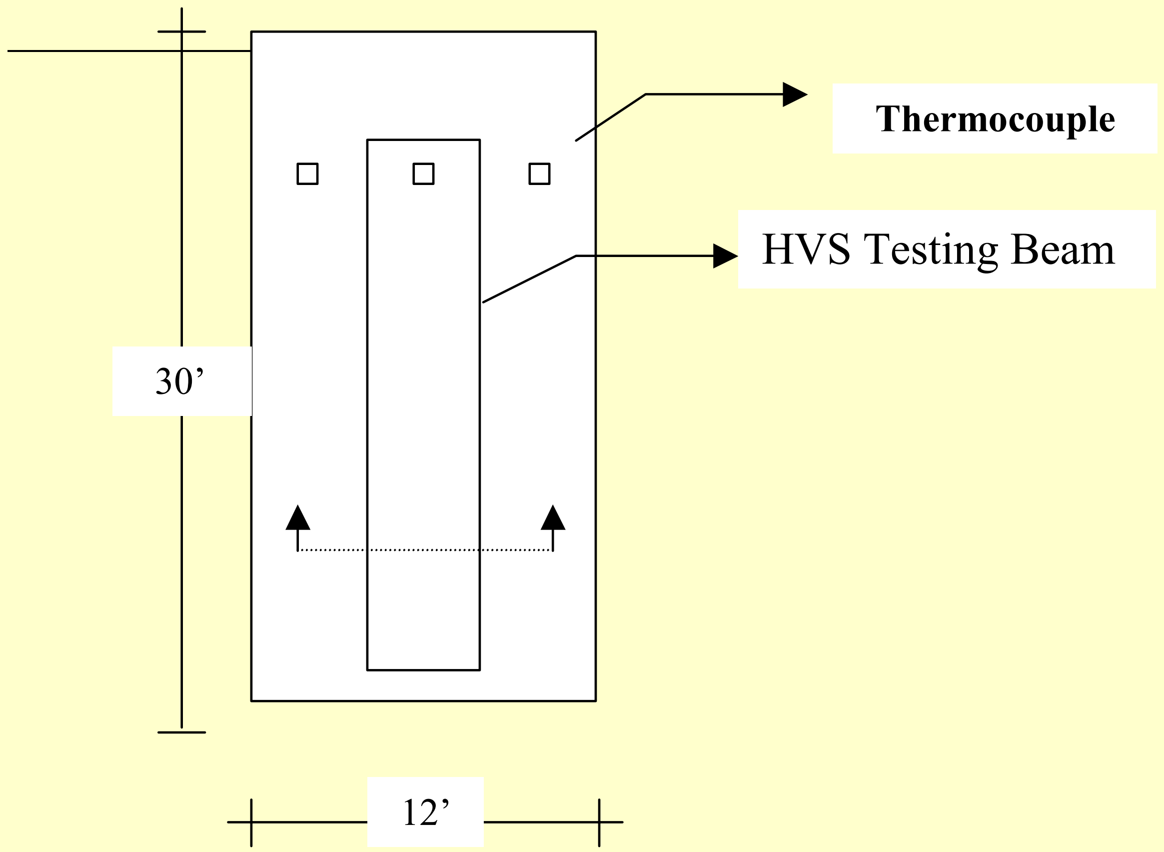


3 passes of vibratory roller & 3 passes of static roller.

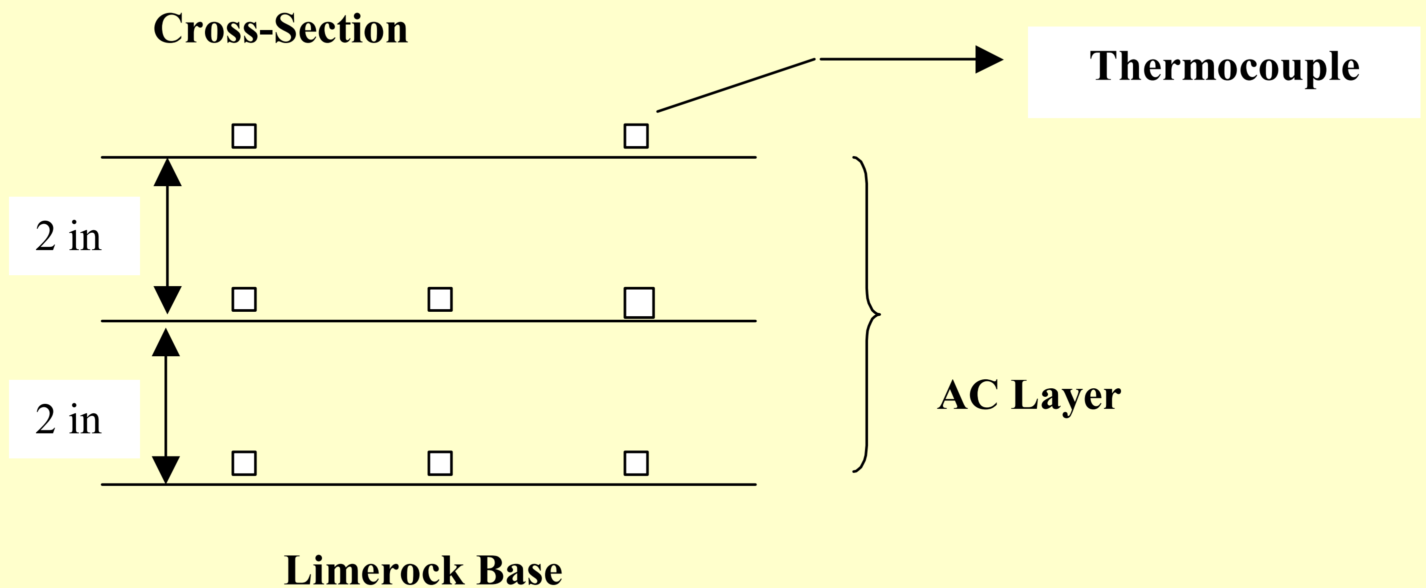
25,000-pound Roller in Operation


Target Density:
93 ±1% of G_{mm}
Taking of cores
to check density

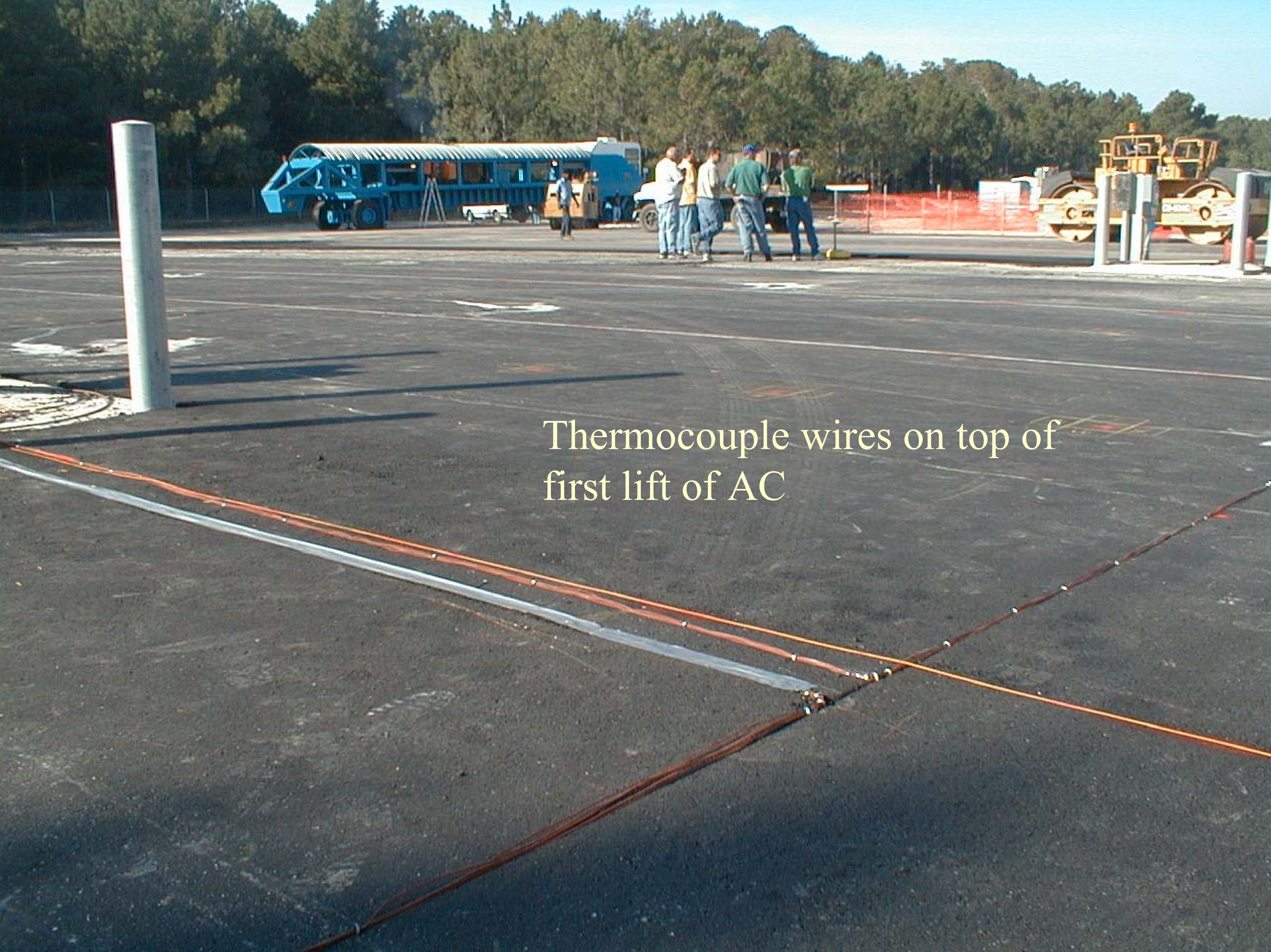

Placement of K-Type
Thermocouple



Plane view of locations of thermocouples on a test section



Cross-section view of locations of thermocouples on a test section


Thermocouple wires on top of
first lift of AC

First Experiment

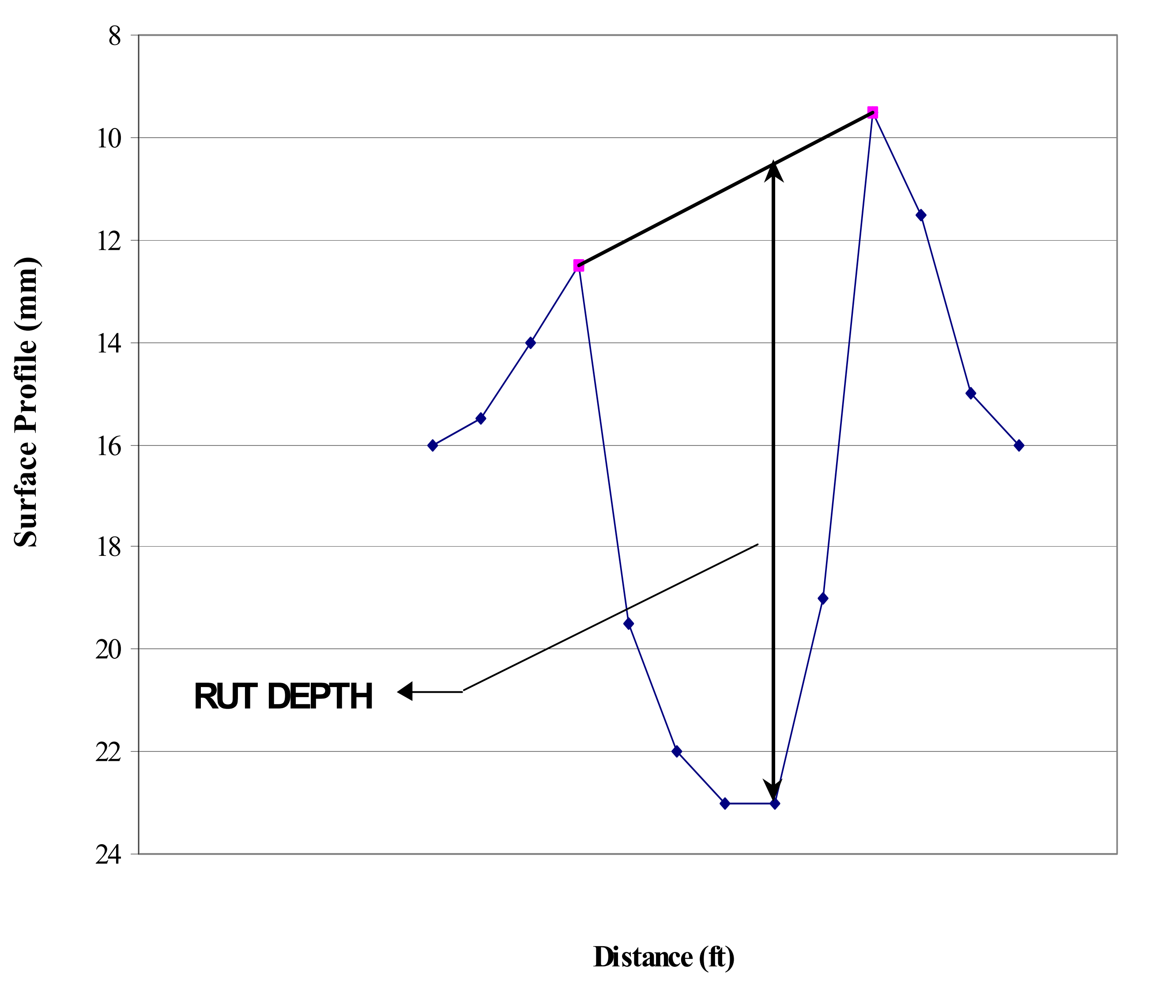
To perform trial tests on lane 7 to determine the optimum HVS test configuration to be used in the main testing program.


