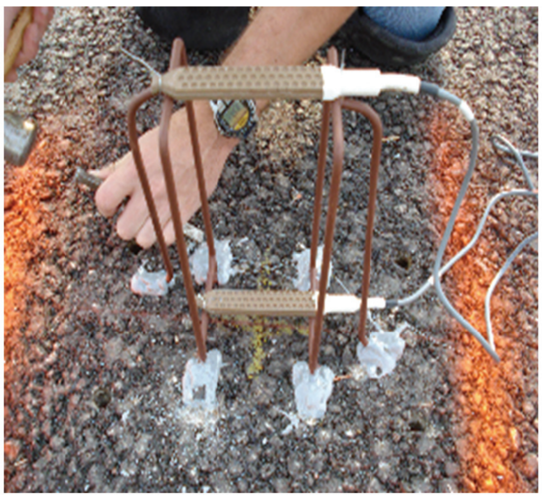
MONITORING AND MODELING OF PAVEMENT RESPONSE AND PERFORMANCE

TASK A: OHIO

Pooled Fund Project TPF-5 (121)



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for the
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16. Abstract
Over the years, the Ohio Department of Transportation has constructed several pavements with a range of designs and materials to study and improve overall statewide performance. These pavements require constant monitoring to determine how they perform over time and what mechanisms are at work to cause distress. One major effort was the DEL-23 Test Road where 40 AC and PCC test sections in the SPS-1, SPS-2, SPS-8 and SPS-9 experiments were constructed for SHRP. While many sections have been replaced, many other sections remain in service. These remaining sections and seven PCC replacement sections need to be evaluated periodically. Perpetual AC pavement and long lasting PCC pavements were constructed on US-30 in Wayne County to compare the performance of these new designs and to reduce maintenance and the associated traffic delays. ATH-33 was a rigid pavement constructed in Nelsonville using blast furnace slag and fly ash as a partial replacement for cement. Sections with these materials were also cured with membrane and wet burlap to observe any differences in performance. ATH-50 was a rigid pavement with ground granulated blast furnace slag added to the concrete. A few stainless steel tube dowel bars filled with concrete and a few fiberglass dowel bars were installed and compared with standard epoxy coated steel dowel bars. LOG-33 was an AC pavement containing six different bases to determine their effect on performance. MEG-33 was a PCC pavement constructed partially on a clay subgrade and partially on a sandy subgrade. Some of the joints in both sections were sealed and some were unsealed to set up a test matrix of joint sealing and subgrade type. Various testing was performed at these sites, but the most common types of testing were FWD and controlled vehicle testing with loaded dump trucks to measure responses to dynamic loading.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

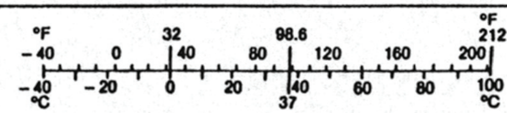
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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TASK A: OHIO

Final Report

Prepared in Cooperation with the
Ohio Department of Transportation
and the
U.S. Department of Transportation
Federal Highway Administration

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ABSTRACT

Over the years, the Ohio Department of Transportation has constructed several pavements with a range of designs and materials to study and improve overall statewide performance. These pavements require constant monitoring to determine how they perform over time and what mechanisms are at work to cause distress. One major effort was the DEL-23 Test Road where 40 AC and PCC test sections in the SPS-1, SPS-2, SPS-8 and SPS-9 experiments were constructed for SHRP. While many sections have been replaced, many other sections remain in service. These remaining sections and seven PCC replacement sections need to be evaluated periodically. Perpetual AC pavement and long lasting PCC pavements were constructed on US-30 in Wayne County to compare the performance of these new designs and to reduce maintenance and the associated traffic delays. ATH-33 was a rigid pavement constructed in Nelsonville using blast furnace slag and fly ash as a partial replacement for cement. Sections with these materials were also cured with membrane and wet burlap to observe any differences in performance. ATH-50 was a rigid pavement with ground granulated blast furnace slag added to the concrete. A few stainless steel tube dowel bars filled with concrete and a few fiberglass dowel bars were installed and compared with standard epoxy coated steel dowel bars. LOG-33 was an AC pavement containing six different bases to determine their effect on performance. MEG-33 was a PCC pavement constructed partially on a clay subgrade and partially on a sandy subgrade. Some of the joints in both sections were sealed and some were unsealed to set up a test matrix of joint sealing and subgrade type. Various testing was performed at these sites, but the most common types of testing were FWD and controlled vehicle testing with loaded dump trucks to measure responses to dynamic loading.

Chapter 1
Introduction

This report documents work by the Ohio Research Institute for Transportation and the Environment (ORITE) at Ohio University on specific tasks to be performed in Ohio under pooled fund study, TPF-5(121), "Monitoring and Modeling of Pavement Response and Performance," funded by the Ohio Department of Transportation (ODOT) and the Federal Highway Administration (FHWA). Other tasks to be funded by and performed for the New York Department of Transportation will be documented in separate reports. Overall objectives for the study were presented as follows in the proposal.

Perpetual asphalt concrete (AC) and long-lasting Portland cement concrete (PCC) pavements are relatively new to the pavement community. These newer pavements require the use of innovative Mechanistic-Empirical (ME) design procedures, advanced climatic models, updated specifications, test methods providing detailed material properties, and construction techniques not been entirely adopted into standard practice. Standard practice for rehabilitating distressed highway pavements generally involves the application of AC overlays. When AC overlays are placed on distressed PCC pavements, slab movements cause stress concentrations to develop at joints and cracks, which often results in premature cracks reflecting up through to the surface at these locations. By breaking PCC slabs into smaller pieces prior to overlay, stresses are distributed over a wider area. Instrumentation installed in these pavement sections will provide data regarding measured responses under known environmental and loading conditions.

The four primary objectives of the proposed research are to: (1) monitor new perpetual AC and long-lasting PCC pavements constructed on US-30 in Ohio, rehabilitated PCC pavements on I-86 in New York, and other existing instrumented pavements in both states, (2) verify ME design procedures for all pavements in the study by comparing theoretical calculations with measured responses and performance, (3) calibrate ME procedures presented in the NCHRP 1-37A AASHTO Pavement Guide for Ohio and New York using data collected in this and other previous studies, (4) conduct controlled testing of perpetual pavement systems to determine their relative performance and to recommend the most promising layer configurations, and (5) document all research findings in a final report. Within each of these primary objectives are various secondary objectives which must be completed to achieve the primary goals. Accordingly, the following objectives are set forth for this project:

1. Monitor new perpetual AC and long-lasting PCC pavements in Ohio, rehabilitated PCC pavements in New York, and other existing instrumented pavements in both states. Within this objective are the following secondary objectives:

   A. Monitor construction of the US-30 and I-86 pavements to observe construction practices and environmental conditions which may affect pavement response and performance. Identify specific deficiencies which should be corrected on future projects.

   B. Determine the physical properties of materials incorporated into the rehabilitated PCC pavements on I-86 in New York State. Organize these data and material data from the US-30 project into a Microsoft Access database for validation and calibration of NCHRP 1-37A guidelines.

   C. Periodically collect response and performance data on the study pavements in Ohio and New York State for the duration of this project, as the availability of functional sensors permits. In addition to US-30 in Ohio and I-86 in New York, locations will include: I-490 in New York; the Ohio US-23 SHRP Test Road in Delaware County, Ohio; US-50 in Athens County, Ohio; US-33 in Meigs County, Ohio; US-33 in Logan County, Ohio; US-33 in the city of Nelsonville, Ohio; and I-77 in Stark County, Ohio. Specific data collected will include:

      i. Climatic data obtained at on-site weather stations located on the US-30, US-50, I-86 test sections, and at the Ohio SHRP Test Road (US 23).
      ii. Temperature and moisture conditions monitored in all pavement structures with sensors similar to those installed on Long Term Pavement Performance (LTPP) projects.
      iii. Traffic loading obtained with weigh-in-motion scales mounted in the US-30, I-86 and US 23 SHRP pavements.

iv. Condition surveys collected at all sites according to LTPP protocol and profile measurements to determine rutting on AC pavements and curling/warping on PCC pavements. Profiles will be performed with a dipstick and/or a rolling wheel profilometer developed and constructed at ORITE. These data will be analyzed to note trends with environmental factors, and to determine possible links to the development of pavement distress.

v. Pavement stiffness measured with the Falling Weight Deflectometer (FWD) and skid resistance measured with available test equipment. These tests will be performed on all projects by state DOTs responsible for the individual projects. The FWD data will be used to identify weakened zones in the pavement structures, to document the potential areas of distress, and to backcalculate stiffness properties of the pavement layers.

vi. Strain, deflection and pressure responses measured on the US 30 and I 86 projects using the FWD and a matrix of truck loads, truck speeds, pavement temperatures, and subgrade moisture.

D. Conduct a maximum of three forensic investigations on pavement sections exhibiting severe distress to determine the specific causes of the distress. Each investigation will include in-situ tests and laboratory testing of cores and samples collected at the site. These investigations will follow procedures established by LTPP with additional guidelines developed by ORITE during previous forensic investigations in Ohio. State DOTs will furnish all equipment and personnel required to perform NDT and to dig trenches and repair them after the forensic investigations are complete. ORITE will conduct all field measurements and perform all laboratory tests necessary to identify the cause(s) of distress.

E. Enter all data collected by ORITE and by the Ohio and New York DOTs into a Microsoft Access database. Develop a web page with supporting files to allow the display and downloading of climatic and environmental data to be posted on a web site residing or linked to one of ODOT's computer servers. Provide assistance to parties interested in accessing and using the environmental and structural databases created by ORITE.

2. Verify ME design procedures for all pavements in the study by comparing theoretical calculations with measured response and performance.

A. Review and determine the accuracy of available pavement analysis and design procedures, including the new ME procedures introduced in the 2002 Guide through project NCHRP 1-37A and peripheral models, such as VESYS, using response and performance data collected on this project and on earlier monitoring efforts in Ohio.

B. Determine how environmental factors such as temperature and moisture affect PCC slab curling and warping, AC layer stiffness, subgrade stiffness, and overall pavement response and performance.

C. Determine the accuracy of existing models, including the LTPP Model, for estimating temperature in asphalt concrete pavements. These models will be calibrated if no suitable agreement is found.

D. Determine input parameters and determine the accuracy of the Enhanced Integrated Climatic Model (EICM) to be released with the 2002 Guide for predicting temperature and moisture profiles in rigid and flexible pavements. Evaluate specific inputs to the EICM, develop input guidelines for Ohio and New York, and compare calculated temperature and moisture profiles with actual measurements obtained at test sites in Ohio and New York.

3. Calibrate ME procedures presented in the NCHRP 1-37A AASHTO Pavement Guide for Ohio and New York State using data collected during this study and previously in Ohio. Develop calibration factors for the distress models in the NCHRP 1-37A software so calculated response and performance on projects in this study agree more closely with actual measured response and performance.

A. Review Level 1, 2, and 3 hierarchies in the 2002 Guide and perform a sensitivity analysis of input parameters to determine the relative effect of each parameter in each hierarchy. A decisive effort will be made to use the results of sensitivity analyses being conducted on other projects, i.e. Kansas pooled fund study TPF-5(079), FHWA, NCHRP, and AASHTO.

B. By comparing calculated response, measured response and performance on the study pavements, recommend calibration factors for distress models in the 1-37A software that would improve the accuracy of designs in Ohio and New York State. Pavement analysis codes for both flexible and rigid pavements adopted by the 2002 Guide will be used in this part of the study.

C. Determine information required to perform Level 1, 2, and 3 analyses and develop guidelines for selecting input values. Recommend appropriate values based on the results of Part B.

D. Considering the estimated accuracy of Level 1, 2, and 3 designs, and the effort required to obtain input data for each design, evaluate the relative effectiveness of each design level and recommend levels appropriate for different functional classes of pavement.

4. Controlled Testing of Perpetual Pavement Systems to Determine their Relative Performance and to Recommend the Most Promising Layer Configurations (Materials and Thicknesses).

A. Select no less than three perpetual pavement configurations to be tested under carefully controlled conditions. These will include an asphalt concrete surface layer over a very stiff base, a buildup based on the South African method of perpetual pavement design, and a pavement consisting of thick asphalt concrete on a thick granular base.

B. Build the proposed test sections at the Accelerated Pavement Load Facility at the Ohio University Campus in Lancaster, Ohio. Each section will be instrumented with strain gages, pressure cells, LVDTs, and accelerometers to monitor pavement response to applied loads. Prior to construction of pavement layers, the subgrade will be tested to primarily determine its stiffness and other properties needed for the complete characterization of materials. As new layers are added, characterization tests will be conducted in the finished surface of each layer. Tests will be of both destructive and non-destructive nature.

C. Collect pavement response data from embedded gages to obtain their response time series and conduct other primarily non-destructive tests to monitor material property changes after scheduled number of load repetitions have been applied to the pavement sections.

D. Analyze pavement performance data and validate available pavement analysis methods. Once testing is completed, a comparative study will help determine what pavement configuration is more advantageous under the tested conditions, from which future design recommendations can be developed. Similarly, pavement response and material characterization data obtained during the controlled indoor testing will be used in the additional verification of pavement analysis models. If suitable analysis methods are found, they can be used in the development of mechanistic-based design charts, which may be used by practitioners in future designs.

5. Document all findings of the research.

A. Prepare annual interim reports documenting the construction of test sections and reviewing trends in environmental data, sensor status, and performance of the test sections.

B. Prepare final reports documenting all work performed on this study and all important findings.

C. Any major findings with immediate application will be reported in an appropriate format as the project progresses.

The availability of instrumented pavement sections to be constructed on WAY-30 in Ohio and on NY-17 (I-86) in New York, along with existing test sections at the Ohio SHRP Test Road, US-50 in Athens County Ohio, US-33 in Meigs County Ohio, US-33 in Logan County Ohio, US-33 in the city of Nelsonville, Ohio, I-77 in Stark County Ohio, and I-490 in New York offer a unique opportunity to meet the objectives of this proposed national pooled fund research project. While these projects were constructed to obtain specific data for ODOT and NYDOT, they can continue to be monitored, and the data adapted to the broader goal of calibrating the NCHRP 1-37A 2002 Guide.

Chapter 2

Evaluation of Perpetual AC and Long Lasting PCC Pavements on WAY 30

2.1 Background

This chapter discusses work performed for the Ohio Department of Transportation (ODOT) on a perpetual asphalt concrete (AC) pavement and a long lasting Portland cement concrete (PCC) pavement constructed along a section of US 30 in Wayne County. Early results were provided in Report FHWA/OH-2008/7, entitled "Instrumentation of the WAY 30 Test Pavements," authored by Shad Sargand, J. Ludwig Figueroa and Michael Romanello, and published in June of 2008 (Ref.1). Additional results are included in this report and in the WAY 30 database.

A section of relocated US 30 in Wayne County, Ohio was selected as the site for constructing perpetual AC and long lasting PCC pavement in 2005. This new four-lane divided rural freeway began east of Wooster at an interchange with SR-83, and ran east for approximately 8 miles (13 km). The westbound lanes were perpetual AC pavement and the eastbound lanes were long lasting PCC pavement with either ground granulated blast furnace slag (GGBFS) (Mix A) or fly ash (Mix B) used as a partial replacement for cement. Fly ash was used between Stations 626+00 and 852+00, and GGBFS was used between Stations 852+00 and 1047+50. The AC lanes were uniform throughout the length of the project.

Two PCC test sections were originally laid out to represent each of the materials being used to replace cement, and at a third section was laid out to evaluate different types of dowel bars used to provide load transfer across joints. Corresponding AC sections were located directly across from each of the three PCC sections, making a total of six test sections, as summarized in Table 2.1. All sites had relatively flat topography, straight alignment and minimal grade cuts. FWD measurements were recorded in the six sections as each material layer was completed during construction, and response instrumentation was added to two AC and two PCC sections. Prior to placement of the pavement layers, it was decided to consolidate the six test sections into four sections by: 1) moving the dowel bar experiment from Section A to Section D, 2) moving the response sensors planned for Section B to serve as a set of redundant sensors in Section C, and 3) removing Sections A and B from the experiment entirely.

Table 2.1

WAY 30 Test Sections

Section ID	Note Below	Station	Instrumented Section ID	Pavement Type		
				AC	PCC Mix A	PCC Mix B
A	1	884-889 EB	Deleted		X	
B	1	884-889 WB	Deleted	X		
C	2	875-881 WB	876A AC, 876B AC	X		
D	2, 3	875-881 EB	876 PCC		X	
E	2	661-667 WB	664 AC	X		
F	2	661-667 EB	664 PCC			X

(1) Section removed, (2) Response instrumentation added, (3) Dowel bar section

The perpetual AC pavement consisted of the following design:

1.5 in. (3.8 cm) ODOT 856 stone mastic wearing course with PG 76-22M polymer modified binder
1.75 in. (4.5 cm) ODOT 442 Superpave, Type A leveling course, with PG 76-22M polymer modified binder
9 in. (22.9 cm) ODOT 302 large stone ATB with PG 64 -22 asphalt binder
4 in. (10.2 cm) Modified ODOT 302 fatigue resistant ATB with 3 % air voids and 94 - 97% density
6 in. (15.2 cm) ODOT 304 crushed granular base with underdrains

The long lasting PCC sections consisted of the two following designs:

<u>Mix A - Station 852+00 – 1047+50</u>

10 in. (25.4 cm) ODOT 452 jointed plain concrete*
3 in. (7.5 cm) ODOT 301 ATB with PG 64-22 asphalt binder
4 in. (10.2 cm) ODOT 304 crushed granular base with underdrains
* GGBFS, 30% total cementitious material, 4.9% total weight

<u>Mix B – Station 626+00 – 852+00</u>

10 in. (25.4 cm) ODOT 452 jointed plain concrete*
3 in. (7.5 cm) ODOT 301 ATB with PG 64-22 asphalt binder
4 in. (10.2 cm) ODOT 304 crushed granular base with underdrains
* Fly ash, 20% total cementitious material, 3.3% total weight

The physical properties of these materials are to be provided in a report entitled "Determination of Mechanical Properties of Materials Used in WAY 30 Test Pavements," (Ref. 2).

The PCC slabs were 15 feet (4.6 m) long by 14 feet (4.27 m) wide with standard 1.5 inch (3.8 cm) diameter epoxy coated steel dowel bars spaced 12 inches (30.5 cm) apart at most joints.

Stainless steel dowel bars were installed in joints at Stations 877+10, 877+25 and 877+40; zinc clad steel dowel bars were installed in joints at Stations 877+55, 877+71 and 877+86; and composite dowel bars were installed in a joint at Station 878+03. Twelve feet (3.66 m) of slab width was the right hand driving lane and the outer two feet (0.61 m) extended into the shoulder. Eight additional feet (2.44 m) of concrete shoulder was tied to the outside of the 14 foot (4.27 m) wide slabs to provide a 10 foot (3.05 m) wide shoulder.

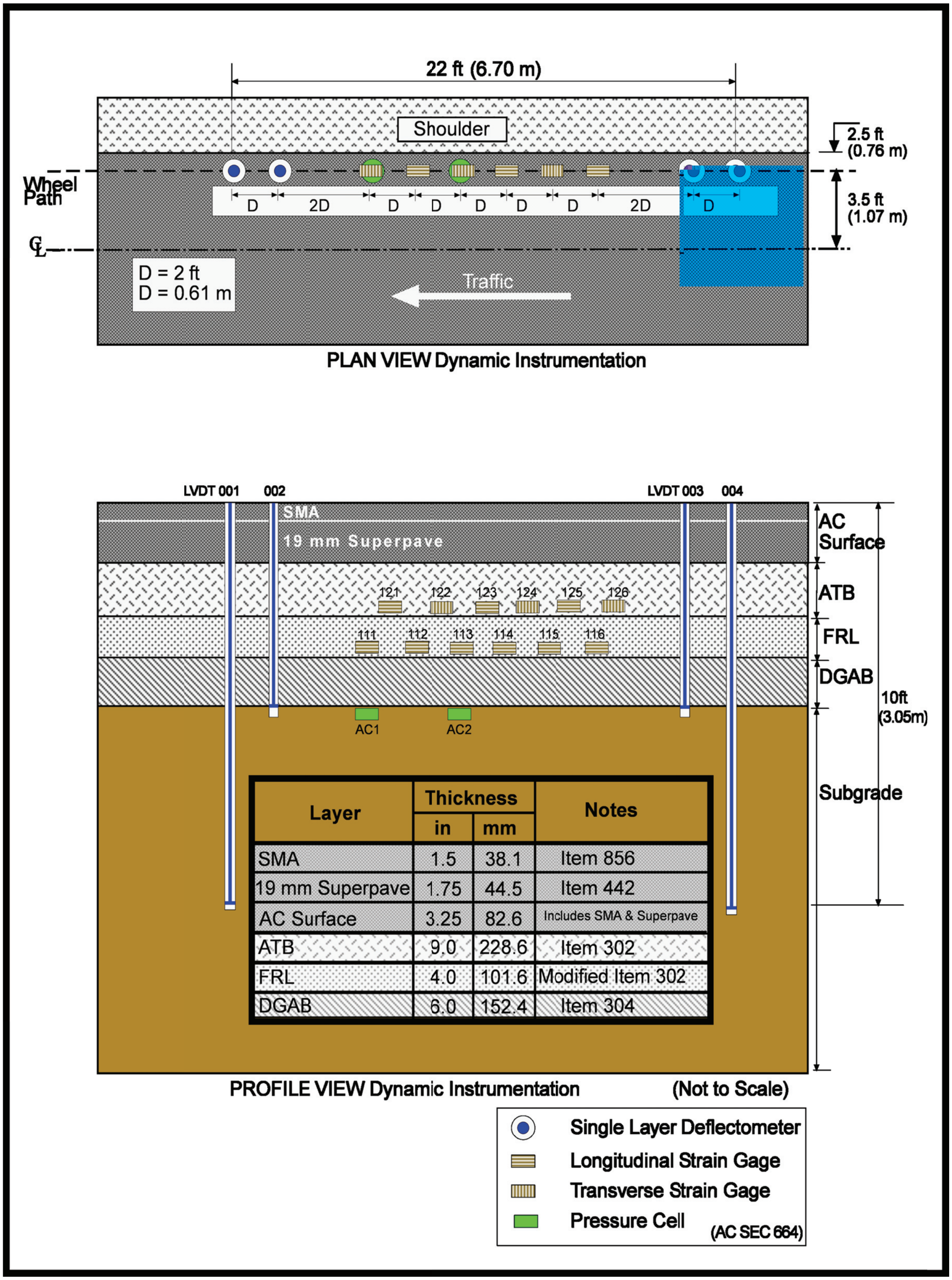
2.2 Response and Environmental Instrumentation

Table 2.2 summarizes the types of instrumentation placed in the right wheelpath (RWP) of the four test sections, and Figures 2.1 - 2.4 show their location. Thermocouples were also added in each section to monitor pavement temperature.

Table 2.2

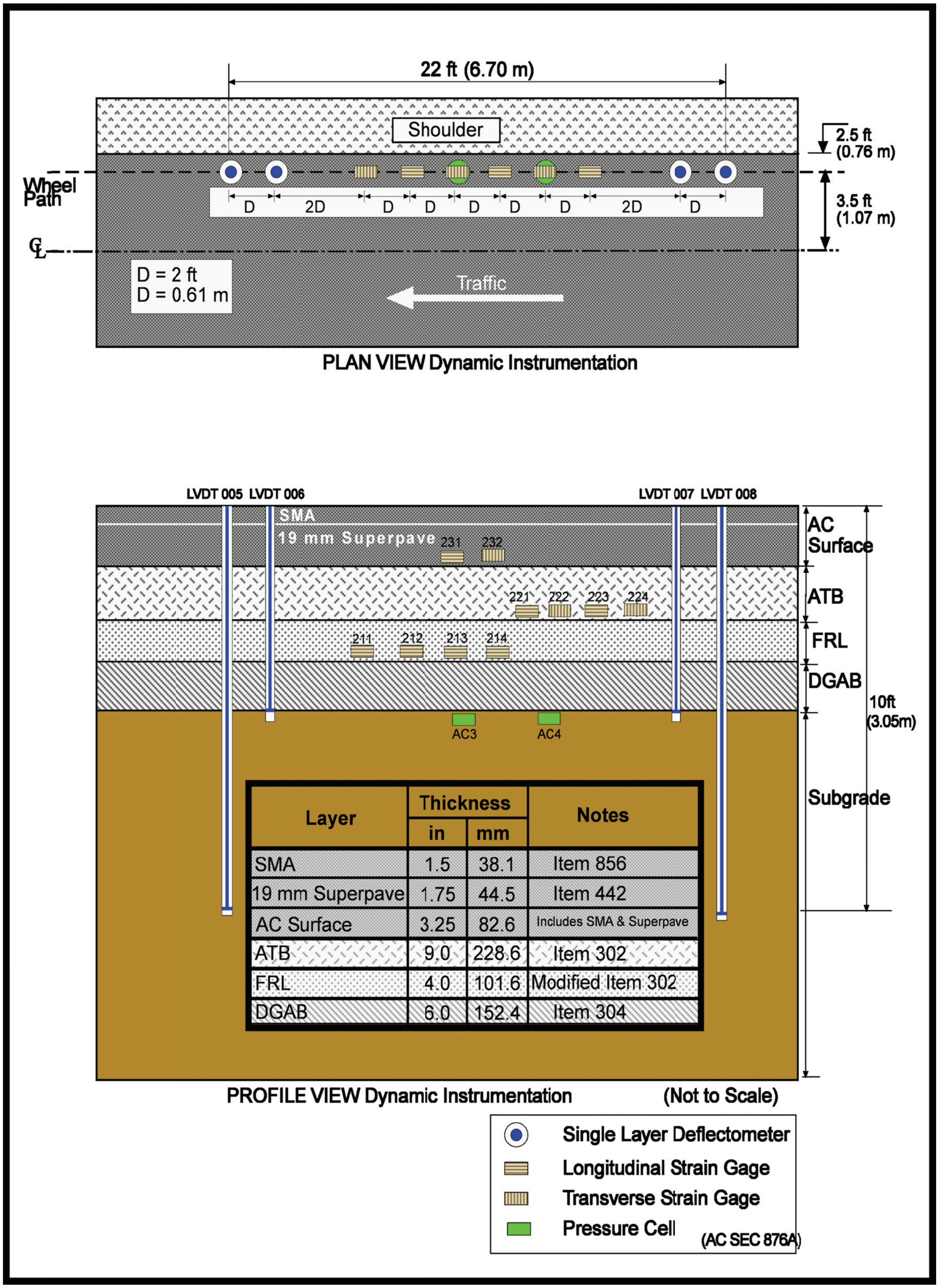
Instrumentation Summary

Instrumentation Type	Measurement	Parameters	Sensor	Manufacturer
AC Load Response	Displacement	Load & Seasonal Response	GPD 121-500 LVDT GPD 121-250 LVDT	Lucas Schaevitz
	Strain	Load Response	Dynatest PAST II - AC SG	Dynatest Consulting
	Pressure	Load & Seasonal Response	Geokon 3500 PC	Geokon
PCC Load Response	Displacement	Load & Seasonal Response	GPD 121-500 LVDT	Lucas Schaevitz
	Pressure	Load & Seasonal Response	Geokon 3500 PC	Geokon
Environmental	Temperature	Pavement, Base, and Subgrade	MRC Thermistor	Measurement Research Corporation
	Moisture	Base and Subgrade	FHWA TDR Probe	Cambell Scientific
	Frost Depth	Base and Subgrade	CRREL Resistivity Probe	Cold Regions Research & Engineering Laboratory
	Groundwater Table	Base and Subgrade	Piezometers	------



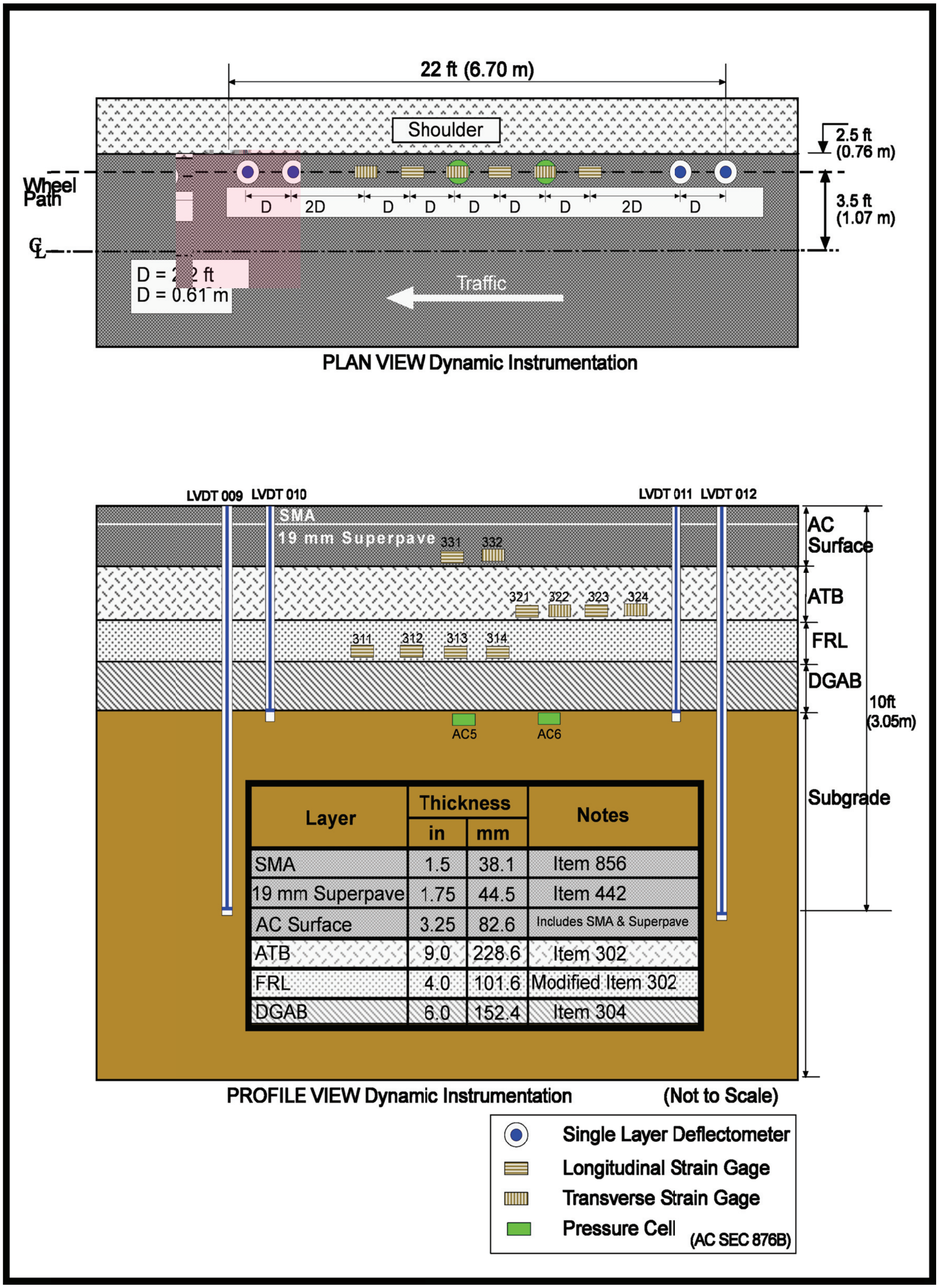
Layer	Thickness		Notes
	in	mm	
SMA	1.5	38.1	Item 856
19 mm Superpave	1.75	44.5	Item 442
AC Surface	3.25	82.6	Includes SMA & Superpave
ATB	9.0	228.6	Item 302
FRL	4.0	101.6	Modified Item 302
DGAB	6.0	152.4	Item 304