Super Single Tire
115 psi, 8 mph

Pavement rutting measured with a straight edge

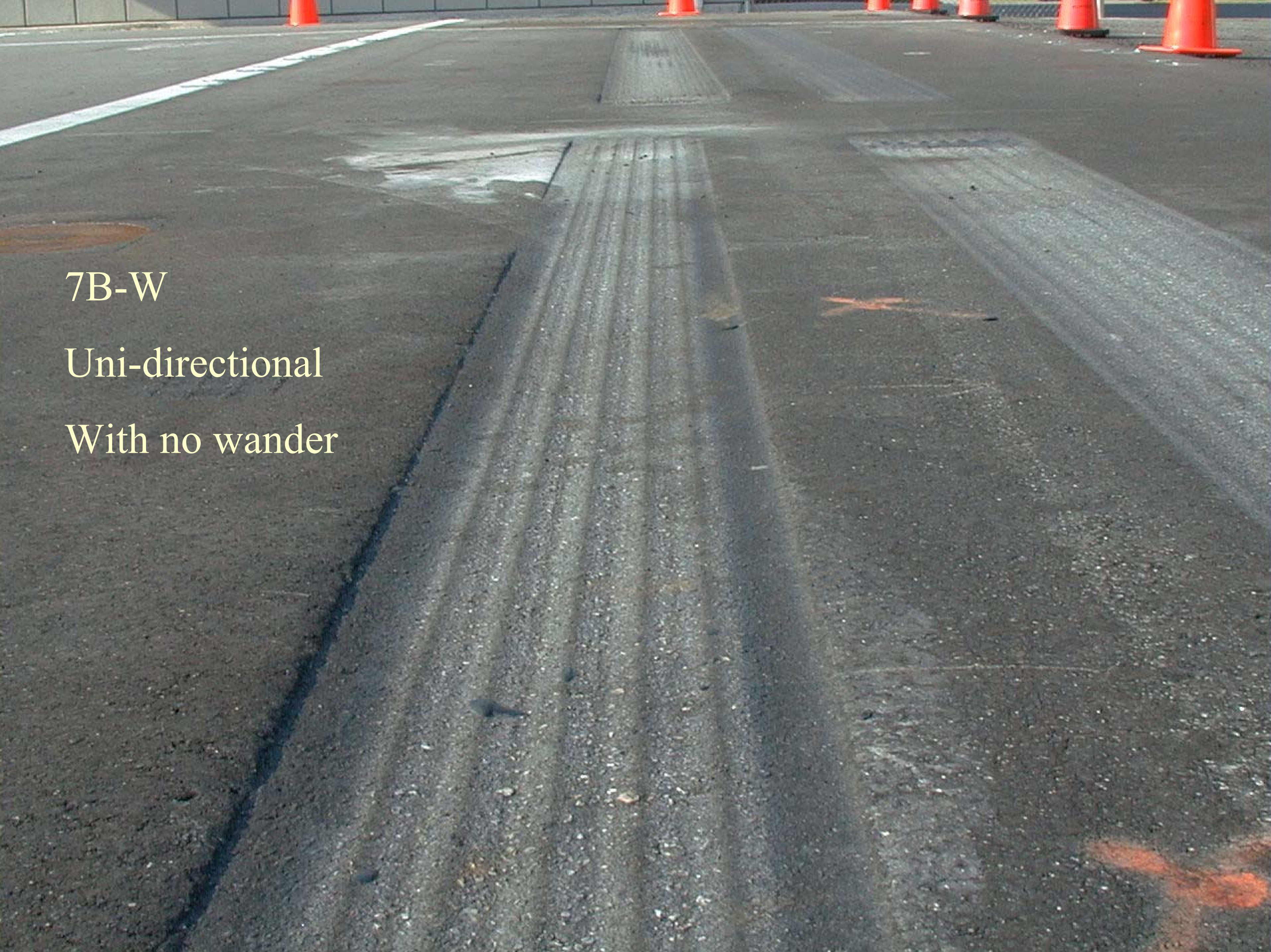
Two Methods of Rut Measurement used in the Trial Tests

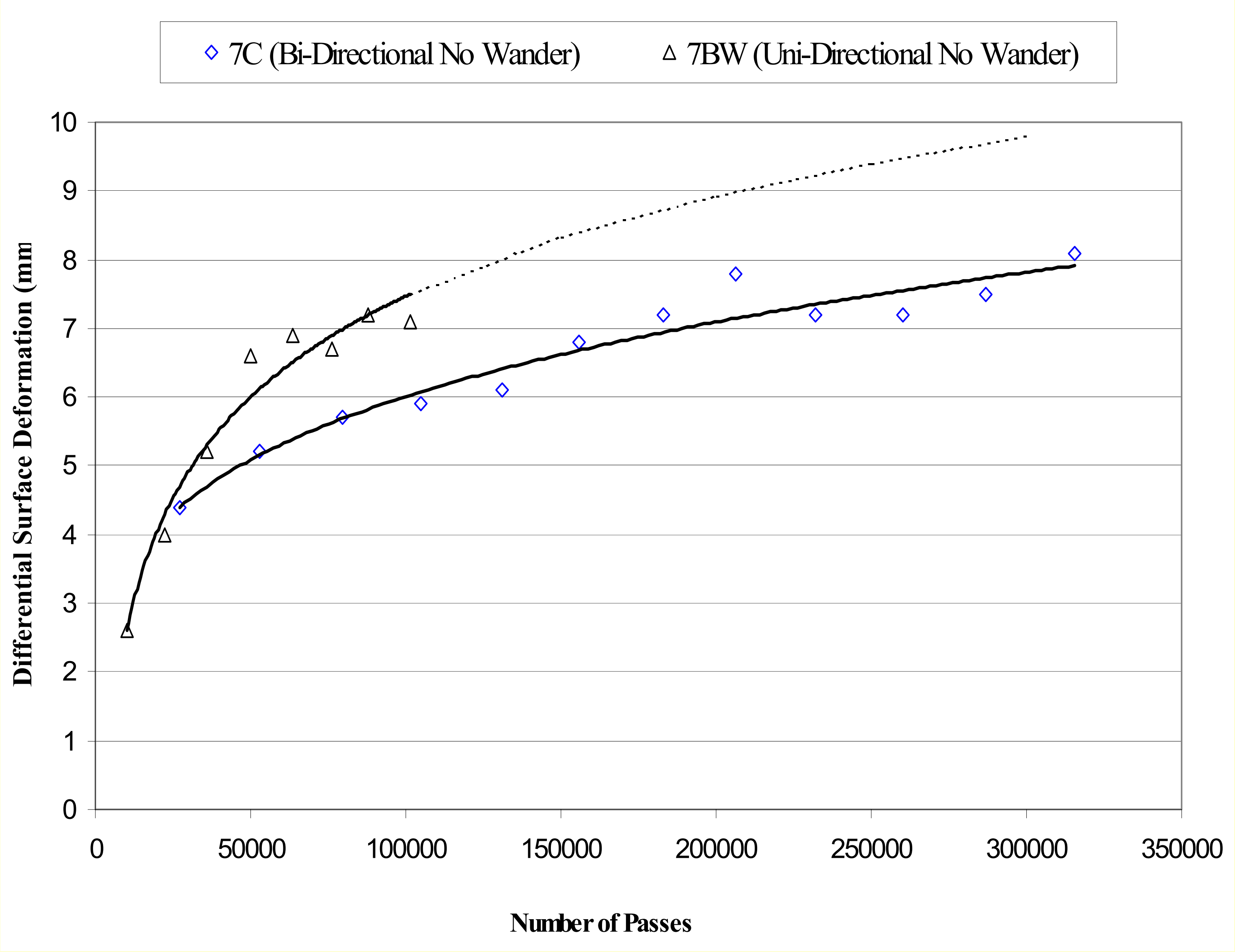
1. Differential surface deformation method - The vertical surface deformation relative to the initial surface profile was determined.
2. Rut depth determination from pavement surface profile. (see next slide)



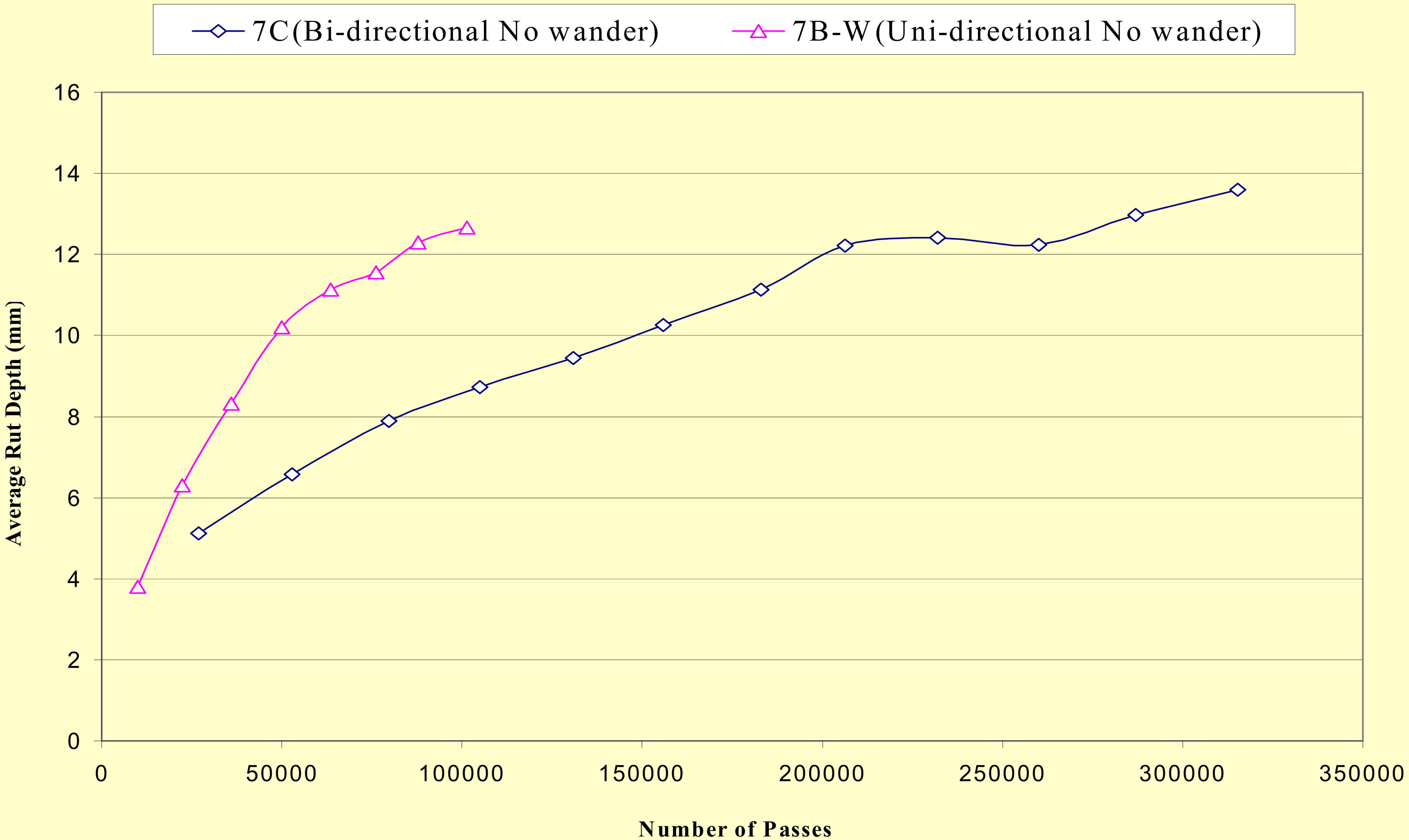
Determination of rut depth by surface profile method


7C Bi-directional
With no wander
344


7B-W
Uni-directional
With no wander



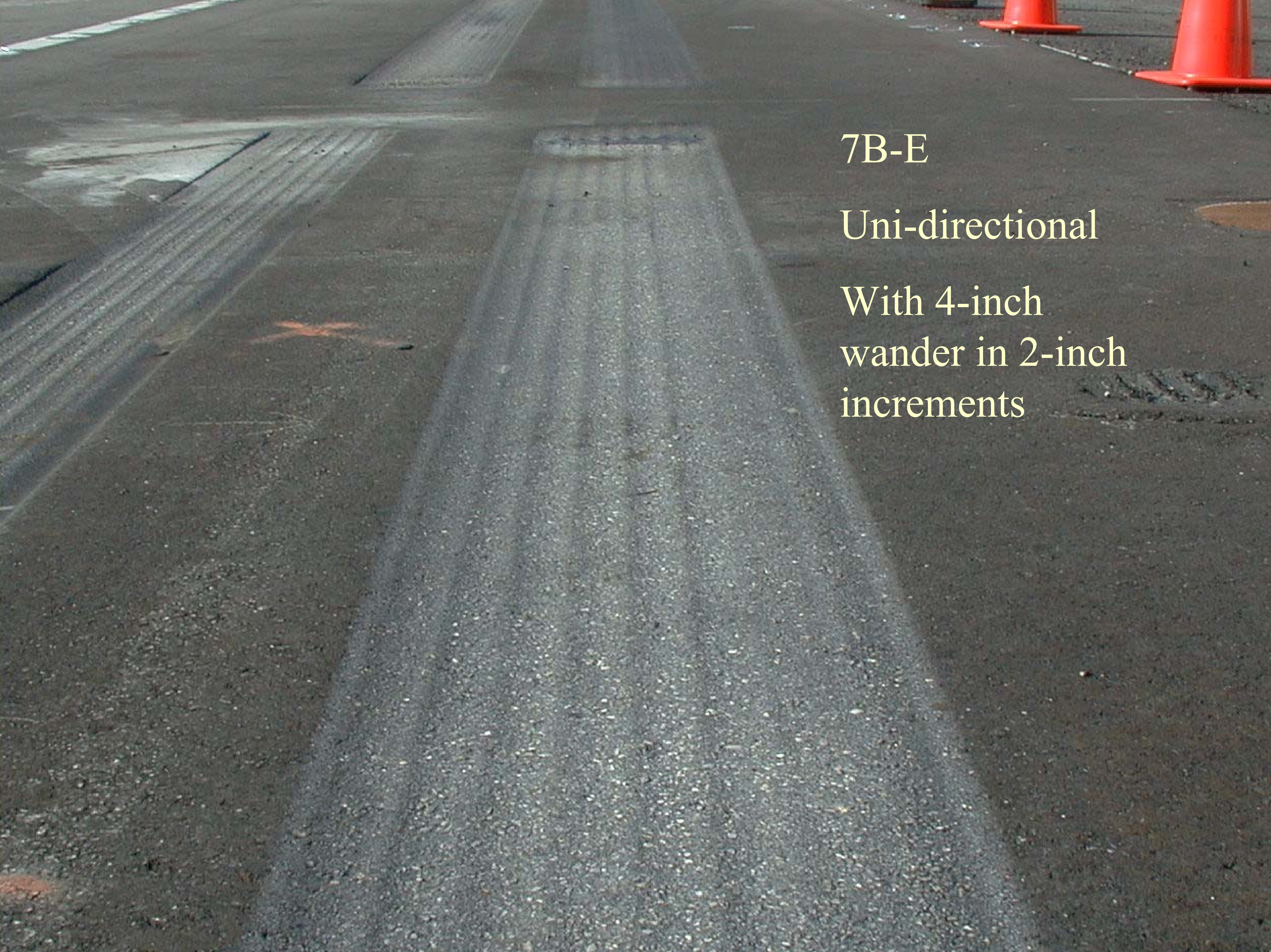
Comparison of Differential Surface Deformation Between Bi-Directional and Uni-Directional Loading with No Wander