Figure 2.1 - Instrumentation Plan and Profile Views for AC Section 664



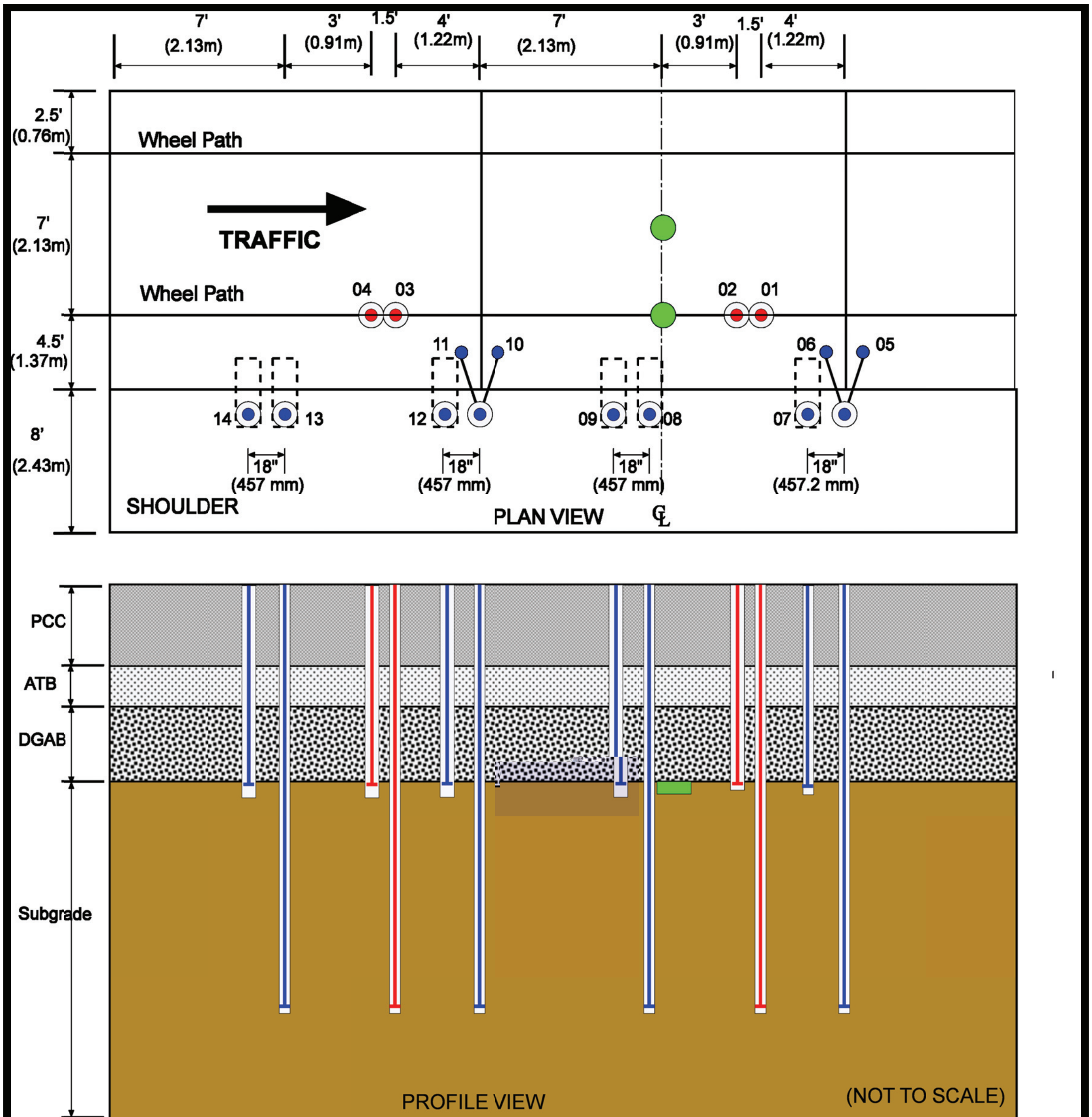
Layer	Thickness		Notes
	in	mm	
SMA	1.5	38.1	Item 856
19 mm Superpave	1.75	44.5	Item 442
AC Surface	3.25	82.6	Includes SMA & Superpave
ATB	9.0	228.6	Item 302
FRL	4.0	101.6	Modified Item 302
DGAB	6.0	152.4	Item 304

Figure 2.2 - Instrumentation Plan and Profile Views for AC Section 876A



Layer	Thickness		Notes
	in	mm	
SMA	1.5	38.1	Item 856
19 mm Superpave	1.75	44.5	Item 442
AC Surface	3.25	82.6	Includes SMA & Superpave
ATB	9.0	228.6	Item 302
FRL	4.0	101.6	Modified Item 302
DGAB	6.0	152.4	Item 304

Figure 2.3 - Instrumentation Plan and Profile Views for AC Section 876B



Layer	Thickness		Notes
	in	mm	
PCC	10.0	254.0	JPCC
ATB	3.0	76.2	Item 301
DGAB	4.0	101.6	Item 304

Single Layer Deflectometer
Pressure Cell

Figure 2.4 - Instrumentation Plan and Profile Views for PCC Sections 664 and 876

2.3 Controlled Vehicle Tests

Controlled vehicle tests were performed before the pavements were opened to traffic in December 2005, in July and August 2006, and in May 2008, as summarized in Tables 2.3-2.7. Results from the 2005 and 2006 tests are presented in ODOT Report FHWA/OH-2008/7 (Ref. 1). Dynamic responses and lateral offsets for all tests are included in the WAY 30 database.

Table 2.3 – Controlled Vehicle Test Summary

WAY 30 Controlled Load Tests							
Test Date	Test Series	Rear Truck Axles	No. Passes	Sections Monitored		Dynamic Parameters	
				AC	PCC	Load	Speed
12/5,7/05	I	Single	34	3	1	X	X
		Tandem	34				
7/18-19/06	II	Single	57	3	0	X	X
		Tandem	57				
7/18-19/06	II	FWD	45	3	0	X	
8/15-17/06	III	Single	50	1	2	X	X
		Tandem	55				
8/15-17/06	III	FWD	13	0	2	X	
5/20-21/08	IV	Single	39	3	2	X	X
		Tandem	38				

- Pavement Temperature, soil moisture and lateral truck position are inherent variables within each series of tests

Table 2.4 – Controlled Vehicle Test Series I, December 2005

Test Date	Nominal Load (K)	Rear Axle (K)	Nominal Speed (mph)	Load I.D.	Sections Monitored	Data Set No.
ODOT Single Axle Truck						
12/5/05	28	28.20	5,30,45,60	A	AC 664, PCC 664	2-22(1)
12/7/05	18	17.5	5,30,45,60	B	AC 876 A&B	1-47 (2)
ODOT Tandem Axle Truck						
12/5/05	40	40.15	5,30,45,55	A	AC 664, PCC664	1-21 (2)
12/7/05	28	28.5	5,30,45,55	B	AC 876 A&B	2-48 (1)

(1) Run Numbers (2) Odd Run Numbers

Table 2.5 - Controlled Vehicle Test Series II, July 2006

Test Date	Nominal Load (K)	Rear Axle (K)	Nominal Speed (mph)	Load I.D.	Sections Monitored	Data Set No.
ODOT Single Axle Truck						
7/18/06	20	20.35	5,25,45,55	A	AC 876 A&B	30-36 (1), 39-87 (2)
7/19/06	20	20.35	5,25,45,55	A	AC 664	19-75 (2)
ODOT Tandem Axle Truck						
7/18/06	35	34.55	5,25,45,55	A	AC 876 A&B	29-37 (2), 40-86 (1)
7/19/06	35	34.55	5,25,45,55	A	AC 664	18-74 (1)
Falling Weight Deflectometer						
7/18/06	9,12, 16	N/A	N/A	-	AC 876 A&B	1-26
7/19/06	9,12,16	N/A	N/A	-	AC 664	1-17

(1) Even Run Numbers (2) Odd Run Numbers

Table 2.6 - Controlled Vehicle Test Series III, August 2006

Test Date	Nominal Load (K)	Rear Axle (K)	Nominal Speed (mph)	Load I.D.	Sections Monitored	Data Set No.
ODOT Single Axle Truck						
8/15/06	20	21.3	5,25,40,55	B	PCC 876	9-12,21-24,33-41
8/16/06	20	21.3	5,25,40,55	B	PCC 664	7-19, 34-37, 42-50 (1)
8/17/06	20	21.3	5,25,40,55	B	AC 876 A&B	1-10, 21-25 (2), 27-36, 46-50 (1)
ODOT Tandem Axle Truck						
8/15/06	35	33.9	5,25,40,55	B	PCC 876	13-20’ 25-32’ 42-45
8/16/06	35	33.9	5,25,40,55	B	PCC 664	20-33, 38-41, 43-49 (2)
8/17/06	35	33.9	5,25,40,55	B	AC 876 A&B	11-22, 24-26 (1), 37-45, 49,51,52
Falling Weight Deflectometer						
8/15/06	9,12, 16	N/A	N/A	-	PCC 876	1-8
8/16/06	9,12,16	N/A	N/A	-	PCC 664	1-6

(1) Even Run Numbers (2) Odd Run Numbers

Table 2.7 - Controlled Vehicle Test Series IV, May 2008

Test Date	Nominal Load (K)	Rear Axle (K)	Nominal Speed (mph)	Load I.D.	Sections Monitored	Data Set No.
ODOT Single Axle Truck						
5/20/08	28	27.60	5,25,55	A	AC 876 A&B PCC 876	4-6, 8-18 (1), 22-24, 28-39 (1)
5/21/08	28	27.60	5,25,55	A	AC 664 PCC 664	1-6, 13-17 (2), 19-24, 32-38 (1)
ODOT Tandem Axle Truck						
5/20/08	48	47.35	5,25,50	A	AC 876 A&B PCC 876	1-3, 7-17 (2), 19-21, 25-37 (2)
5/21/08	48	47.35	5,25,50	A	AC 664 PCC 664	7-12, 14-18 (1), 25-31, 33-37 (2)

(1) Even Run Numbers (2) Odd Run Numbers

2.4 Water Tables

One piezometer was installed at each station where sensors were placed to monitor dynamic response. One location was on the eastbound side at Station 663+70, but no measurements have been recorded there to date. The second location was on the westbound side at Station 877+00 where measurements on 11/24/08 and 12/16/08 showed the water table to be 10.0 and 10.4 feet (3.0 and 3.2 m), respectively, below the top of the well.

2.5 FWD Measurements - Test Sections

As mentioned earlier, FWD measurements were obtained in the six test sections as each material layer was completed and accepted by ODOT during construction. Measurements on the subgrade and 304 aggregate base were performed with a 17.7 inch (450 mm) diameter load plate and the standard 11.8 inch (300 mm) diameter load plate was used on the remaining layers. It was necessary, therefore, to normalize the FWD data for load by converting deflections measured at approximately 9 kips (40 kN) to mils/kip (mm/MN) to account for variations in applied load, and renormalize for plate area by converting mils/kip (mm/MN) to mils/ksf (mm/MPa) to account for the different size load plates (Ref. 1).

FWD measurements were initially obtained on individual material layers of the six original WAY 30 test sections during construction in 2005. Additional measurements were taken in 2006, 2007 and 2008. Sections A and B were removed from the experiment and not measured in 2008. Figures 2.5-2.10 compare profiles of various deflection parameters for the test sections in 2005, 2007 and 2008. These parameters include: maximum deflection and spreadability along the centerline of all sections (midslab on PCC sections), joint approach deflection and load transfer in the RWP of PCC sections, and maximum deflection and spreadability in the centerline and RWP of AC sections. Table 2.8 shows average values for the sections, and Table 2.9 summarizes the times, air temperatures and pavement surface temperatures recorded for the runs.

In Figures 2.5-2.10, the same shaped points were used for AC and PCC sections located across from each other and, to help differentiate AC sections from PCC sections, AC points were connected with thin lines and PCC points were connected with heavy lines. Because of the higher stiffness of PCC pavements, they consistently exhibited lower deflections and higher spreadabilities than AC pavements. Spreadability is an indicator of E_1/E_2 where E_1 is the pavement modulus and E_2 is the composite modulus of the supporting layers. Midslab deflections on PCC pavements increased slightly over time while AC deflections increased by 50%, probably due to the 15-20° F rise in pavement temperature between 2005 and 2007/2008. PCC joint deflections increased after the pavement was opened to traffic and load transfer, while becoming more variable, remained relatively constant on average. This consistency in the average was likely due to a lack of damage to the joints and pavement temperatures remaining below the threshold of about 70° F (21° C), when aggregate interlock begins to affect load transfer.