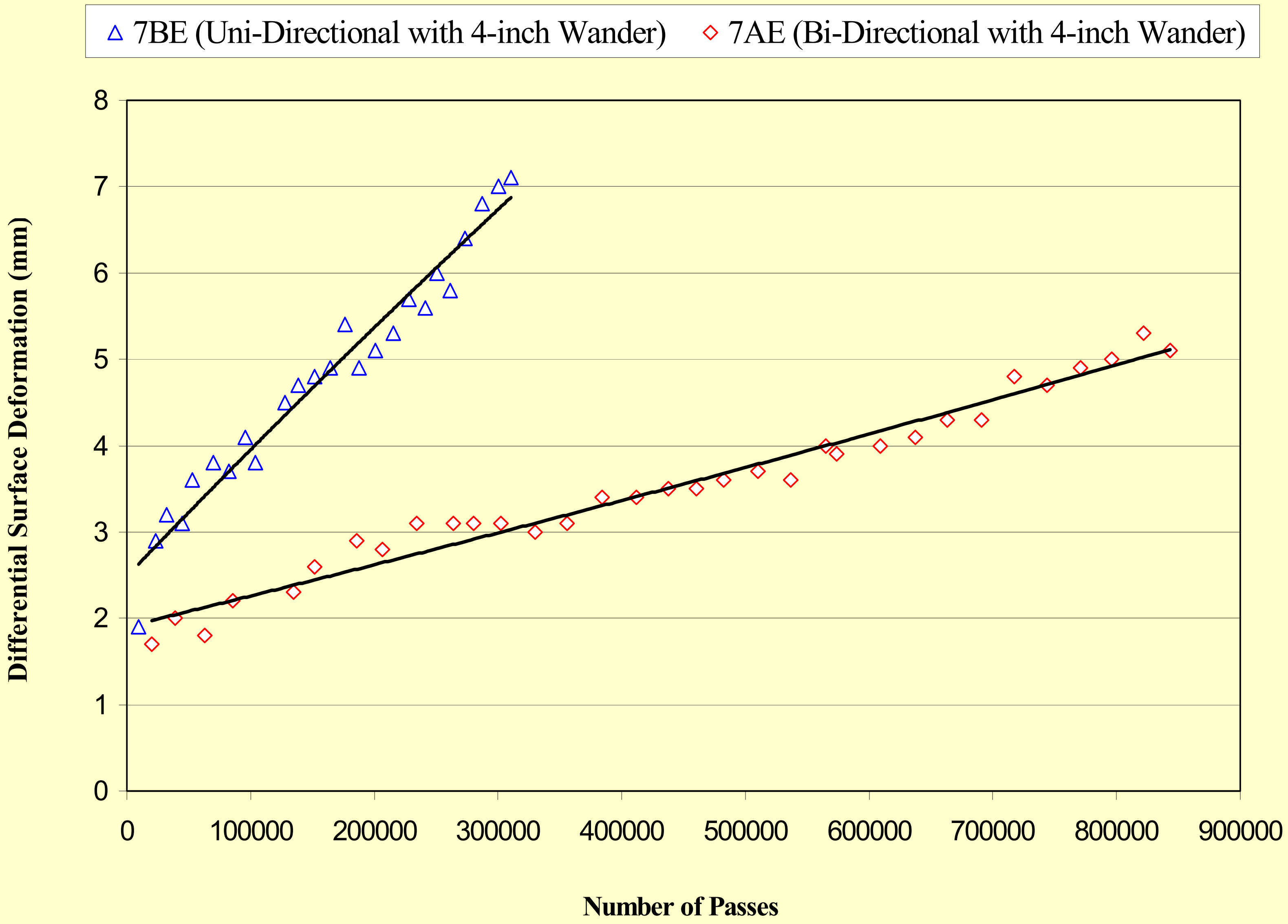
Comparison of Average Rut Depth as Measured by the Surface Profile Method Between Bi-Directional and Uni-Directional Loading

Temperatures of Trial Test Pavements as Measured by Thermocouples Placed at Two-inch (5.1-cm) Depth

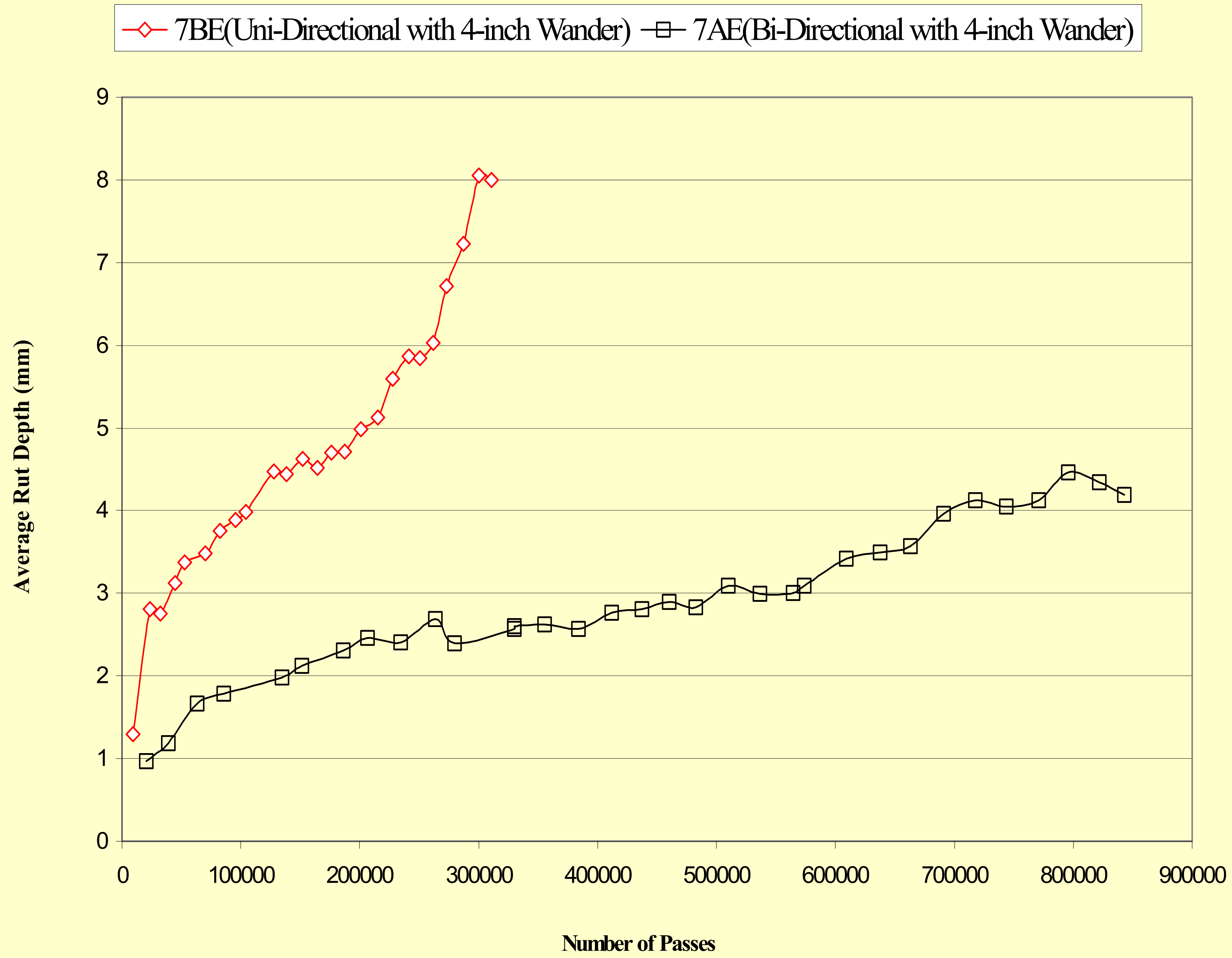
Section 7C	**Bi-Directional loading, No wander**			
	Thermocouple 4	Thermocouple 5	Thermocouple 6	**Average**
Avg. Daily Min.	20.6	20.4	20.3	**20.4**
Avg. Daily Max.	31.3	31.6	33.3	**32.1**
Overall Min.	18.9	20.1	18.0	**19**
Overall Max.	34.2	33.7	37.5	**35.1**
Section 7B-W	**Uni-Directional loading, No wander**			
	Thermocouple 4	Thermocouple 5	Thermocouple 6	**Average**
Avg. Daily Min.	19.2	18.9	19.0	**19.0**
Avg. Daily Max.	33.1	28.4	27.7	**29.7**
Overall Min.	13.3	12.7	13.1	**13**
Overall Max.	36.7	31.9	32.4	**33.6**


7B-E
Uni-directional
With 4-inch
wander in 2-inch
increments


7A-E
Bi-directional with
4-inch Wander in
2-inch increments

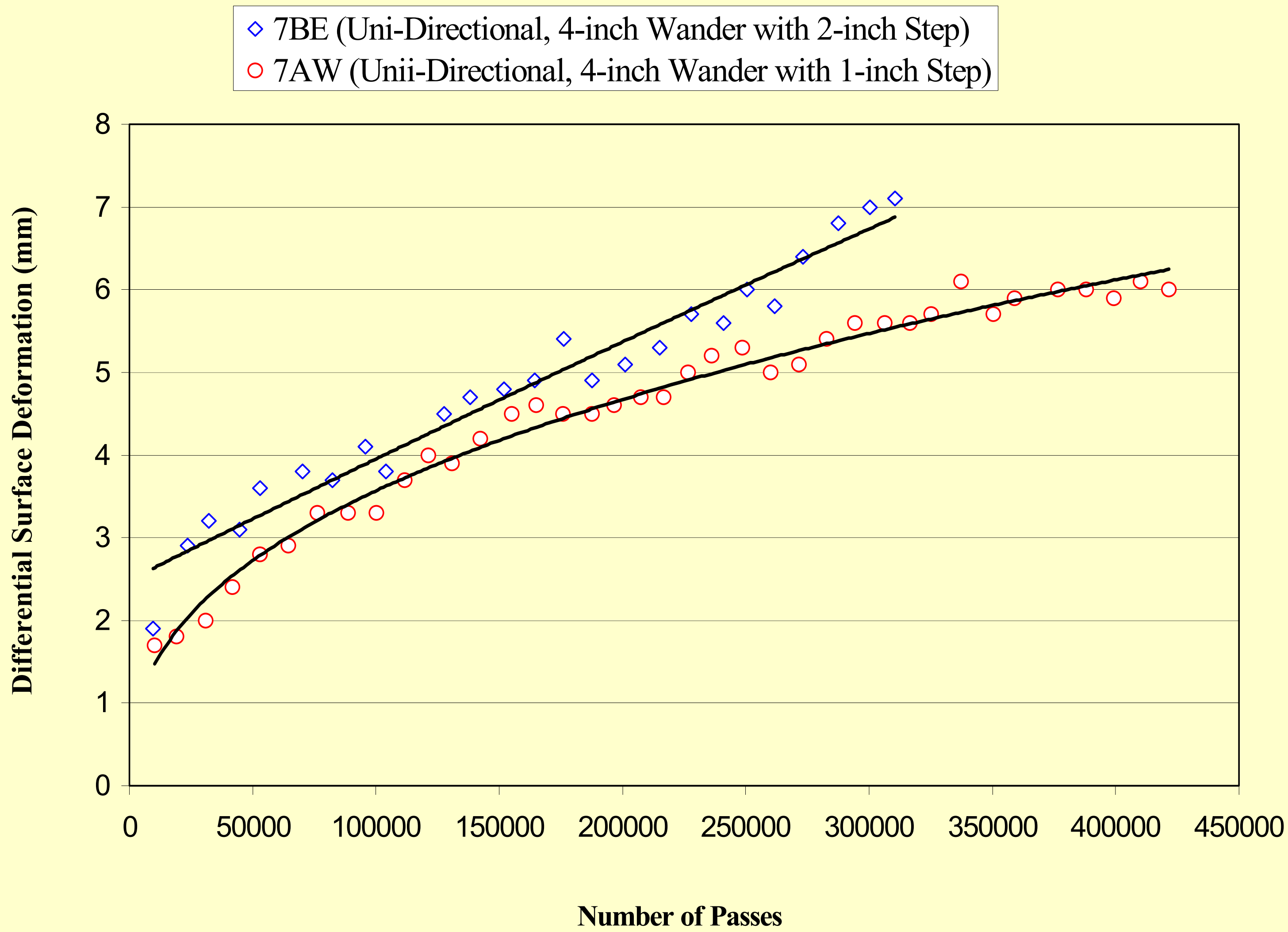


Comparison of Differential Surface Deformation Between Uni-Directional and Bi-Directional Loading with 4-inch Wander

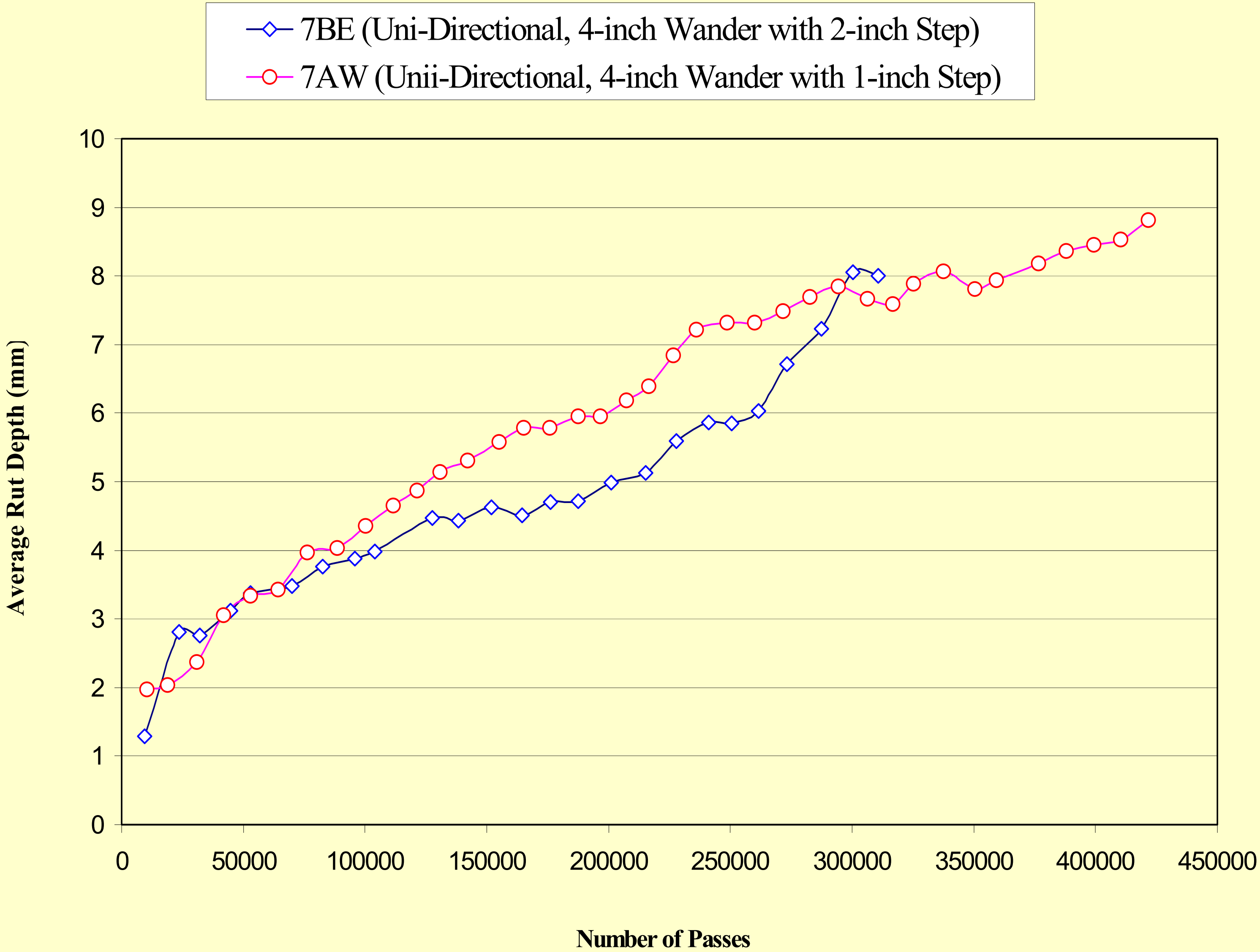


Comparison of Average Rut Depth by Surface Profile Method Between Uni-Directional and Bi-Directional Loading with 4-inch Wander


7A-W
Uni-directional
With 4-inch
Wander in 1-inch
increments



Comparison of Differential Surface Deformation Between Loading with Wander in 2-inch (5.1-cm) Increments and 1-inch (2.54-cm) Increments



Comparison of Average Rut Depth by the Surface Profile Method Between Loading with Wander in 2-inch Increments and 1-inch Increments

SUMMARY OF FINDINGS FROM THE TRIAL TESTS

1) The uni-directional loading is a more efficient mode for evaluation of rutting performance using the HVS as compared with the bi-directional mode.
2) When the bi-directional loading with no wander was used, the wheel appeared to travel along the exact tire print 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.

SUMMARY OF FINDINGS FROM THE TRIAL TESTS (Continued)

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 that was more representative of field conditions.
5) The loading mode with wander using 1-inch (2.54-cm) increments appeared to produce slightly higher rut depths than those in the case using 2-inch (5.1-cm) increments.
6) The uni-directional loading mode with 4-inch (10.2-cm) wander using 1-inch (2.54-cm) increments was selected to be used for evaluation of rutting performance based on consideration of testing efficiency and realistic rutting results.

	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5
Phase II (Controlled Temp.)	M 7 (65°C)	M 9 (65°C)	U+M 5 (50°C)	U 8 (50°C)	U 10(50°C)
	M 6 (50°C)	M 2 (50°C)	U+M 3 (50°C)	U 4(50°C)	U 1(50°C)
Phase I (Ambient Temp.)	**M 5**	**M 2**	**U+M 4**	**U 3**	**U 1**

HVS TESTING PLAN

U➔ Unmodified Mix

M➔ Modified Mix

1, 2,3 etc ➔Testing Sequence No

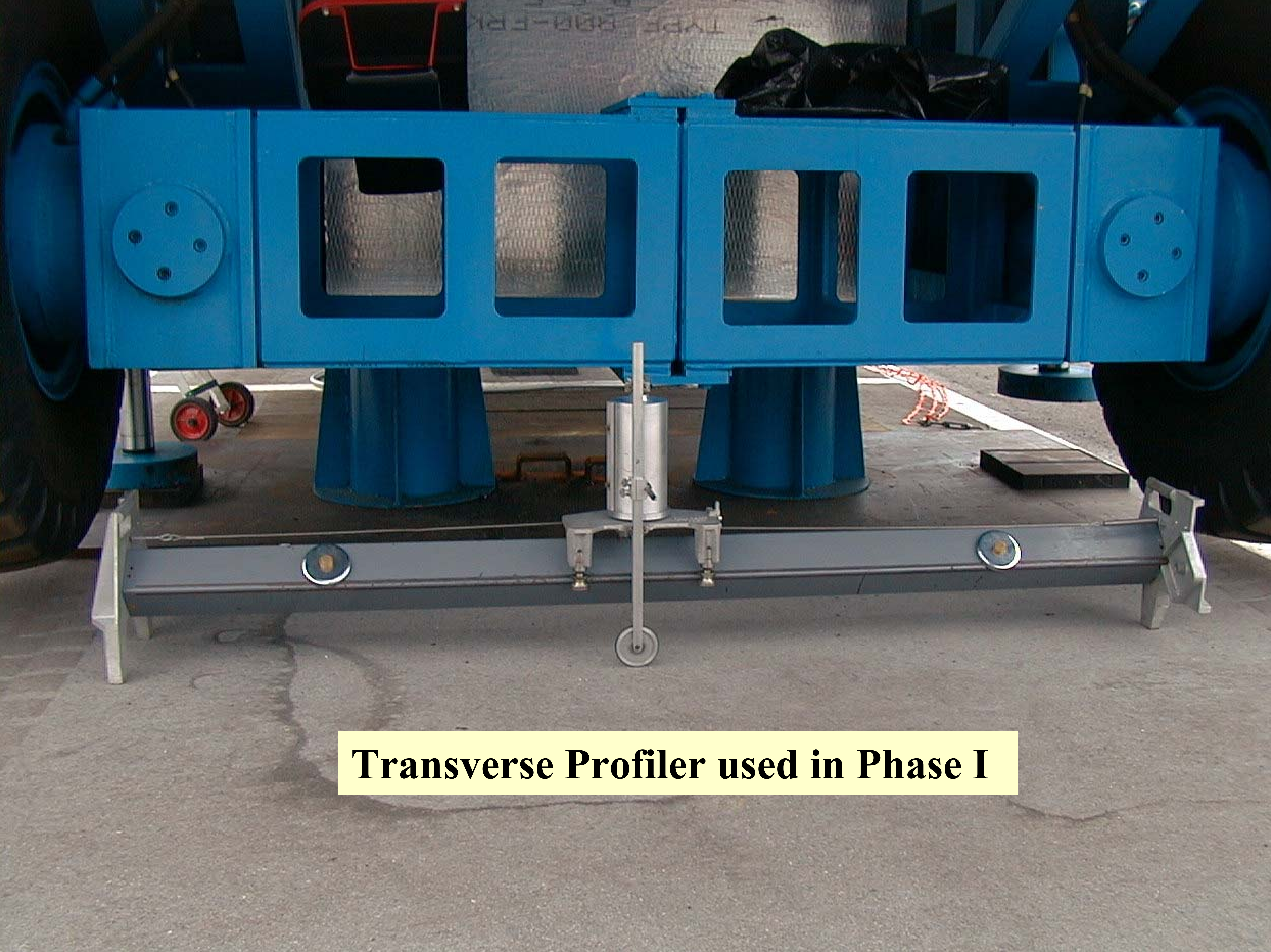
U+M ➔ Unmodified+Modified mix


Super Single Tire
115 psi, 6 mph

TESTING CONFIGURATION

The uni-directional loading mode with 4-inch (10.2-cm) wander using 1-inch (2.54-cm) increments was selected to be used for evaluation of rutting performance based on consideration of testing efficiency and realistic rutting results.

RESULTS FROM PHASE I
(Tests at ambient condition)