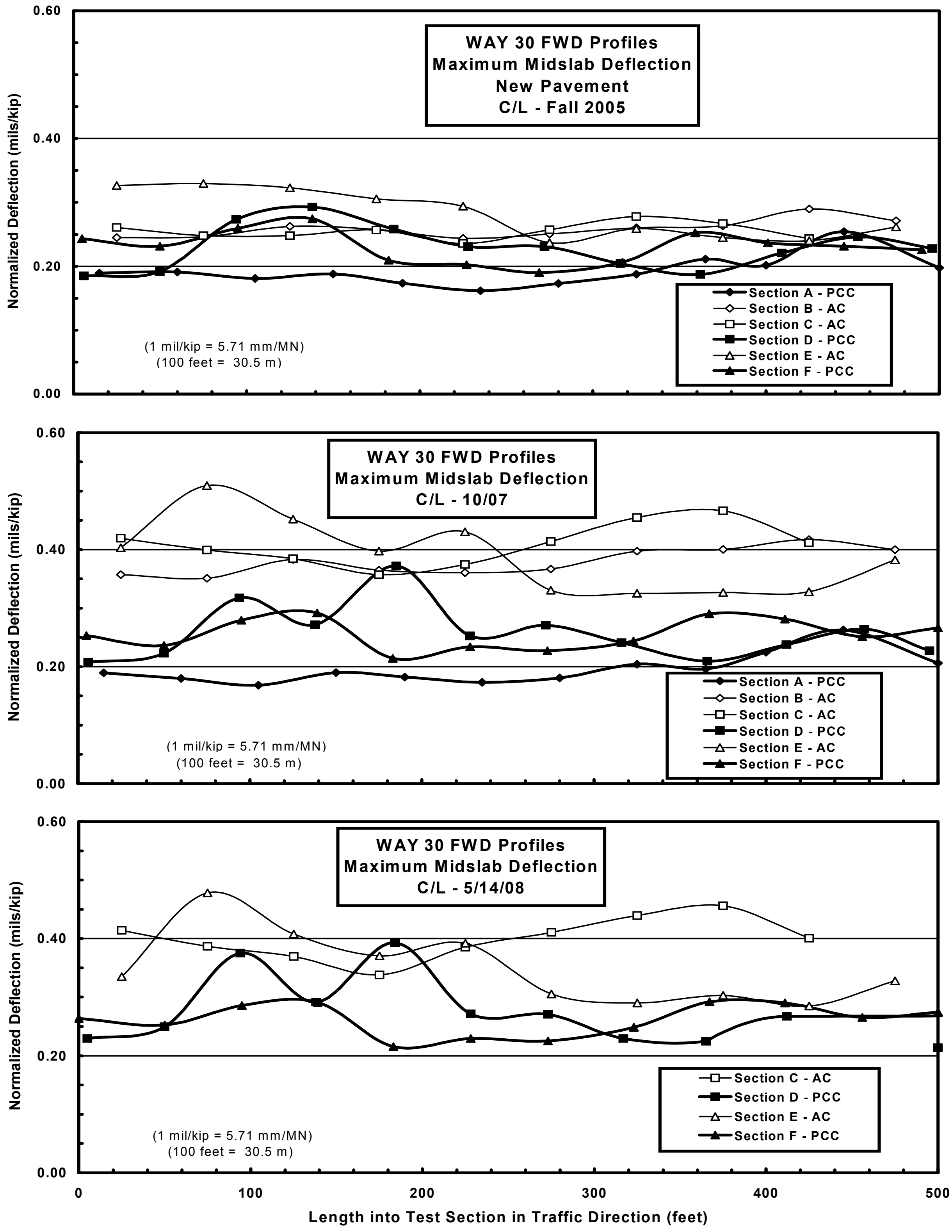


Figure 2.5 – Maximum FWD Deflections along Centerlines

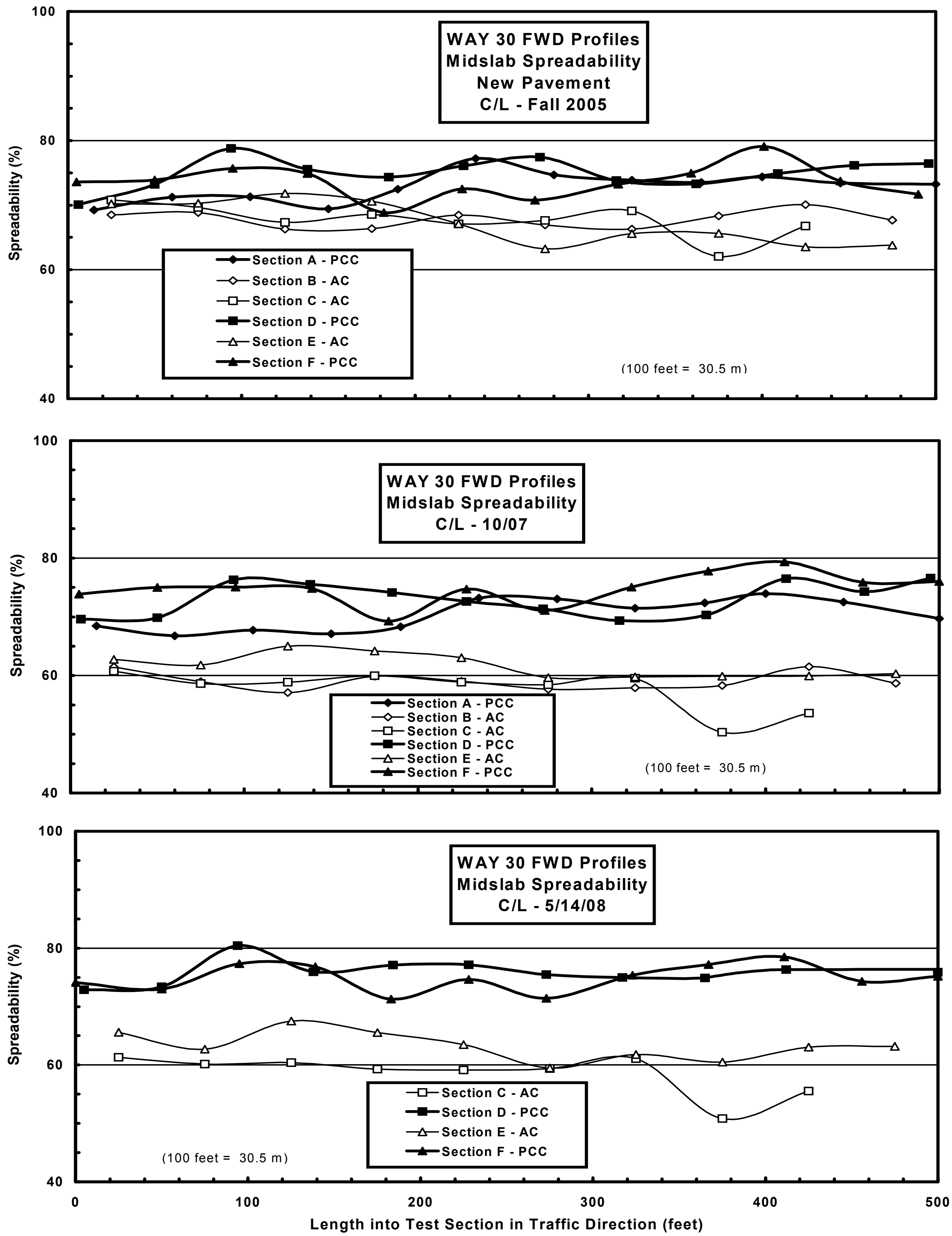


Figure 2.6 – FWD Spreadability along Centerlines

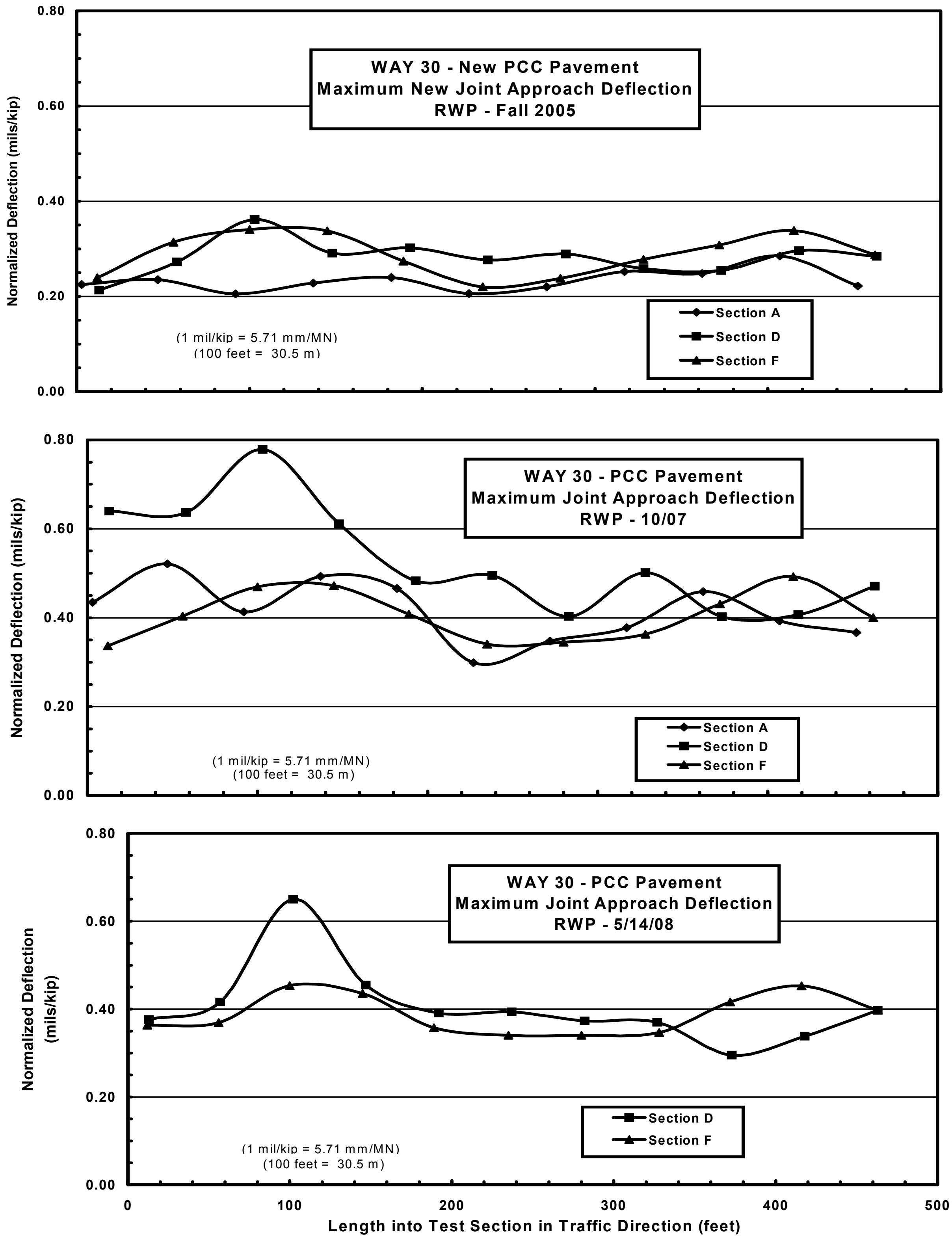


Figure 2.7 – Joint Deflections in RWP of PCC Sections

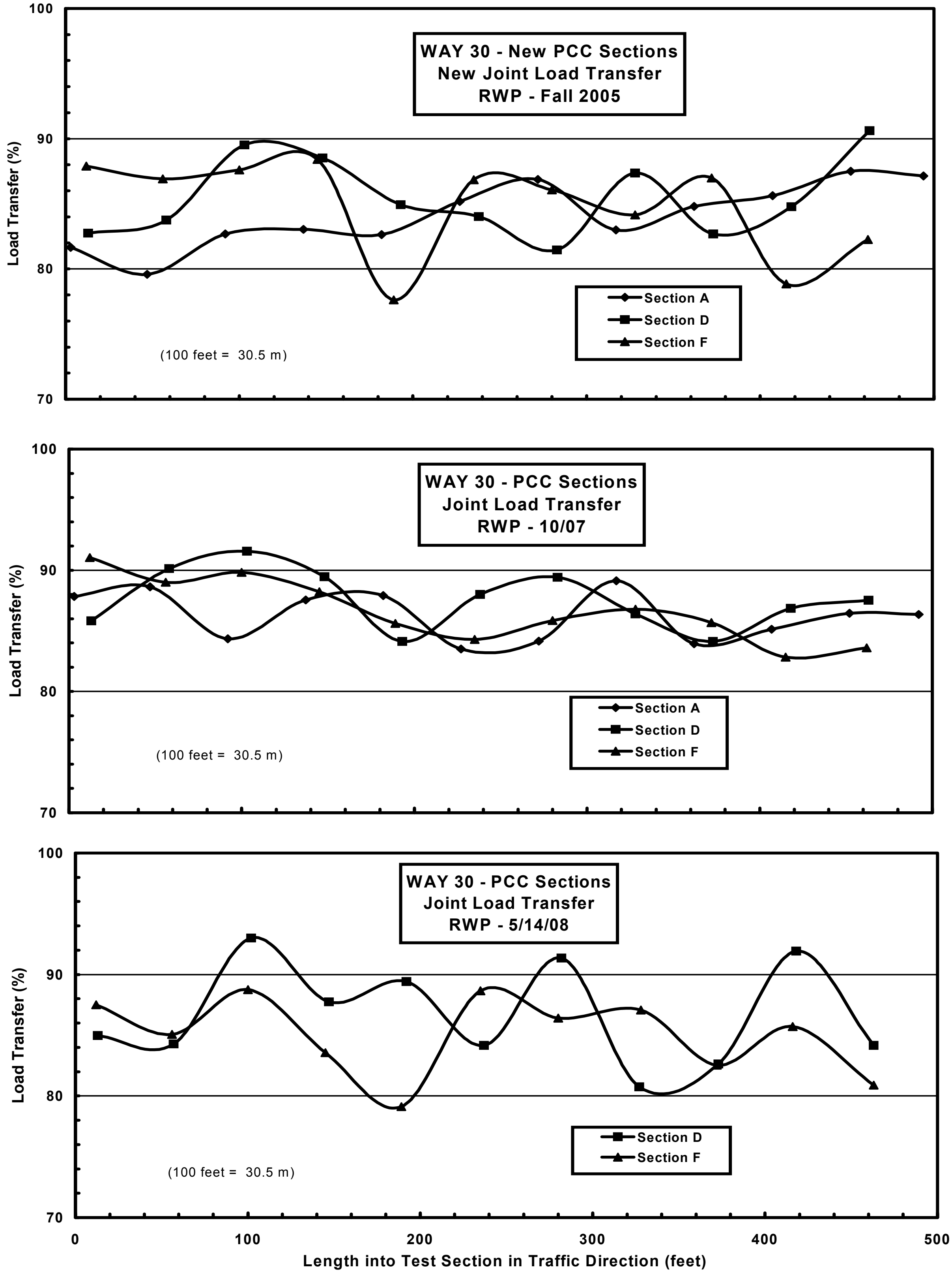


Figure 2.8 – Load Transfer in RWP of PCC Sections

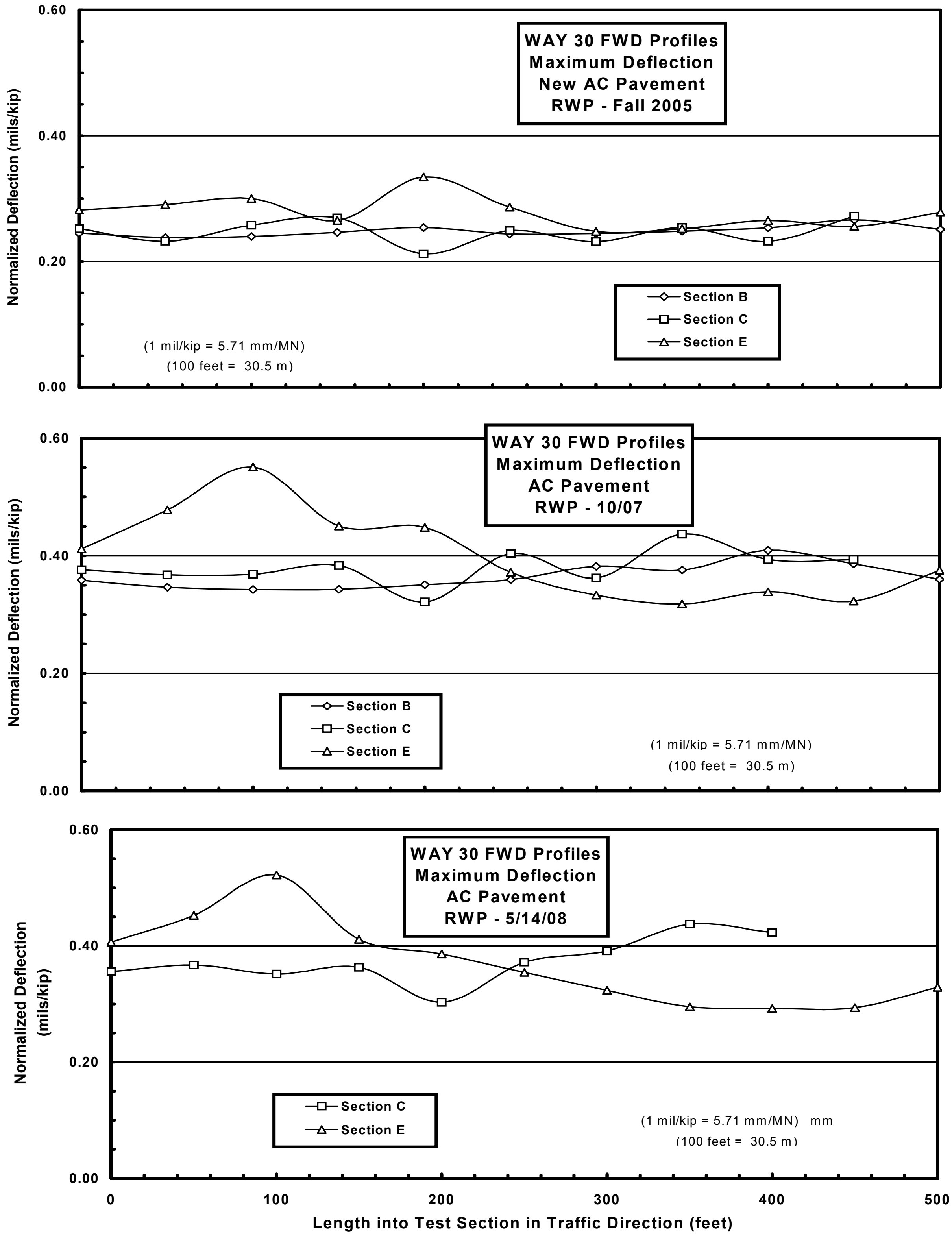


Figure 2.9 – Maximum Deflection in RWP of AC Sections

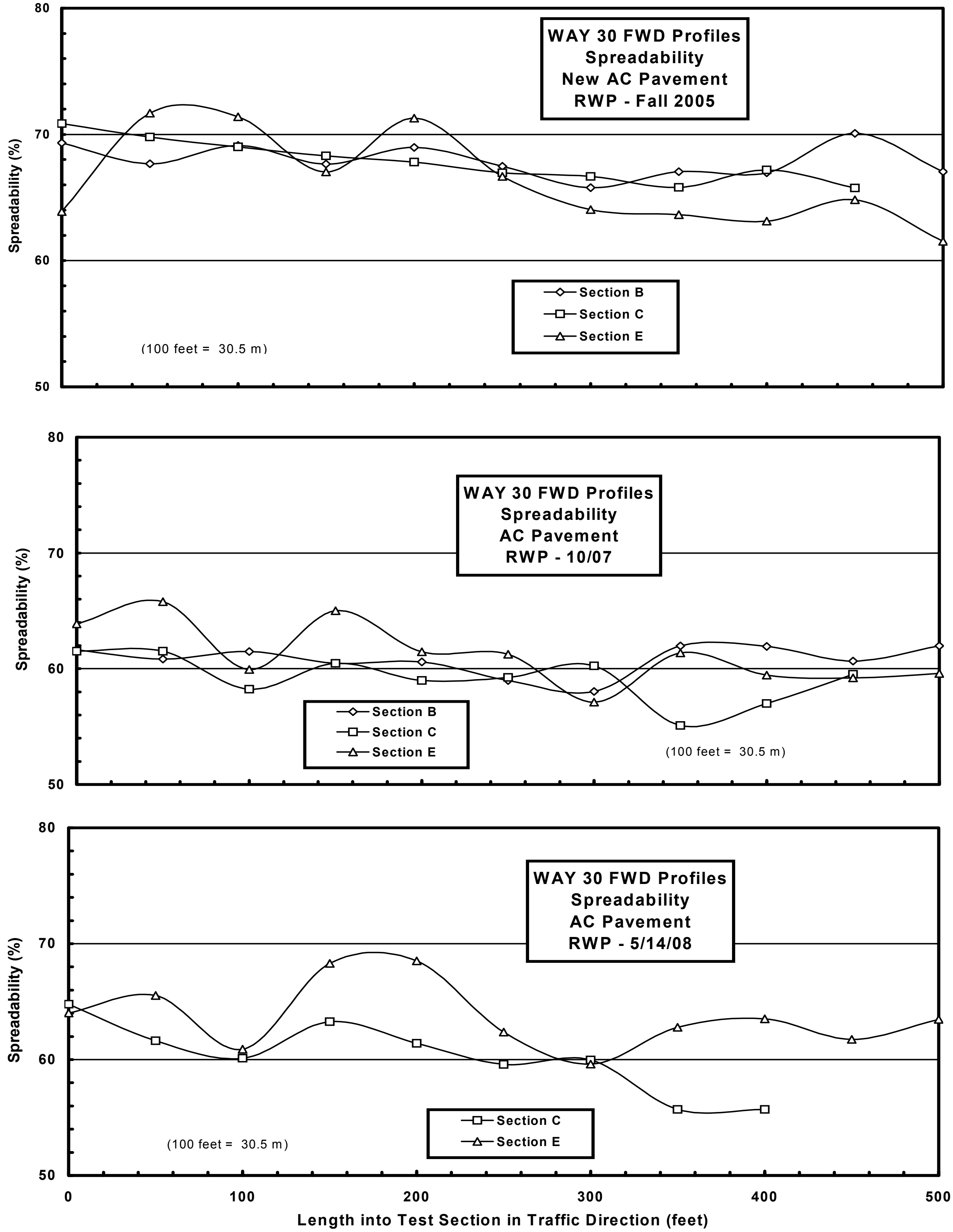


Figure 2.10 – Spreadability in RWP of AC Sections

Table 2.8
FWD Section Averages – English units

WAY 30 - FWD Summary

Prior to opening to traffic; 10/21/05 - 11/29/05

AC Sections

Section ID	Pavement Surface Temp. (°F)	C/L Df1 (mil/kip)	C/L Df7 (mil/kip)	C/L SPR (%)	C/L Df1/Df7	RWP Df1 (mil/kip)	RWP Df7 (mil/kip)	RWP SPR (%)	RWP Df1/Df7
B	47	0.26	0.09	67.8	2.97	0.25	0.08	67.9	3.05
C	47-50	0.25	0.09	67.7	2.89	0.25	0.08	67.8	2.95
E	50	0.28	0.09	67.2	3.15	0.28	0.09	66.3	3.31

PCC Sections

Section ID	Pavement Surface Temp. (°F)	Midslab Df1 (mil/kip)	Midslab Df7 (mil/kip)	Midslab SPR (%)	Midslab Df1/Df7	Joints $Df1_A$ (mil/kip)	Joints LT (%)	Joints $Df1_L$ (mil/kip)	Joints LT (%)	JSR ($Df1_L/Df1_A$)
A	46	0.19	0.07	72.8	2.65	0.23	84.1	0.23	82.5	0.99
D	43-44	0.23	0.09	75.0	2.66	0.28	85.5	0.28	83.4	0.99
F	46	0.23	0.09	73.6	2.56	0.29	84.9	0.28	82.6	0.98

10/10/2007

AC Sections

Section ID	Pavement Surface Temp. (°F)	C/L Df1 (mil/kip)	C/L Df7 (mil/kip)	C/L SPR (%)	C/L Df1/Df7	RWP Df1 (mil/kip)	RWP Df7 (mil/kip)	RWP SPR (%)	RWP Df1/Df7
B	66	0.38	0.09	59.0	4.07	0.37	0.09	60.8	3.90
C	66	0.41	0.10	57.7	4.30	0.38	0.09	59.2	4.25
E	67	0.39	0.10	61.6	3.91	0.40	0.10	61.3	4.15

PCC Sections

Section ID	Pavement Surface Temp. (°F)	Midslab Df1 (mil/kip)	Midslab Df7 (mil/kip)	Midslab SPR (%)	Midslab Df1/Df7	Joints $Df1_A$ (mil/kip)	Joints LT (%)	Joints $Df1_L$ (mil/kip)	Joints LT (%)	JSR ($Df1_L/Df1_A$)
A	60-62	0.20	0.07	70.4	2.87	0.42	86.2	0.41	86.4	0.98
D	59-60	0.26	0.10	73.0	2.63	0.53	87.6	0.52	87.3	0.98
F	64-67	0.26	0.10	74.8	2.54	0.41	86.6	0.42	82.8	1.03

5/14/2008

AC Sections

Section ID	Pavement Surface Temp. (°F)	C/L Df1 (mil/kip)	C/L Df7 (mil/kip)	C/L SPR (%)	C/L Df1/Df7	RWP Df1 (mil/kip)	RWP Df7 (mil/kip)	RWP SPR (%)	RWP Df1/Df7
B	Section Deleted								
C	61	0.40	0.10	58.6	3.96	0.37	0.10	60.2	3.82
E	58	0.35	0.10	63.3	3.50	0.37	0.11	63.7	3.58

PCC Sections

Section ID	Pavement Surface Temp. (°F)	Midslab Df1 (mil/kip)	Midslab Df7 (mil/kip)	Midslab SPR (%)	Midslab Df1/Df7	Joints $Df1_A$ (mil/kip)	Joints LT (%)	Joints $Df1_L$ (mil/kip)	Joints LT (%)	JSR ($Df1_L/Df1_A$)
A	Section Deleted									
D	58-61	0.27	0.12	76.0	2.41	0.41	86.8	0.41	84.4	1.00
F	56-57	0.26	0.11	74.9	2.49	0.39	85.0	0.38	85.2	0.98

Table 2.8 continued
FWD Section Averages – metric units

WAY 30 - FWD Summary

Prior to opening to traffic; 10/21/05 - 11/29/05

AC Sections

Section ID	Pavement Surface Temp. (°C)	C/L				RWP			
		Df1 (mm/MN)	Df7 (mm/MN)	SPR (%)	Df1/Df7	Df1 (mm/MN)	Df7 (mm/MN)	SPR (%)	Df1/Df7
B	8.3	1.48	0.51	67.8	2.97	1.43	0.46	67.9	3.05
C	8.3-10.0	1.43	0.51	67.7	2.89	1.43	0.46	67.8	2.95
E	10.0	1.60	0.51	67.2	3.15	1.60	0.51	66.3	3.31

PCC Sections

Section ID	Pavement Surface Temp. (°C)	Midslab				Joints				
		Df1 (mm/MN)	Df7 (mm/MN)	SPR (%)	Df1/Df7	$Df1_A$ (mm/MN)	LT (%)	$Df1_L$ (mm/MN)	LT (%)	JSR ($Df1_L/Df1_A$)
A	7.8	1.08	0.40	72.8	2.65	1.31	84.1	1.31	82.5	0.99
D	6.1-6.7	1.31	0.51	75.0	2.66	1.60	85.5	1.60	83.4	0.99
F	7.8	1.31	0.51	73.6	2.56	1.66	84.9	1.60	82.6	0.98

10/10/2007

AC Sections

Section ID	Pavement Surface Temp. (°C)	C/L				RWP			
		Df1 (mm/MN)	Df7 (mm/MN)	SPR (%)	Df1/Df7	Df1 (mm/MN)	Df7 (mm/MN)	SPR (%)	Df1/Df7
B	18.9	2.17	0.51	59.0	4.07	2.11	0.51	60.8	3.90
C	18.9	2.34	0.57	57.7	4.30	2.17	0.51	59.2	4.25
E	19.4	2.23	0.57	61.6	3.91	2.28	0.57	61.3	4.15

PCC Sections

Section ID	Pavement Surface Temp. (°C)	Midslab				Joints				
		Df1 (mm/MN)	Df7 (mm/MN)	SPR (%)	Df1/Df7	$Df1_A$ (mm/MN)	LT (%)	$Df1_L$ (mm/MN)	LT (%)	JSR ($Df1_L/Df1_A$)
A	15.6-16.7	1.14	0.40	70.4	2.87	2.40	86.2	2.34	86.4	0.98
D	15.0-15.6	1.48	0.57	73.0	2.63	3.03	87.6	2.97	87.3	0.98
F	17.8-19.4	1.48	0.57	74.8	2.54	2.34	86.6	2.40	82.8	1.03

5/14/2008

AC Sections

Section ID	Pavement Surface Temp. (°C)	C/L				RWP			
		Df1 (mm/MN)	Df7 (mm/MN)	SPR (%)	Df1/Df7	Df1 (mm/MN)	Df7 (mm/MN)	SPR (%)	Df1/Df7
B	Section Deleted								
C	16.1	2.28	0.57	58.6	3.96	2.11	0.57	60.2	3.82
E	14.4	2.00	0.57	63.3	3.50	2.11	0.63	63.7	3.58

PCC Sections

Section ID	Pavement Surface Temp. (°C)	Midslab				Joints				
		Df1 (mm/MN)	Df7 (mm/MN)	SPR (%)	Df1/Df7	$Df1_A$ (mm/MN)	LT (%)	$Df1_L$ (mm/MN)	LT (%)	JSR ($Df1_L/Df1_A$)
A	Section Deleted									
D	14.4-16.1	1.54	0.69	76.0	2.41	2.34	86.8	2.34	84.4	1.00
F	13.3-13.9	1.48	0.63	74.9	2.49	2.23	85.0	2.17	85.2	0.98

Table 2.9
Temperatures/Times for FWD Measurements on Test Sections

Section	2005			2007			2008		
	Date	Military Time	Pavement Surface Temp. (°F(°C))	Date	Military Time	Pavement Surface Temp. (°F(°C))	Date	Military Time	Pavement Surface Temp. (°F(°C))
A	10/21	8:36-9:31	46 (7.8)	10/10	8:47-9:51	60-62 (15.6-16.7)	5/14	Section deleted	
B	11/29	8:56-9:22	47 (8.3)	10/10	10:36-10:56	66 (18.9)	5/14	Section deleted	
C	11/29	9:26-9:48	47-50 (8.3-10)	10/10	11:00-11:18	66 (18.9)	5/14	11:31-11:49	61 (16.1)
D	10/28	8:55-9:48	43-44 (6.1-6.7)	10/10	8:16-9:36	59-60 (15-15.6)	5/14	10:35-11:11	58-61 (14.4-16.1)
E	11/29	9:57-10:19	50 (10)	10/10	12:23-12:42	67 (19.4)	5/14	9:20-9:58	58 (14.4)
F	10/31	8:10-9:05	46 (7.8)	10/10	13:40-14:17	64-67 (17.8-19.4)	5/14	8:15-9:10	56-57 (13.3-13.9)

2.6 FWD Measurements - Dowel Bars

Twenty joints were set aside in Section D (Station 875+00 – 881+00 EB) to evaluate the performance of various types of dowel bars. FWD measurements were made in 2006, 2007 and 2008 to determine joint deflection and load transfer. Table 2.10 summarizes the types of bars installed and their location, and Figures 2.11 and 2.12 show longitudinal profiles of joint approach deflection and load transfer along the centerline and 6 inches (15 cm) inside the outside paint line. Measurements were not obtained during the paint line run in 2006 due to a battery failure on the FWD. In general, deflection increased and load transfer decreased over time, especially in the one joint with fiberglass composite dowel bars which showed no signs of surface distress as of 2008.