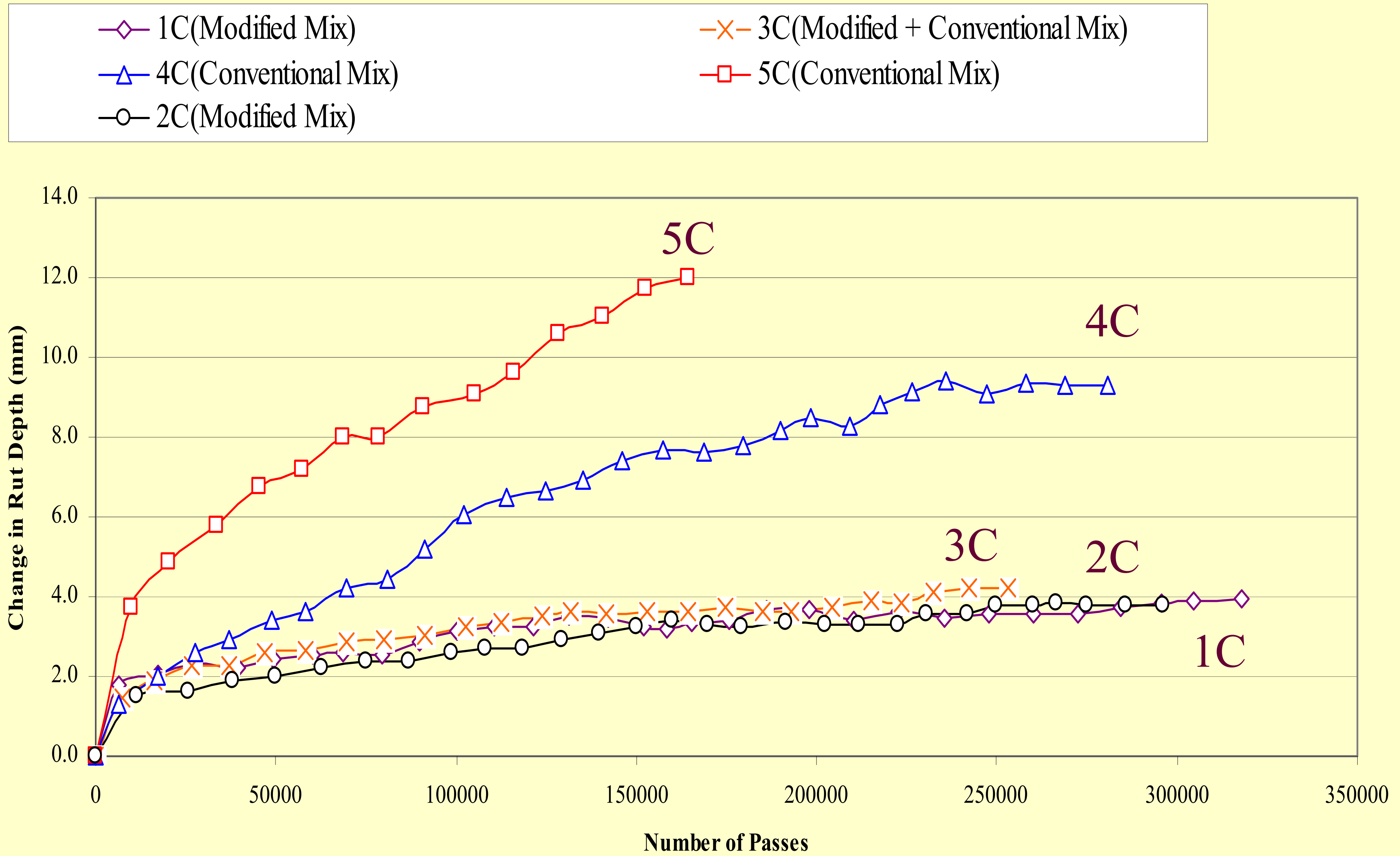
Transverse Profiler used in Phase I

Temperatures of test pavement as measured by thermocouples

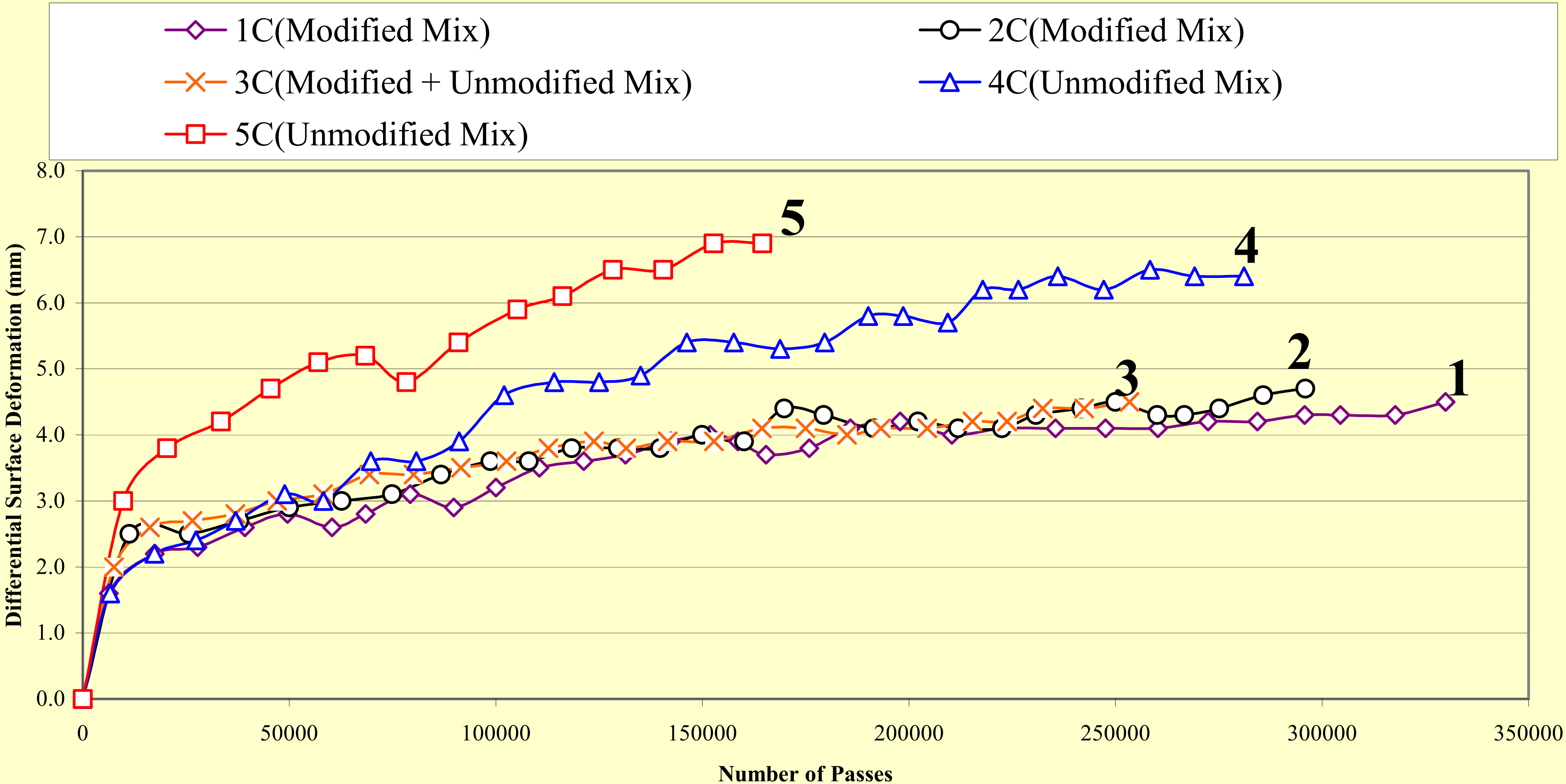
Section 5C	Uni-Directional loading, 4-inch wander with 1-inch Increment			
	Thermocouple 4	Thermocouple 5	Thermocouple 6	**Average**
Avg. Daily Min. Temp (°C)	27.1	26.2	26.9	**26.7**
Avg. Daily Max. Temp (°C)	41.9	39.1	37.8	**39.6**
Overall Min. Temp (°C)	24.2	23.8	25.0	**24.3**
Overall Max. Temp (°C)	41.8	46.4	48.5	**45.6**
Section 2C	Uni-Directional loading, 4-inch wander with 1-inch Increment			
	Thermocouple 4	Thermocouple 5	Thermocouple 6	**Average**
Avg. Daily Min. Temp (°C)	27.6	27.2	27.8	**27.5**
Avg. Daily Max. Temp (°C)	39.5	35.7	40.0	**38.4**
Overall Min. Temp (°C)	25.5	25.6	24.9	**25.3**
Overall Max. Temp (°C)	46.9	39.4	46.0	**44.1**
Section 4C	Uni-Directional loading, 4-inch wander with 1-inch Increment			
	Thermocouple 4	Thermocouple 5	Thermocouple 6	**Average**
Avg. Daily Min. Temp (°C)	37.4	28.8	29.4	**31.9**
Avg. Daily Max. Temp (°C)	39.5	37.9	39.5	**39.0**
Overall Min. Temp (°C)	30.6	30.7	31.3	**30.9**
Overall Max. Temp (°C)	44.1	41.7	44.5	**43.4**

Temperatures of test pavement as measured by thermocouples (continued)

Section 3C	Uni-Directional Loading with 4-inch Wander in 1-inch Increments			
	Thermocouple 4	Thermocouple 5	Thermocouple 6	**Average**
Avg. Daily Min. Temp (^{o}C)	26.5	26.8	27.9	**27.1**
Avg. Daily Max. Temp (^{o}C)	40.5	34.2	35.8	**36.8**
Overall Min. Temp (^{o}C)	21.5	21.9	24.0	**22.5**
Overall Max. Temp (^{o}C)	48.4	54.0	48.2	**50.2**
Section 1C	Uni-Directional Loading with 4-inch Wander in 1-inch Increments			
	Thermocouple 4	Thermocouple 5	Thermocouple 6	**Average**
Avg. Daily Min. Temp (^{o}C)	23.8	23.2	22.5	**23.2**
Avg. Daily Max. Temp (^{o}C)	30.4	30.5	32.2	**31.0**
Overall Min. Temp (^{o}C)	19.1	17.3	16.6	**17.7**
Overall Max. Temp (^{o}C)	34.2	34.7	39.0	**36.0**



Comparison of Changes in Rut Depth as measured by the Surface Profile Method of Test Sections in Phase I



Comparison of Differential Surface Deformation for Test Sections in Phase I

Section 5C after HVS testing (Unmodified Mix)

Section 2C after the testing (SBS-Modified Mix)

Section 1C

Modified Mixture

Summary of Findings from Phase I

- The SBS-modified mixture outperformed by far the unmodified mixture in rutting resistance.
- There were not much observed difference in rutting performance between the pavement with a lift of SBS-modified mixture over a lift of unmodified mixture and the pavement with two lifts of SBS-modified mixture when tested at ambient condition.

	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5
Phase II (Controlled Temp.)	M 7 (65°C)	M 9 (65°C)	U+M 5 (50°C)	U 8 (50°C)	U 10(50°C)
	M 6 (50°C)	M 2 (50°C)	U+M 3 (50°C)	U 4(50°C)	U 1(50°C)
Phase I (Ambient Temp.)					