Table 2.10
Dowel Bar Locations

Bar Type	Joint Stations
Epoxy Coated Steel	876+04, 876+19, 876+35, 876+49, 876+64, 876+80, 876+95
MMFX 2 Stainless Steel	877+10, 877+25, 877+40
Zinc Clad Steel	877+55, 877+71, 877+86
Fiberglass Composite	878+03
Epoxy Coated Steel	878+19, 878+34, 878+51, 878+66, 878+83, 878+99

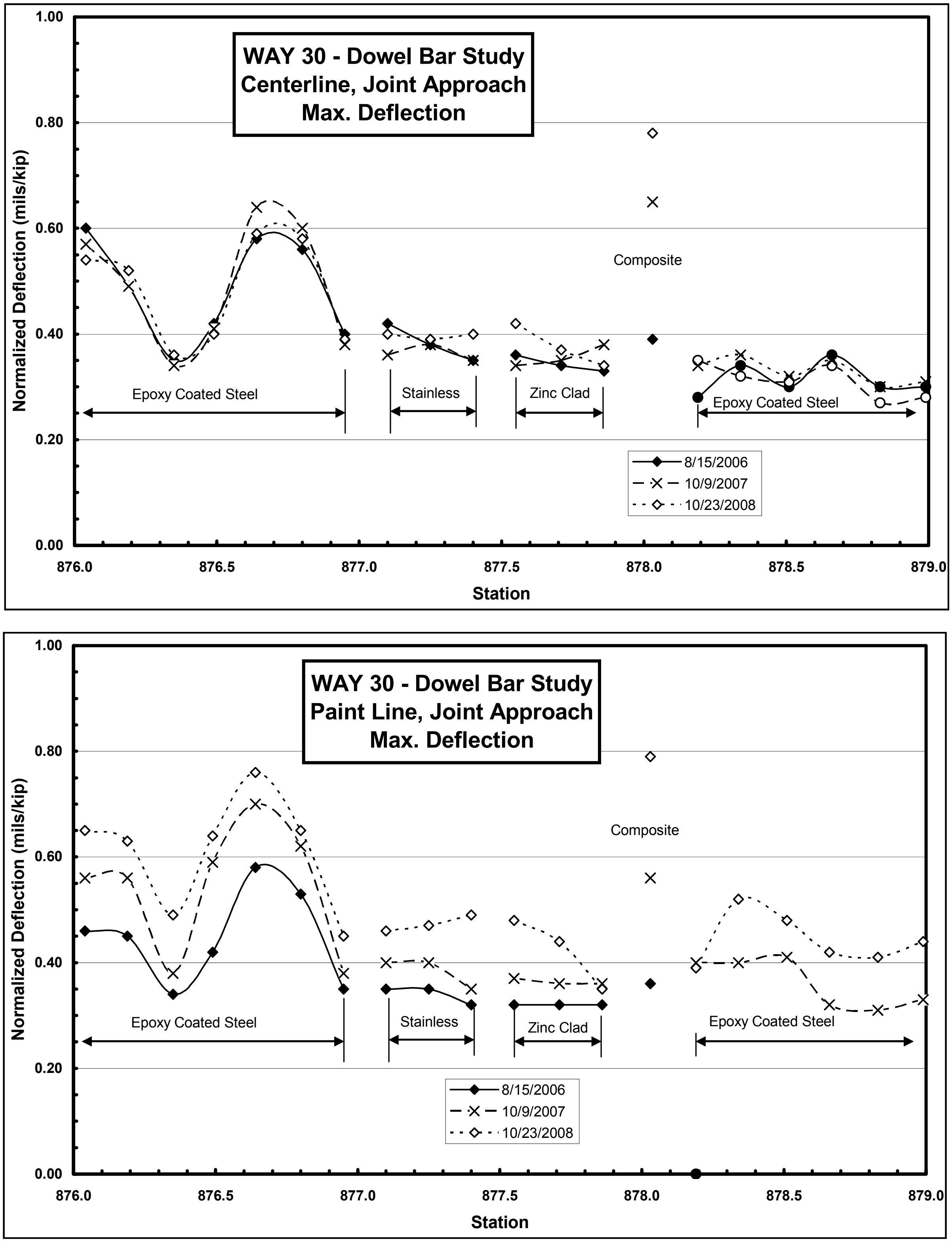
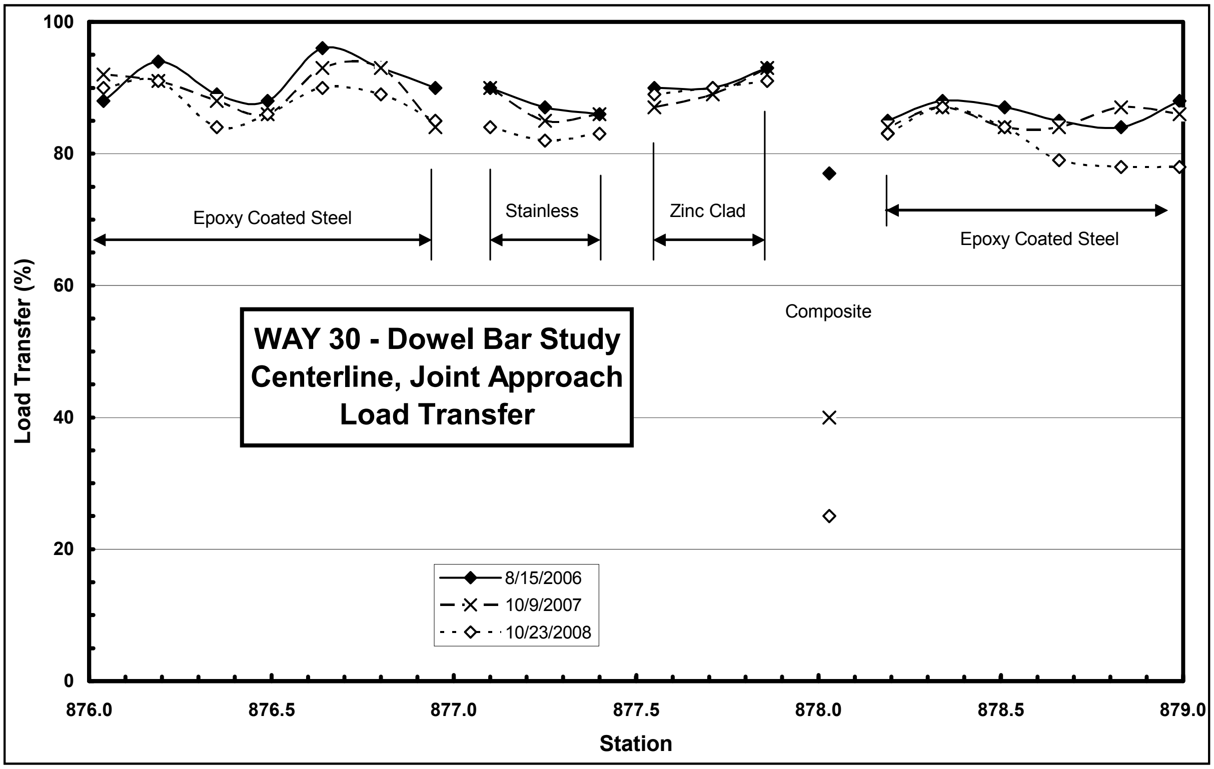


Figure 2.11 – FWD Joint Approach on Dowel Bars



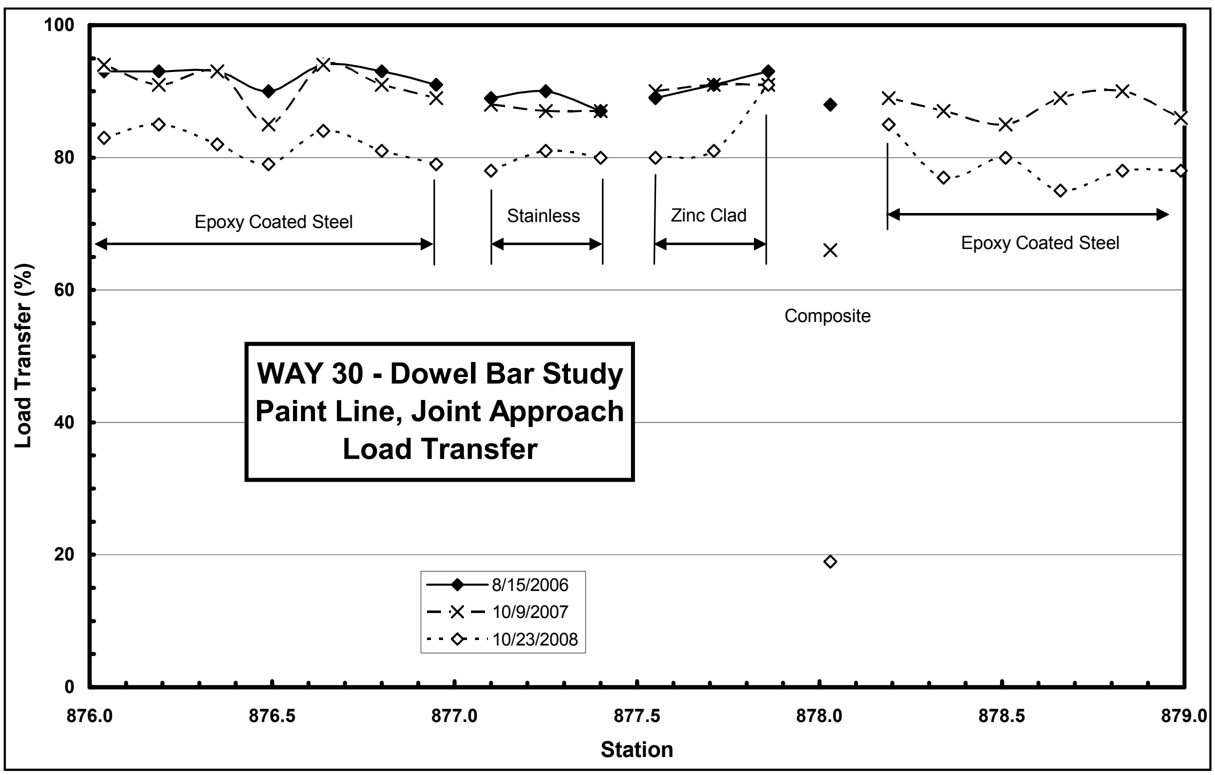


Figure 2.12 – FWD Load Transfer of Dowel Bars

2.7 TDR Measurements of Subgrade Moisture

Time Domain Reflectometry (TDR) cables were installed at Sections 664 and 876 to monitor the moisture in the soil under both the asphalt and concrete sides. Results are shown in Figures 2.13 and 2.14 for the AC pavements, and in figures 2.15 and 2.16 for the PCC pavements. The top sensor was in the base. Below that the recorded moisture content lies in the 20%-30% range at all times recorded, with a few occasional outliers.

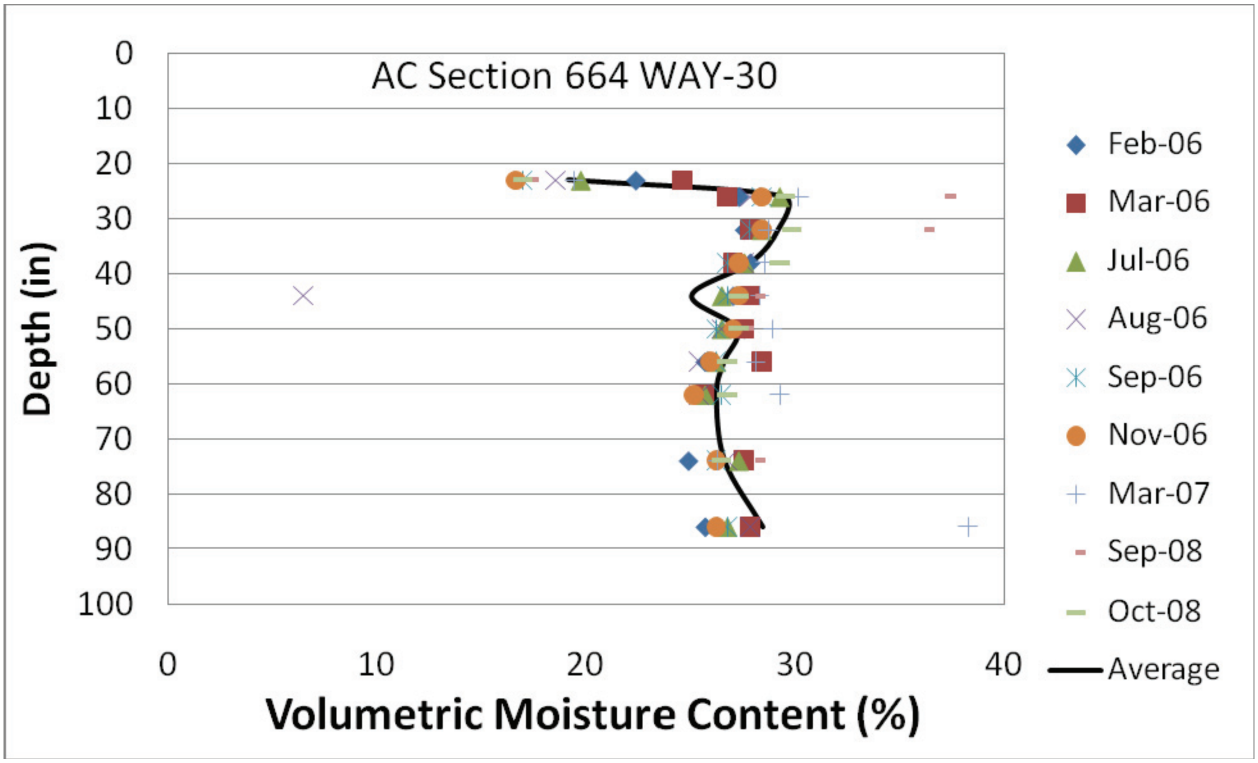


Figure 2.13 – Soil volumetric moisture content measured by TDR as a function of depth under AC pavement at Section 664 (1 in = 0.0254 m).

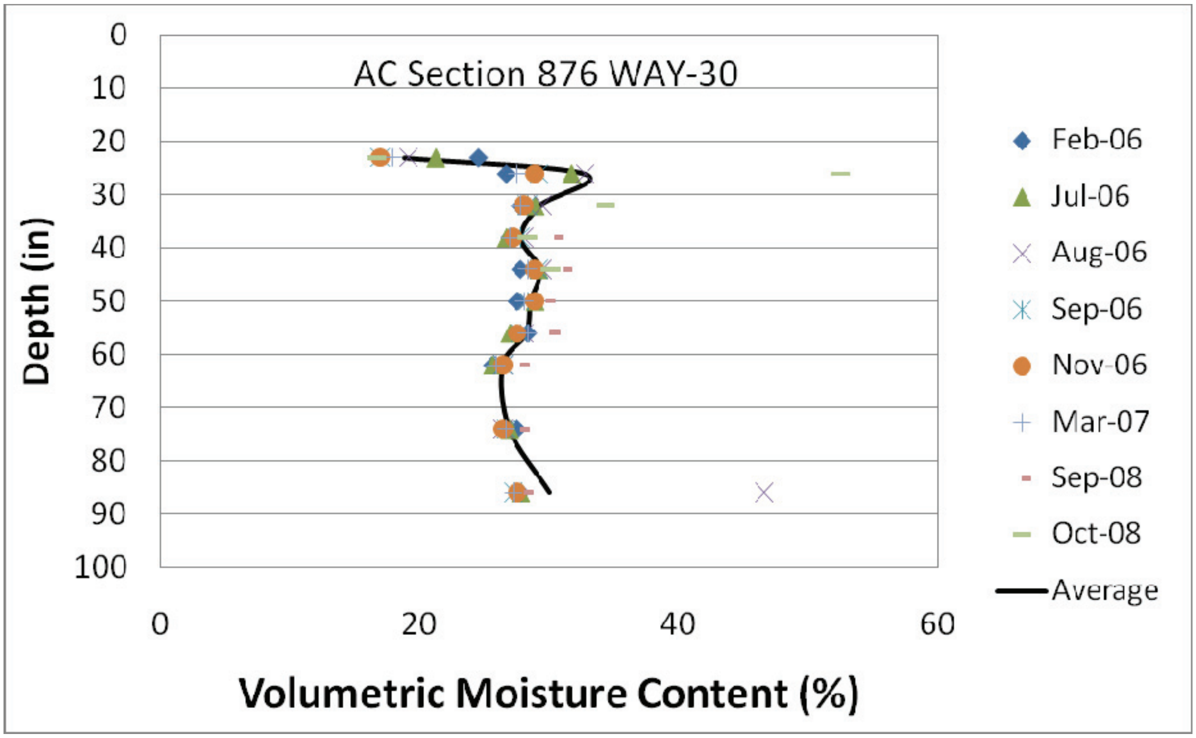


Figure 2.14 – Soil volumetric moisture content measured by TDR as a function of depth under AC pavement at Section 876 (1 in = 0.0254 m).

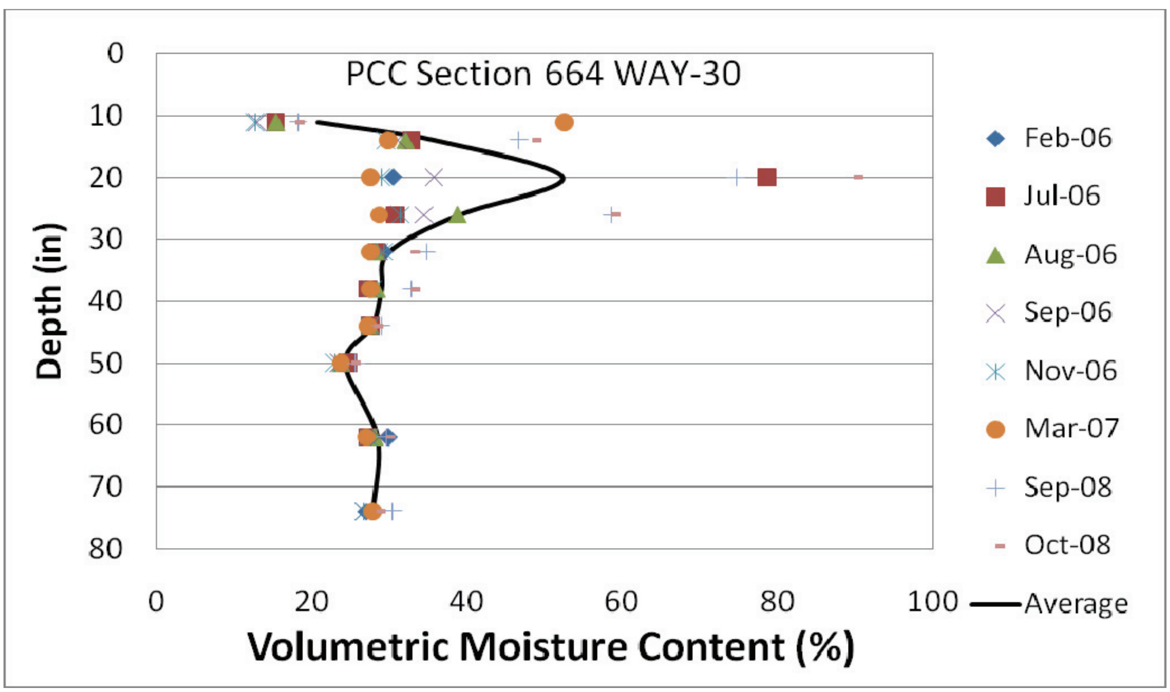


Figure 2.15 – Soil volumetric moisture content measured by TDR as a function of depth under PCC pavement at Section 664 (1 in = 0.0254 m).

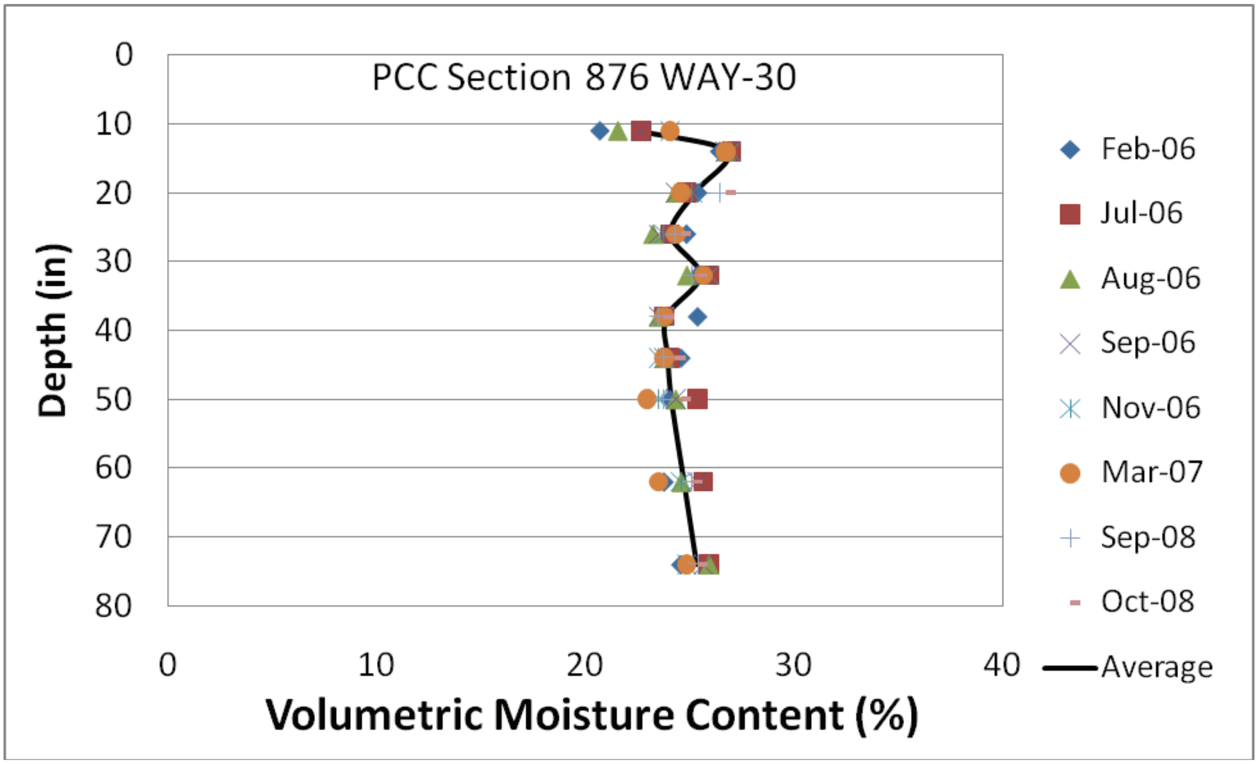


Figure 2.16 – Soil volumetric moisture content measured by TDR as a function of depth under PCC pavement at Section 876 (1 in = 0.0254 m).

2.8 Weather Station Measurements

Weather station data were recorded for the period beginning June 2, 2005 (July 1, 2005 for solar radiation data), and ending March 22, 2007. Statistics from the data collected during that period are given in Table 2.11. The complete data set is included in the database.

2.9 Distress Surveys

Distress surveys were conducted on March 22, 2007 and October 10, 2008. Results are given in Appendix C. In March, no defects were found Section 283 (Station 664). In PCC Section 284 (Station 876), four small cracks were found. No distress was observed on the AC sections. The October inspection did not turn up any new distress on the PCC sections, and minor surface distress on the AC sections.

Table 2.11

WAY30 Weather Statistics June 2, 2005 – March 22, 2007, Based on Daily Collected Data

Data Type	unit	Min	Max	Total	Average	Std Dev
Max Wind Speed	m/s	2.11	16.38	-	6.08	2.56
	mph	4.71	36.64	-	13.59	5.72
Min Wind Speed	m/s	0.00	4.65	-	0.31	0.58
	mph	0.00	10.41	-	0.69	1.30
Average Wind Speed	m/s	0.46	7.40	-	2.29	1.27
	mph	1.02	16.55	-	5.12	2.84
Total Rain	cm	0.00	1.13	11.61	0.02	0.07
	in	0.00	2.87	29.493	0.04	0.19
Max Air Temperature	°C	-14.77	34.07	-	15.34	11.40
	°F	5.41	93.33	-	59.61	52.52
Min Air Temperature	°C	-21.08	23.66	-	5.35	9.97
	°F	-5.94	74.59	-	41.63	49.94
Average Air Temperature	°C	-17.56	28.07	-	10.25	10.43
	°F	0.39	82.53	-	50.44	50.78
Max Humidity	%	38.09	99.00	-	89.69	8.06
Min Humidity	%	14.70	94.20	-	49.88	15.94
Max Solar Radiation	watts	45.76	1308.00	-	696.20	297.15
	hp	0.061	1.754	-	0.934	0.398
Min Solar Radiation	watts	0.00	5.98	-	0.14	0.68
	hp	0.000	0.008	-	0.000	0.001
Average Solar Radiation	watts	5.54	407.40	-	135.44	86.91
	hp	0.007	0.546	-	0.182	0.117
Total Solar Energy	kJ	479	29483	7342998	11674	7462
	BTU	454	27962	6964100	11072	7077

Chapter 3
Replacement of SPS-2 Sections on DEL 23

3.1 Background

On August 15, 1996, nineteen pavement sections constructed for the SHRP SPS-2 experiment on US 23 north of the city of Delaware were opened to traffic. With the exception of Sections 205 and 206, which began to show transverse/longitudinal cracking, pumping and faulting in 1998, the sections performed reasonably well. By February 16, 2006, these two distressed sections became quite rough and the entire SPS-2 experiment was closed for repairs.

During an evaluation of the SPS-2 sections after closure, it was noted that sections constructed of high strength concrete had a higher rate of transverse cracking and about 10 skid numbers lower skid resistance than sections containing standard Class "C" concrete. (Ref. 3) Seven of the SPS-2 sections showed various levels of distress and were replaced, including five of the six sections with an 8-inch (20.3 cm) thick pavement and five of the seven sections containing high strength concrete. The two distressed 11-inch (27.9 cm) thick sections (204 and 259) were constructed of high strength concrete on 6 inches (15.2 cm) of DGAB base. The two high strength sections not needing replacement (208 and 212) were 11 inches (27.9 cm) thick. Section 208 had 6 inches (15.2 cm) of LCB, and Section 212 had 4 inches (10.2 cm) of PATB over 4 inches (10.2 cm) of DGAB. Lane width did not seem to be a factor in transverse cracking.

Six of the seven replacement sections were 11 inches (27.9 cm) of Class "C" concrete on a base consisting of 4 inches (10.2 cm) of ODOT 301 ATB and 4 inches (10.2 cm) of ODOT 304 DGAB over 18 inches (45.7 cm) of lime-treated subgrade. Section 267 was the exception with 11 inches (27.9 cm) of Class "C" concrete on 8 inches (20.3 cm) of ODOT 304 DGAB over 18 inches (45.7 cm) of lime-treated subgrade. Slab lengths for the replacement sections ranged from 13 – 15 feet (3.96 – 4.57 m) and slab widths were either 12 or 14 feet (3.66 or 4.27 m). Underdrains were added to the previously undrained sections and instrumentation was installed in five of the seven sections. Table 3.1 shows various attributes of the replacement sections, including instrumentation. Larger coarse aggregate seems to reduce transverse cracking, while shorter slab lengths reduce the frequency of having adjacent truck axle groups on opposite ends of a slab at the same time which likely generates higher tensile stresses near the pavement surface at midslab. The SPS-2 replacement sections were opened to traffic on October 2, 2007.

Table 3.1
Attributes of DEL 23 PCC Replacement Sections

OTHER ATTRIBUTES OF PCC REPLACEMENT SECTIONS				
Original Section	**Replacement Section**	**Slab Width ft. (m)**	**PCC Aggregate Size**	**Slab Length ft. (m)**
259	266	12 (3.66)	467	15 (4.57)
204	267	12 (3.66)	467	15 (4.57)
210	268*	14 (4.27)	467	14 (4.27)
202	269*	14 (4.27)	57	13 (3.96)
206	270*	14 (4.27)	57	15 (4.57)
205	271*	14 (4.27)	57	14 (4.27)
201	272*	14 (4.27)	367	14 (4.27)

* Instrumentation installed

3.2 Material Properties

Three concrete pavement mixes were used in the DEL 23 replacement sections. Differences between these mixes included the proportioning of aggregates and the maximum size of coarse aggregate. Table 3.2 shows proportions for the concrete mixes used. The Class I, or Special 467LS Mix, with Type 467 medium coarse aggregate and a top size aggregate of 1.5 in (3.8 cm) and was used in Sections 266, 267 and 268; the Class II, or Special 357LS Mix, with Type 357 large coarse aggregate with and a top size aggregate of 2 in (5.1 cm) and was used in Section 272; and the Class III, or Special 57LS Mix, with Type 57 small coarse aggregate and a top size aggregate of 1 in (2.5 cm) and was used in Sections 269, 270, and 271. AASHTO Specification M 43 provides the complete gradation for #357, #467 and #57 aggregates.

Experience has shown that transverse slab cracking tends to increase with decreasing aggregate size in PCC pavement. This cracking is believed to be caused by higher rates of shrinkage resulting from the increased volume of mortar in mixes containing smaller aggregate. Sehn (Ref. 4) reports that shrinkage due to drying is largely considered to be a function of the volume and water/cement ratio of the cement paste, with coarse aggregate size being a secondary factor. The use of larger coarse aggregate generally reduces the volume of mortar in the mix, thereby lowering the amount of water and the water/cement ratio. Mixes with #57 aggregate typically have slightly higher compressive strengths than mixes containing larger aggregate.