PHASE II OF HVS TESTING PLAN

U→ Unmodified Mix

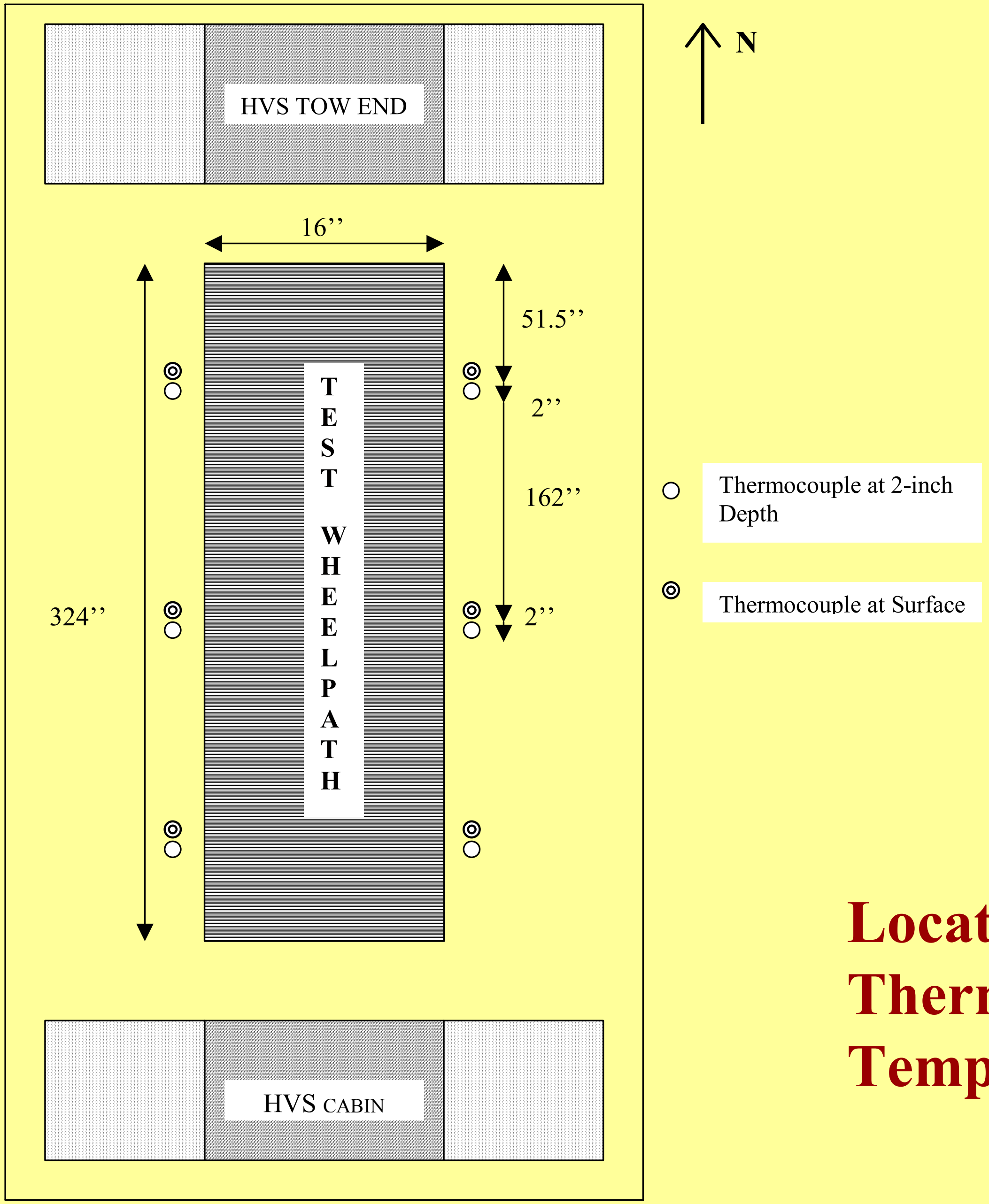
M→ Modified Mix

1, 2,3 etc →Testing Sequence No

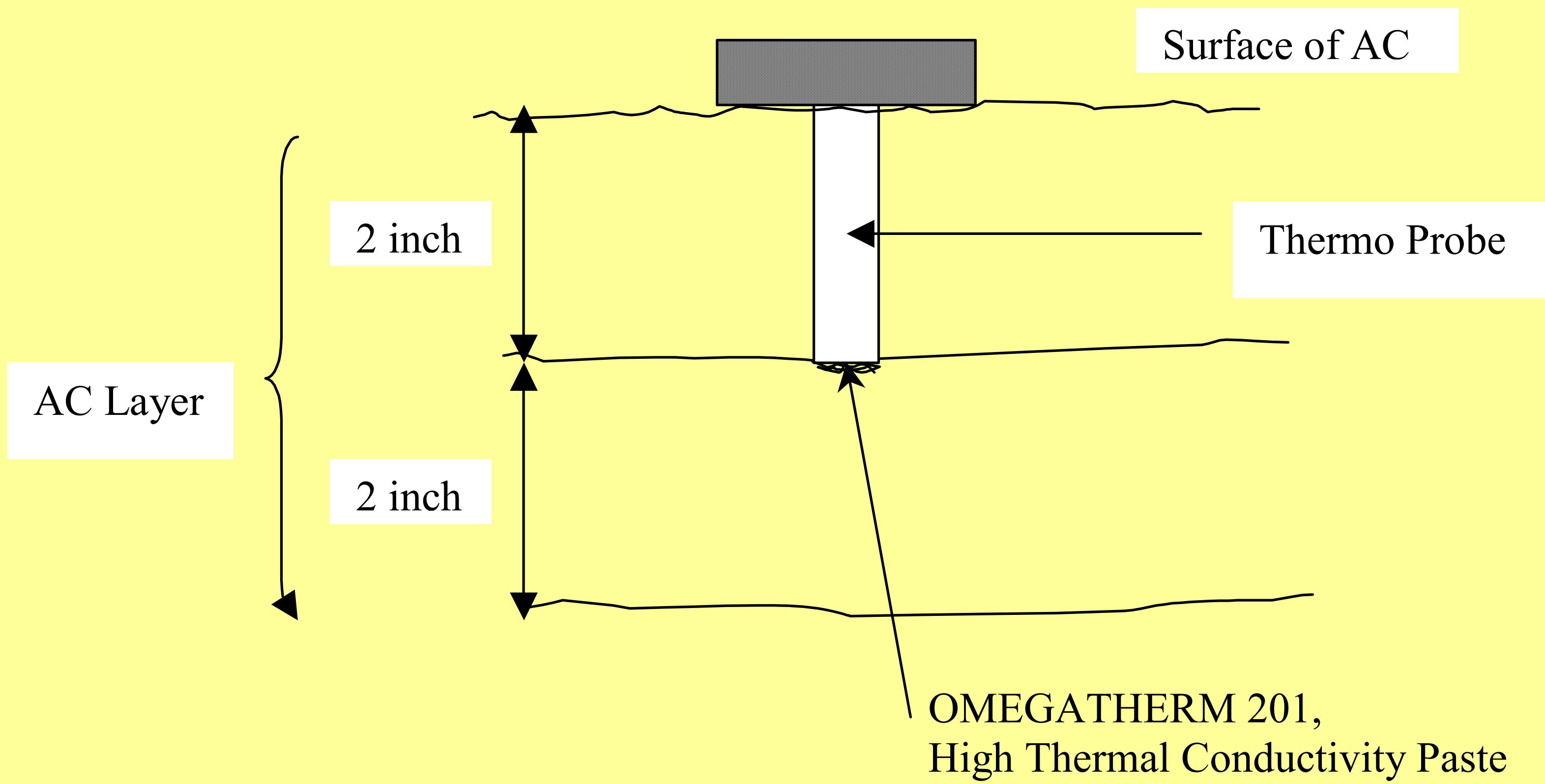
U+M → Unmodified+Modified mix

Results from Phase II of HVS Tests

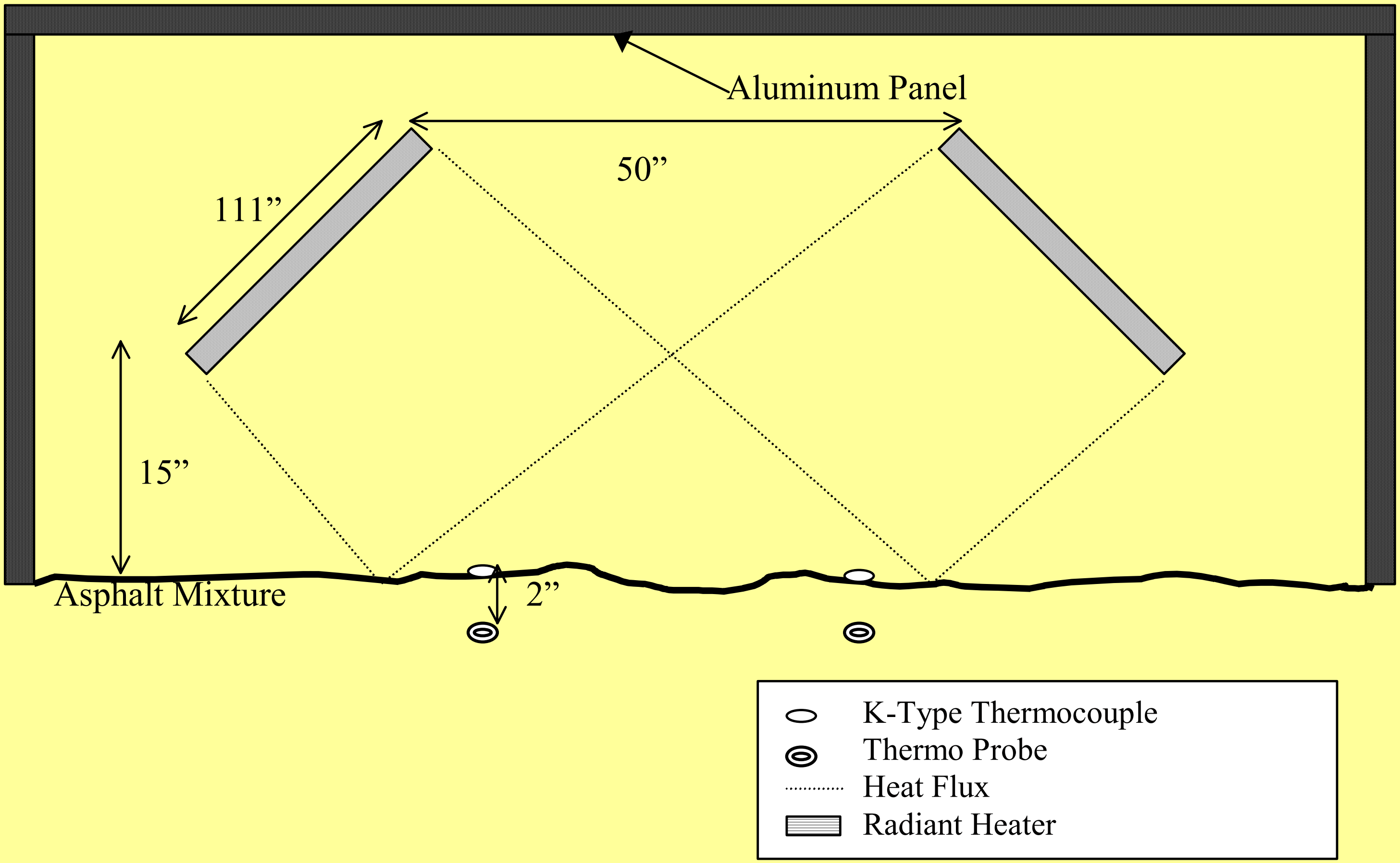
HVS with Temperature
Control & Insulating Panels



Locations of Thermocouples for Temperature Control



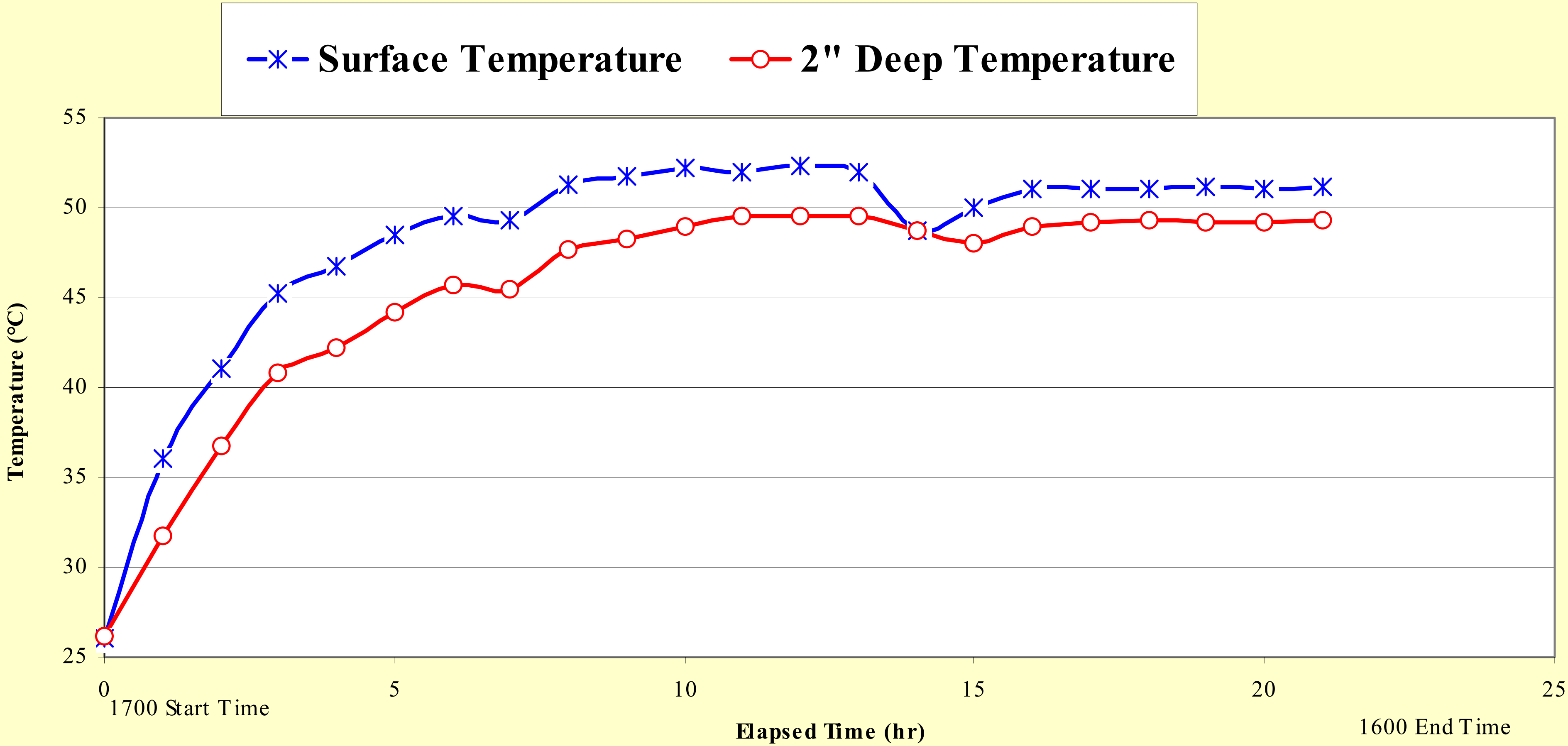
The Installation of Thermo Probe at 2 inch Depth from the Surface



The Dimensions and Heat Flux Ranges of Radiant Heaters

Photo of RAYMAX Hairpin Radiant Heater Unit

PHASE II – WITH CONTROLLED TEMPERATURES



Pavement Temperaure versus Time during Pre-heating before Start of Test

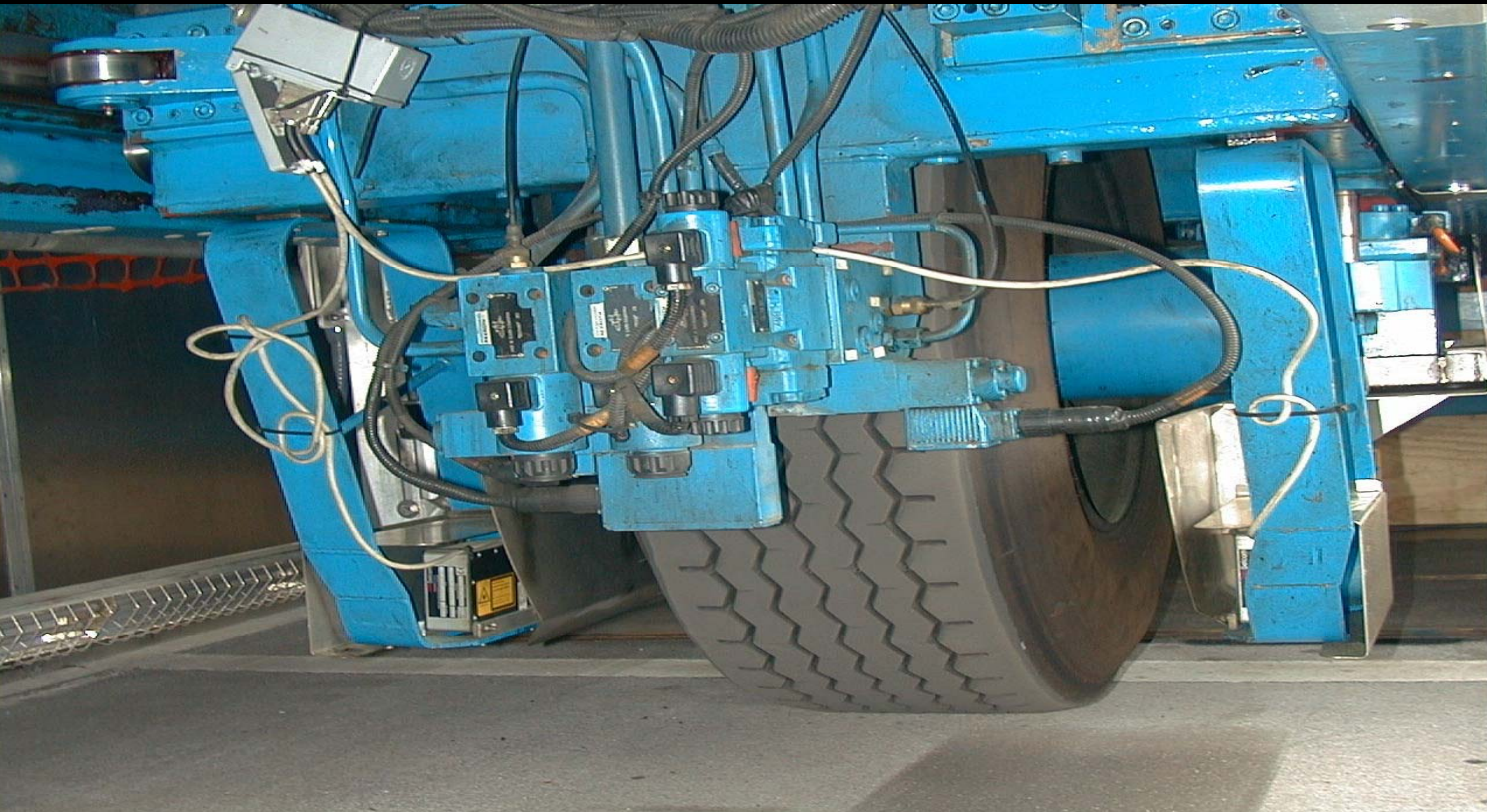
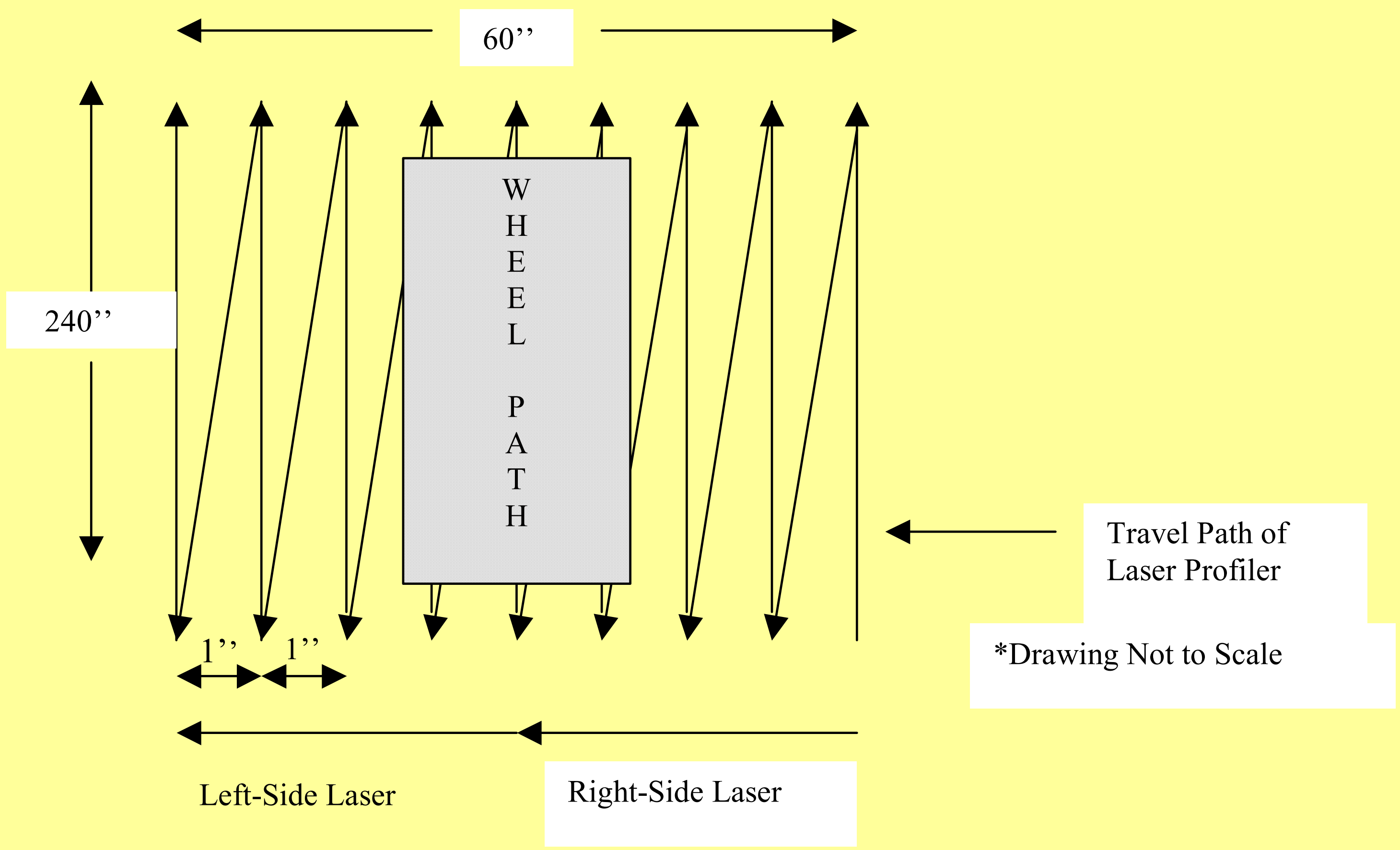
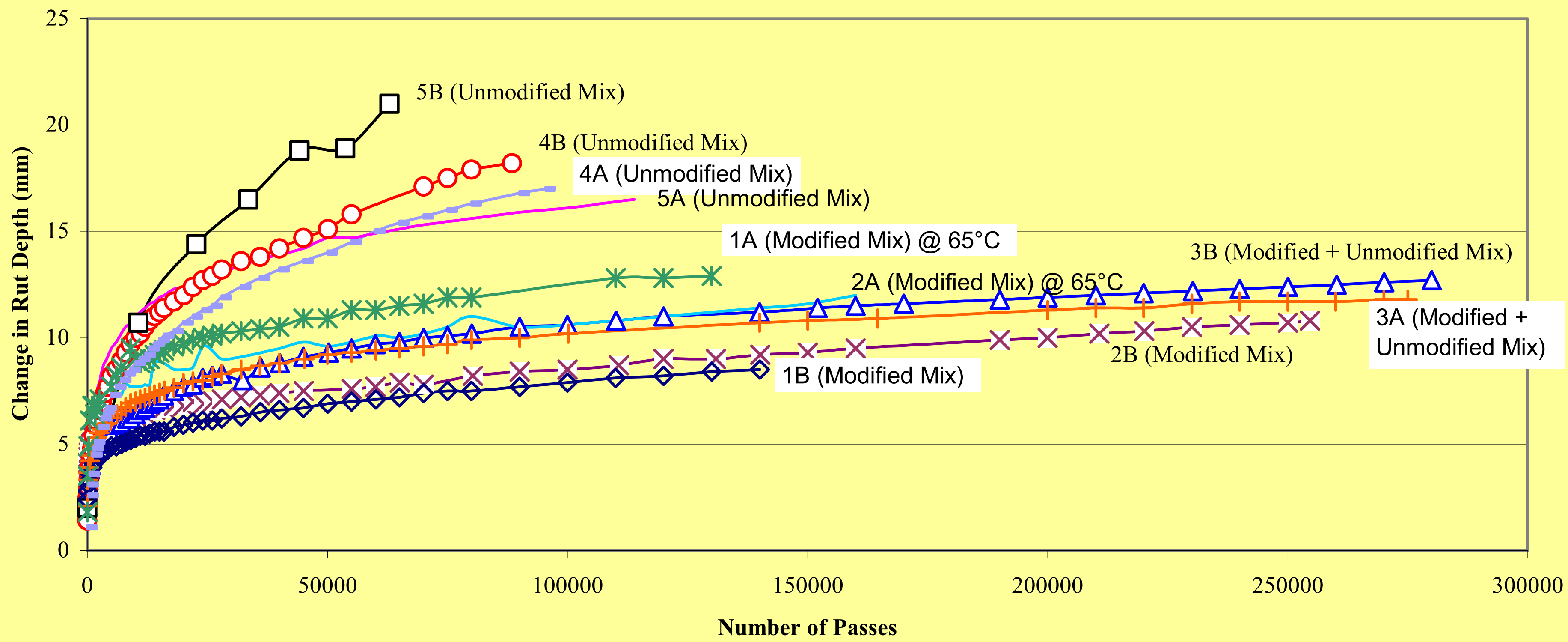


Photo of Lasers Mounted onto Two Sides of the Test Carriage

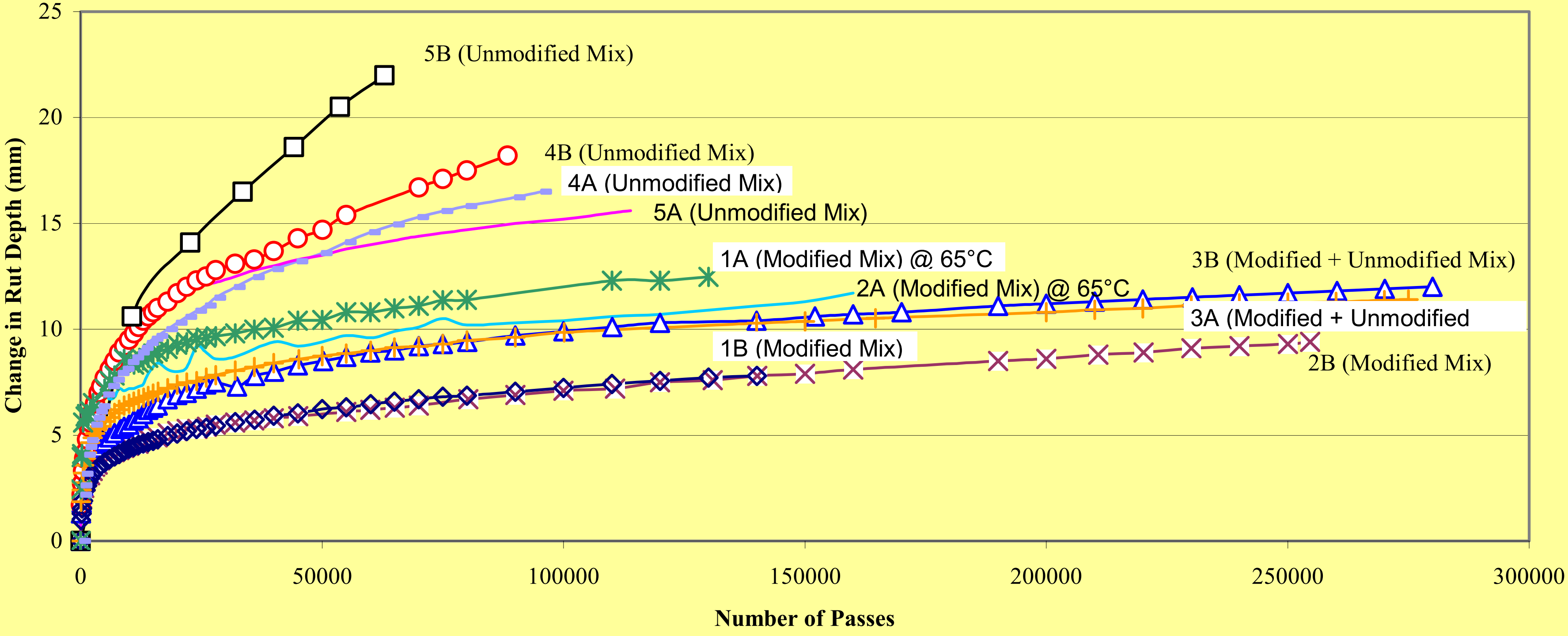


Travel Path of Laser Profiler in Measuring Pavement Surface Profile

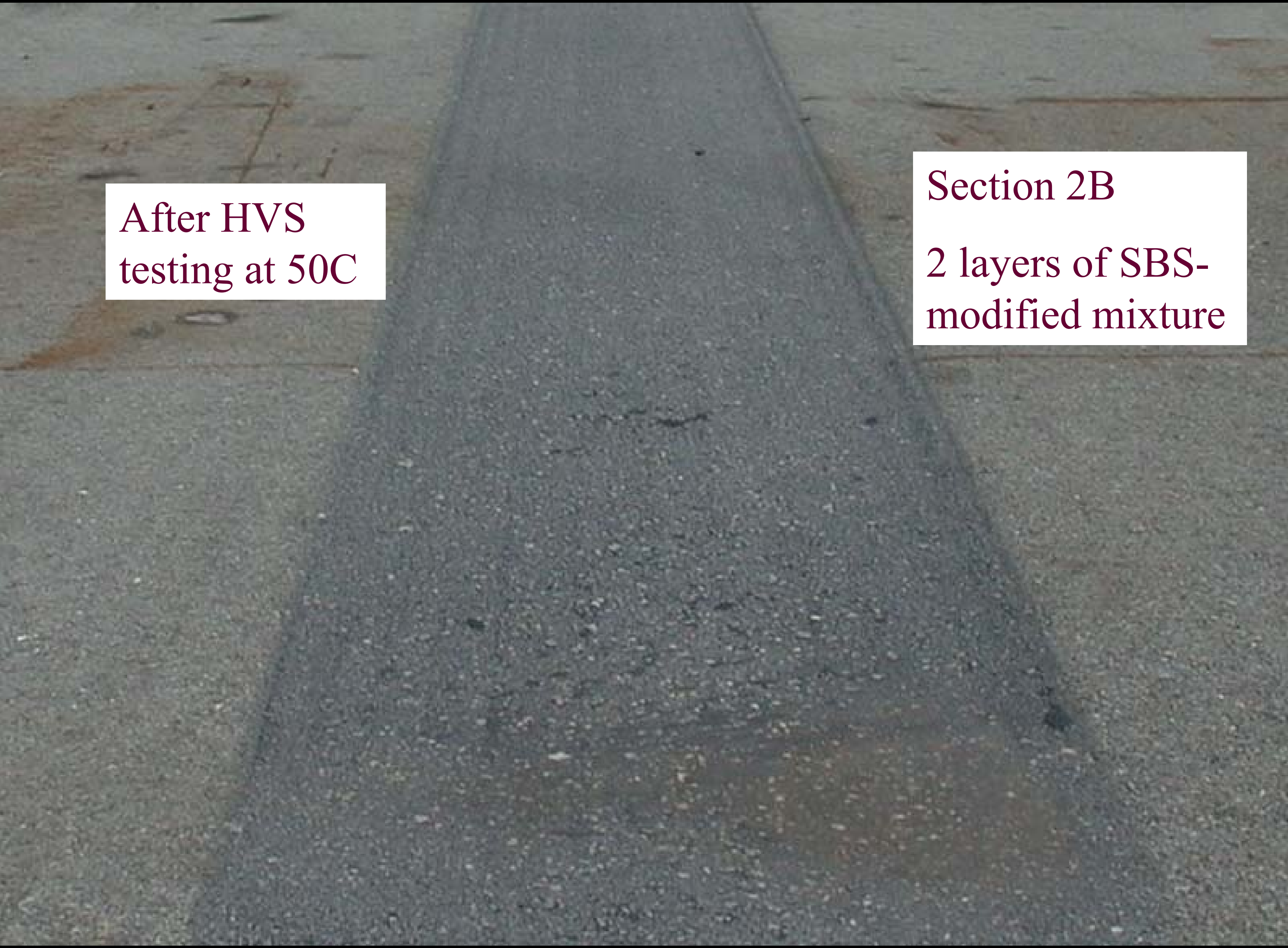
Test Sections 1A & 2A tested at 65 °C. All others were tested at 50 °C.



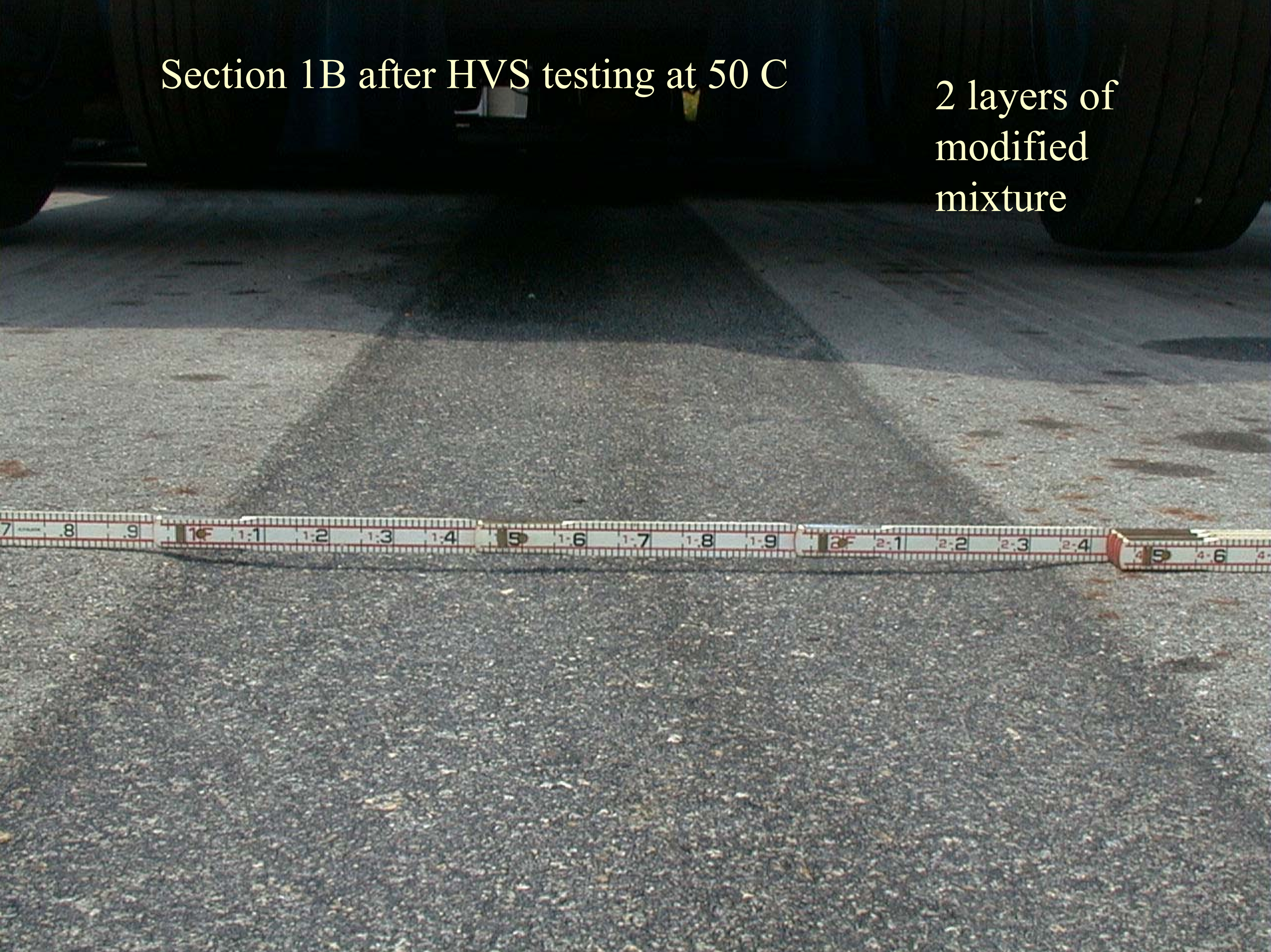
Comparison of Change in Rut Depth as Measured by the Surface Profile Method for Test Sections in Phase II



Comparison of Change in Rut Depth as Measured by the Differential Surface Profile Method


After HVS testing at 50C
Section 2B
2 layers of SBS-modified mixture


Section 2B


Section 1B after HVS testing at 50 C
2 layers of
modified
mixture

Section 3B after HVS testing at 50C

Modified over unmodified mixture


Section 3A
after HVS
testing at 50 C

Section 4B After HVS Testing at 50 C


Section
4B

Photo of Section 4A (Unmodified Mixture Tested at 50°C)


Section 5B (unmodified mixture) after HVS testing at 50 C


Section 5B

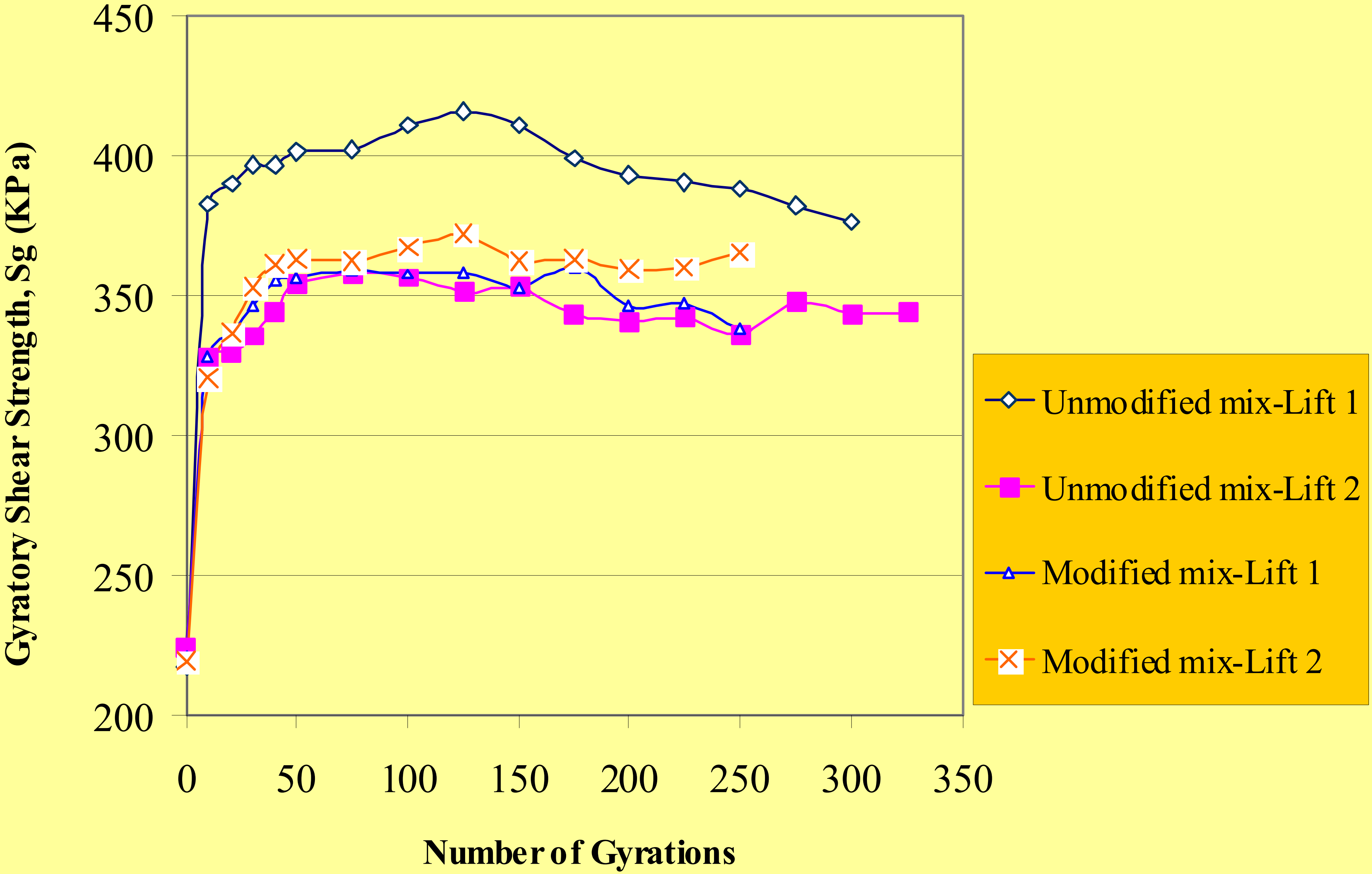
Photo of Section 5A (Unmodified Mixture Tested at 50 °C)

Photo of Section 1A (SBS-Modified Mixture Tested at 65°C)

Photo of Section 2A (SBS-Modified Mixture Tested at 65 °C)

LABORATORY TEST RESULTS

EVALUATION IN THE GTM



GSI values of the four mixtures evaluated in the GTM

Sample No	Unmodified Mix	Unmodified Mix	Modified Mix	Modified
	Lift 1	Lift 2	Lift 1	Lift 2
1	1.15	1.20	1.00	1.00
2	1.23	1.19	1.05	1.00
3	1.17	1.23	1.00	1.12
Average	**1.18**	**1.21**	**1.02**	**1.04**

EVALUATION IN THE ASPHALT PAVEMENT ANALYZER

		Unmodified Mix-Lift 1			Unmodified Mix-Lift 2		
Sample No	Measurement	Rut Measurement			Rut Measurement		
	No	25 Passes	8000 Passes	**Rut Depth**	25 Passes	8000 Passes	**Rut Depth**
1	1	20.2	11.8	8.4	19.8	12.6	7.2
	2	20.6	11.1	9.5	20.3	11.9	8.4
2	1	20.8	10.8	10.0	20.6	12.6	8.0
	2	20.6	11.3	9.3	20.1	13.1	7.0
3	1	20.5	9.4	11.1	20.3	13.0	7.3
	2	20.7	9.6	11.1	20.4	12.6	7.8
4	1	20.8	10.4	10.4	20.4	13.4	7.0
	2	20.0	11.0	9.0	18.5	14.5	4.0*
5	1	20.8	11.1	9.7			
	2	20.4	9.8	10.6			
6	1	20.8	10.6	10.2			
	2	21.0	12.0	9.0			
Overall Average (mm)				**9.9**			**7.5**

* Not considered in the overall average

		Modified Mix-Lift 1			Modified Mix-Lift 2		
Sample No	Measurement	Rut Measurement			Rut Measurement		
	No	25 Passes	8000 Passes	**Rut Depth**	25 Passes	8000 Passes	**Rut Depth**
1	1	20.6	14.4	6.2	21.0	16.1	4.9
	2	20.8	14.5	6.3	21.0	15.8	5.2
2	1	20.7	14.4	6.3	21.2	16.4	4.8
	2	20.9	14.8	6.1	21.0	15.6	5.4
3	1	20.5	15.4	5.1	21.1	16.0	5.1
	2	21.1	14.8	6.3	21.2	15.2	6.0
4	1	21.3	14.3	7.0	21.3	15.7	5.6
	2	20.9	14.8	6.1	21.1	15.6	5.5
Overall Average (mm)				**6.2**			**5.3**

RELATIONSHIP BETWEEN LAB AND FIELD RESULTS

Two laboratory test results which correlate with field rutting performance are:

1. Rut Depth measurements in the APA
2. GSI value as measured in the GTM

- The higher the rutting in the APA, the higher rutting in actual pavement
- A mixture with a GSI of more than 1.0 will be likely to rut more than the one with a GSI of close to 1.0


Cores taken from wheel paths and outside edges of wheel paths

Comparison of Bulk Density and Thickness of Cores from Wheel Path and Edge of Wheel Path

Section		Bulk Density				Thickness (mm)	
		No.1	No.2	Average	% difference	Average	% difference
2C	wheelpath	2.181	2.181	**2.181**	**2.61**	**81.06**	**2.06**
	edge of wheelpath	2.129	2.119	**2.124**		**82.77**	
3C	wheelpath	2.134	2.133	**2.134**	**1.03**	**74.66**	**5.24**
	edge of wheelpath	2.119	2.104	**2.112**		**78.79**	
4C	wheelpath	2.168	2.099	**2.134**	**4.78**	**80.84**	**8.59**
	edge of wheelpath	2.092	1.971	**2.032**		**88.44**	
5C	wheelpath	2.154	2.155	**2.155**	**3.30**	**77.84**	**11.36**
	edge of wheelpath	2.071	2.096	**2.084**		**87.82**	
1B	wheelpath	2.164	2.163	**2.164**	**1.57**	**89.33**	**7.78**
	edge of wheelpath	2.134	2.125	**2.130**		**96.87**	
2B	wheelpath	2.184	2.189	**2.187**	**2.68**	**73.53**	**5.17**
	edge of wheelpath	2.125	2.131	**2.128**		**77.54**	
3B	wheelpath	2.175	2.182	**2.179**	**3.37**	**71.62**	**10.10**
	edge of wheelpath	2.097	2.113	**2.105**		**79.67**	

Comparison of Bulk Density and Thickness of Cores from Wheel Path and Edge of Wheel Path (Continued)

Section		Bulk Density				Thickness (mm)	
		No.1	No.2	Average	% difference	Average	% difference
4B	wheelpath	2.184	2.187	**2.186**	**4.35**	**78.08**	**13.08**
	edge of wheelpath	2.080	2.101	**2.091**		**89.83**	
5B	wheelpath	2.178	2.171	**2.175**	**4.02**	**80.95**	**18.06**
	edge of wheelpath	2.099	2.075	**2.087**		**98.79**	
1A	wheelpath	2.193	2.186	**2.190**	**3.47**	**89.90**	**6.98**
	edge of wheelpath	2.109	2.118	**2.114**		**96.65**	
2A	wheelpath	2.203	2.193	**2.198**	**3.18**	**92.01**	**3.16**
	edge of wheelpath	2.141	2.115	**2.128**		**95.01**	
3A	wheelpath	2.173	2.164	**2.169**	**3.30**	**78.59**	**10.35**
	edge of wheelpath	2.092	2.102	**2.097**		**87.66**	
4A	wheelpath	2.183	2.185	**2.184**	**4.72**	**83.20**	**12.67**
	edge of wheelpath	2.07	2.092	**2.081**		**95.27**	
5A	wheelpath	2.193	2.171	**2.182**	**3.71**	**90.83**	**12.09**
	edge of wheelpath	2.101	2.101	**2.101**		**103.32**	

Comparison of Air Voids of Cores before and after HVS Testing

Section	Sample	Gmb	Gmm	Average Air Voids	% Change in air voids
2C	Original	2.112	2.263	6.7	
	Tested (edge of wheelpath)	2.124	2.263	6.1	**-0.53**
	Tested (wheelpath)	2.181	2.263	3.6	**-3.05**
3C	Original	2.097	2.271	7.7	
	Tested (edge of wheelpath)	2.112	2.271	7.0	**-0.66**
	Tested (wheelpath)	2.134	2.271	6.0	**-1.63**
4C	Original	2.122	2.280	6.9	
	Tested (edge of wheelpath)	2.032	2.280	10.9	**3.95**
	Tested (wheelpath)	2.134	2.280	6.4	**-0.53**
5C	Original	2.118	2.276	7.0	
	Tested (edge of wheelpath)	2.084	2.276	8.4	**1.47**
	Tested (wheelpath)	2.155	2.276	5.3	**-1.65**

Comparison of Air Voids of Cores before and after HVS Testing (Continued)

Section	Sample	Gmb	Gmm	Average Air Voids	% Change in air voids
2B	Original	2.104	2.268	7.2	
	Tested (edge of wheelpath)	2.128	2.263	6.0	**-1.27**
	Tested (wheelpath)	2.187	2.263	3.4	**-3.87**
3B	Original	2.100	2.275	7.7	
	Tested (edge of wheelpath)	2.105	2.271	7.3	**-0.38**
	Tested (wheelpath)	2.179	2.271	4.1	**-3.64**
4B	Original	2.125	2.278	6.7	
	Tested (edge of wheelpath)	2.091	2.280	8.3	**1.57**
	Tested (wheelpath)	2.186	2.280	4.1	**-2.59**
5B	Original	2.121	2.277	6.9	
	Tested (edge of wheelpath)	2.087	2.276	8.3	**1.45**
	Tested (wheelpath)	2.175	2.276	4.4	**-2.41**
3A	Original	2.104	2.268	7.2	
	Tested (edge of wheelpath)	2.097	2.271	7.7	**0.43**
	Tested (wheelpath)	2.169	2.271	4.5	**-2.74**

Beams cut from the test sections


4B
3B
2B

SUMMARY OF FINDINGS

1) The pavement sections with two lifts of SBS-modified mixture clearly outperformed those with two lifts of unmodified mixture, which had two to two and a half times the rut rate. The test sections with two lifts of SBS-modified mixture and tested at 65 °C still greatly outperformed the test sections with two lifts of unmodified mixture and tested at 50°C.
2) The pavement sections with a lift of SBS-modified mixture over a lift of unmodified mixture practically had about the same performance as those with two lifts of SBS-modified mixture. They had about the same rutting performance when tested at ambient condition, and had only about 20% higher rutting when tested at 50 °C when compared with those with two lifts of modified mixture.
3) A mixture with a higher rut depth in the APA will be likely to rut more in the actual pavement. A mixture with a GSI of more than 1.0 as measured by the GTM will be likely to rut more than one with a GSI close to 1.0.

SUMMARY OF FINDINGS (Continued)

4) For the pavements with the unmodified mixture, rutting was caused by a combination of densification and shoving. For the pavements with the SBS-modified mixture, rutting was due primarily to densification of the mixture.

5) The resilient modulus and indirect tensile strength at 25 °C of the SBS-modified mixture were not significantly different from those of the unmodified mixture.

6) The viscosity at 60 °C of the recovered binders from the SBS-modified mixture was two to three times that of the recovered binders from the unmodified mixture. The higher viscosity of the SBS-modified binder was one of the main reasons for the higher rutting resistance of the SBS-modified mixture.

Thank You !