Table 3.2
Proposed Formulae for Replacement PCC Sections

INGREDIENTS	MIX CODE – Quantities per cu. yd. (0.76 cu. m.)		
	XDOTCC3L4W	XDOTCC3L3W	XDOTCC3L5W
	Class I 4,000 PSI (27.6 MPa) □ Pumpable Special 467LS	Class II 4,000 PSI (27.6 MPa) □ Pumpable Special 357LS	Class III 4,000 PSI (27.6 MPa) □ Pumpable Special 57LS
Cement ASTM C150	385 lbs. (173 kg)	385 lbs. (173 kg)	385 lbs. (173 kg)
GGBFS Slag ASTM C989	165 lbs. (74 kg)	165 lbs. (74 kg)	165 lbs. (74 kg)
Fly Ash ASTM C618	-	-	-
Natural Sand	1182 lbs.(532 kg)	1182 lbs. (532 kg)	1232 lbs. (554 kg)
#357 Aggregate*		750 lbs. (338 kg)	
#467 Aggregate*	469 lbs (211 kg)		
#57 Aggregate*	1406 lbs. (633 kg)	1125 lbs. (506 kg)	1825 lbs. (821 kg)
Entrained Air	4 - 8 %	4 - 8 %	4 - 8 %
Water Reducer	22 oz. (619 g)	22 oz. (619 g)	22 oz. (619 g)
Admix 2	-	-	-
Synthetic Fibers	-	-	-
Total Water	246 lbs. (111 kg)	246 lbs. (111 kg)	246 lbs. (111 kg)
Maximum Slump	1.50 in (3.8 cm).	1.50 in (3.8 cm).	1.50 in (3.8 cm).
Water /Cement Ratio	0.45	0.45	0.45
Test sections	390266, 390267, 390268	390272	390269, 390270, 390271

* Aggregate weights are for saturated surface dry conditions and will be adjusted for free moisture.

3.3 Falling Weight Deflectometer

FWD measurements were conducted in the driving lane of the PCC replacement sections on September 18 and 20, 2007, about two weeks before they were opened to traffic, and later in June and October of 2008. Midslab readings were taken along the centerline and joint readings were taken in the right wheelpath. Tables 3.3, 3.4, and 3.5 summarize data obtained from the three sets of measurements. Sections 268 – 272 were constructed identically except for PCC aggregate size and slab length, both of which should have a minimal effect on FWD measurements. Sections 266 and 267 both had narrower slabs, Section 266 had a base of 4 inches (10.2 cm) of ODOT 301 ATB over 4 inches (10.2 cm) of ODOT 304 DGAB , while Section 267 had an 8 inch (20.3 cm) 304 base. Slab width and base type both affect FWD measurements.

By October 2008, Section 267 had the highest midslab deflections and extremely high joint deflections, even though load transfer was excellent. These results suggest the dowel bars were tight, but the DGAB was allowing higher deflections. Section 266 had higher joint deflections than the five wider sections, which would be expected. It is not clear why load transfer was lower in the leave position than in the approach position on this one section.

Table 3.3
Average FWD Measurements before Opening to Traffic - September 2007 – Deflections normalized to load of 9000 lb (40 kN)

DEL 23 - FWD Testing on PCC Replacement Sections Prior to opening to traffic - 9/18, 20/07											
Section ID	C/L Midslab					RWP Joints					
							Joint Approach		Joint Leave		
	Pvt. Surf. Temp. (°F (°C))	Df1 (mils/kip)	Df7 (mils/kip)	SPR (%)	DF1/Df7	Pvt. Temp. (°F (°C))	$Df1_A$ (mils/kip)	LT (%)	$Df1_L$ (mils/kip)	LT (%)	JSR (Df_L/Df_A)
266	69 (20.6)	0.24	0.11	79.5	2.16	64 (17.8)	0.33	89.9	0.33	88.1	0.99
267	69 (20.6)	0.26	0.12	78.9	2.27	64 (17.8)	0.45	94.9	0.47	91.2	1.04
268	73 (22.8)	0.23	0.10	77.4	2.32	73 (22.8)	0.27	90.3	0.26	86.4	0.98
269	80 (26.7)	0.25	0.12	79.4	2.14	77 (25.0)	0.28	91.9	0.28	88.7	0.99
270	75 (23.9)	0.24	0.12	81.2	2.04	71 (21.7)	0.32	90.4	0.31	88.4	0.98
271	75 (23.9)	0.30	0.15	80.7	2.06	73 (22.8)	0.36	92.4	0.35	90.9	0.98
272	78 (25.6)	0.29	0.12	77.0	2.39	73 (22.8)	0.33	90.7	0.33	87.9	0.99

Note: 1 mil/ kip = 40.35 microns/100 kPa on 300 mm diameter load plate

Table 3.4
Average FWD Measurements - June 2008– Deflections normalized to load of 9000 lb (40 kN)

DEL 23 - FWD Testing on PCC Replacement Sections - 6/2, 11/08											
Section ID	C/L Midslab					RWP Joints					
							Joint Approach		Joint Leave		
	Pvt. Surf. Temp. (°F (°C))	Df1 (mils/kip)	Df7 (mils/kip)	SPR (%)	DF1/Df7	Pvt. Temp. (°F (°C))	$Df1_A$ (mils/kip)	LT (%)	$Df1_L$ (mils/kip)	LT (%)	JSR (Df_L/Df_A)
266	93 (33.9)	0.24	0.12	78.4	2.16	73 (22.8)	0.28	86.2	0.28	85.7	0.99
267	96 (35.6)	0.29	0.13	79.2	2.21	85 (29.4)	0.38	90.8	0.38	91.5	0.99
268	104 (40.0)	0.23	0.10	77.4	2.24	103 (39.4)	0.25	87.4	0.25	86.7	0.98
269	74 (23.3)	0.23	0.11	78.6	2.08	75 (23.9)	0.25	88.7	0.26	85.6	1.02
270	75 (23.9)	0.24	0.12	79.1	2.04	85 (29.4)	0.26	88.4	0.26	87.4	1.00
271	90 (32.2)	0.30	0.15	78.8	2.06	85 (29.4)	0.29	88.2	0.29	85.6	1.00
272	97 (36.1)	0.29	0.12	74.8	2.39	90 (32.2)	0.29	89.2	0.29	85.9	1.01

Note: 1 mil/ kip = 40.35 microns/100 kPa on 300 mm diameter load plate

Table 3.5
Average FWD Measurements - October 2008 – Deflections normalized to load of 9000 lb (40 kN)

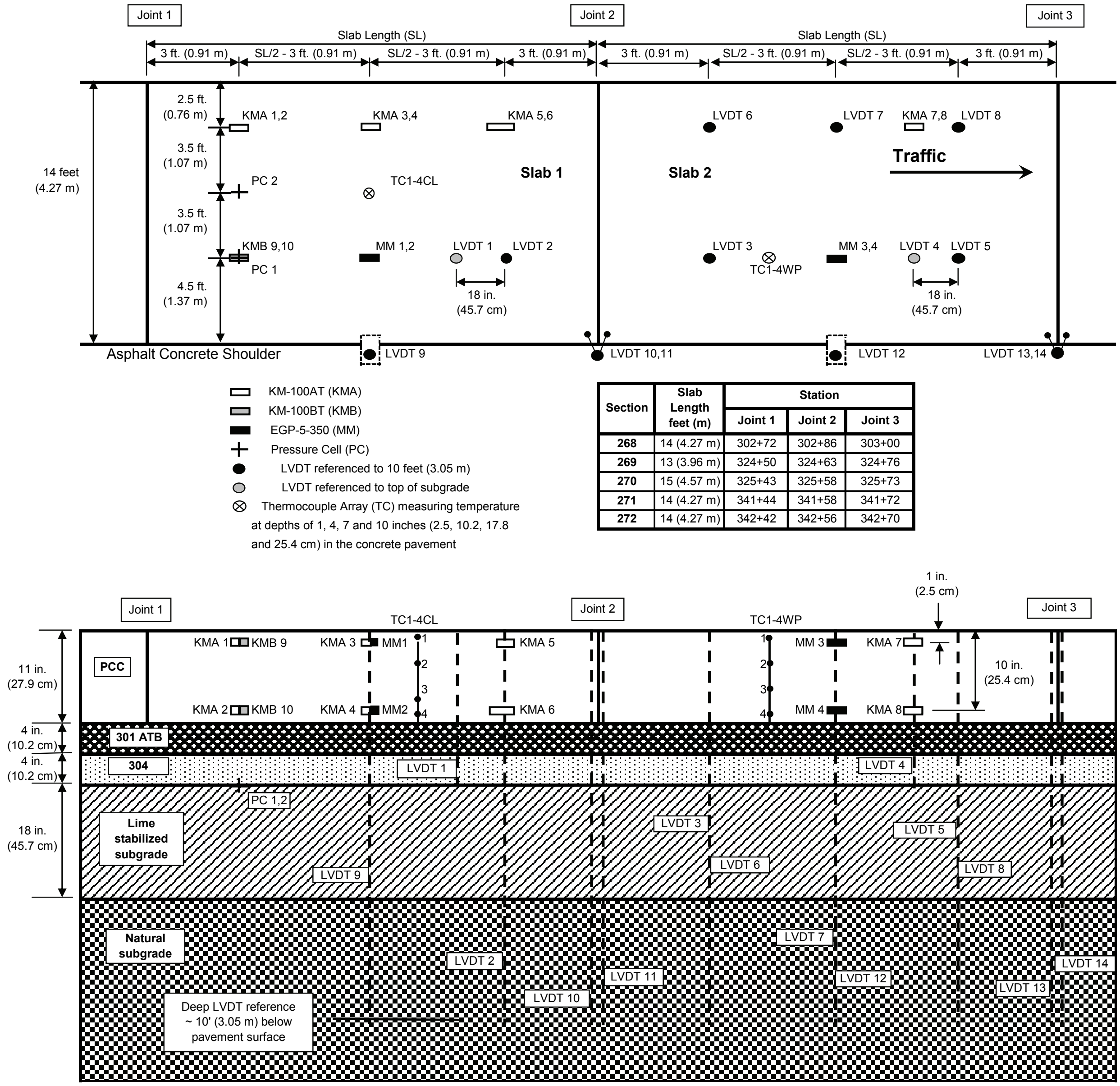
DEL 23 - FWD Testing on PCC Replacement Sections - 10/28/08											
Section ID	C/L Midslab					RWP Joints					
	Pvt. Surf. Temp. (°F (°C))	Df1 (mils/kip)	Df7 (mils/kip)	SPR (%)	DF1/Df7	Pvt. Temp. (°F (°C))	Joint Approach		Joint Leave		
							$Df1_A$ (mils/kip)	LT (%)	$Df1_L$ (mils/kip)	LT (%)	JSR (Df_L/Df_A)
266	40 (4.4)	0.21	0.10	78.7	2.09	39 (3.9)	0.33	84.0	0.34	69.0	1.01
267	41 (5.0)	0.27	0.13	80.4	2.10	39 (3.9)	0.99	93.8	0.99	95.9	1.00
268	41 (5.0)	0.19	0.09	78.2	2.16	39 (3.9)	0.22	85.3	0.22	84.7	1.00
269	45 (7.2)	0.20	0.10	80.0	2.03	39 (3.9)	0.24	86.1	0.24	85.8	0.98
270	45 (7.2)	0.20	0.10	79.7	2.05	39 (3.9)	0.25	85.8	0.24	86.6	0.96
271	45 (7.2)	0.23	0.11	79.6	2.12	40 (4.4)	0.27	84.6	0.25	86.6	0.95
272	45 (7.2)	0.23	0.11	79.4	2.13	40 (4.4)	0.26	87.4	0.26	87.8	0.97

Note: 1 mil/ kip = 40.35 microns/100 kPa on 300 mm diameter load plate

3.4 Response and Environmental Instrumentation

Figure 3.1 shows the arrangement and depth of sensors in the five instrumented replacement slabs. This instrumentation included: 1) strain gauges to measure longitudinal strain in both wheelpaths at depths of 1 in (2.5 cm) and 10 in (25.4 cm) below the surface of the 11-inch (27.9 cm) thick concrete slabs, 2) LVDTs to measure surface deflection in both wheelpaths referenced to the top of the subgrade and approximately 10 feet (3.05 m) below the pavement surface, 3) LVDTs to measure surface deflection along the outside edges and corners of the concrete slabs referenced approximately 10 feet (3.05 m) below the surface, 4) pressure cells to measure pressure at the top of the subgrade in the right wheelpath and centerline, and 5) two arrays of four thermocouples in each section to monitor temperature gradients in the right wheelpath and centerline of the concrete slab.

Eight KM-100AT strain transducers and two KM-100BT strain transducers manufactured by Tokyo Sokki Kenkyujo were installed in each of the five instrumented replacement sections. These sensors have an extremely low modulus of elasticity which allows stain measurements to be monitored as the concrete cures, they are impermeable to moisture, and their thermal coefficient of expansion is similar to that of concrete, allowing them to expand and contract with temperature at about the same rate as concrete. These transducers can also be read out with thermocouple wires. Table 3.6 summarizes the specifications for these gauges.



Section	Slab Length feet (m)	Station		
		Joint 1	Joint 2	Joint 3
268	14 (4.27 m)	302+72	302+86	303+00
269	13 (3.96 m)	324+50	324+63	324+76
270	15 (4.57 m)	325+43	325+58	325+73
271	14 (4.27 m)	341+44	341+58	341+72
272	14 (4.27 m)	342+42	342+56	342+70

Figure 3.1 DEL 23 Slab Instrumentation

Table 3.6
Specifications of KM-100AT and KM-100BT Strain Gauges

Parameter	KM-100AT	KM-100BT
Capacity	$\pm 5000 \times 10^6$ Strain	$\pm 5000 \times 10^6$ Strain
Gauge Length	100mm (3.94 in)	100mm (3.94 in)
Approximate Output Rating	2.5mV/V (5000x10^6)	2.5mV/V (5000x10^6)
Non-linearity	1%RO	1%RO
Apparent Elastic Modulus	1000N/mm^2	40N/mm^2
Integral Temperature	Thermocouple	Thermocouple
Temperature Range	-20 to +80°C (-4 to 176°F)	-20 to +80°C (-4 to 176°F)
Input/Output	350Ω Full Bridge	350Ω Full bridge

Four Vishay EGP-5-350 embedded strain gauges were also installed in each replacement section to measure internal concrete strain. The outside structure and proprietary polymer concrete used in these gauges make them impermeable to water and excellent for concrete embedment. They are self-compensated to reduce thermal output. Table 3.7 summarizes the specifications for these gauges.

Table 3.7
Specifications of EGP-5-350 Embedded Strain Gauges

Parameter	EGP-5-350
Capacity	NA
Gauge length	100mm (3.94 in)
Approximate Output Rating	NA
Non-linearity	NA
Apparent elastic modulus	NA
Integral temperature	None
Temperature range	-5 to +50°C (23 to 122°F)

Fourteen Macro Sensors GHSE 750-1000 LVDTs were installed in each of the five replacement sections to measure dynamic deflection of the pavement surface when dynamic loads were applied with the FWD and loaded dump trucks. These sensors were constructed of stainless steel and hermetically sealed which allows them to be used in a range of applications. With a precision of 0.000025 inches (0.64 μm) or better and a maximum linearity error of $\pm$ 0.10% of full scale, output was determined using a best-fit straight line derived by the least squares method. Specifications for the GHSE 750-1000 LVDTs are summarized in Table 3.8.

Table 3.8

Specifications of GHSE 750-1000 LVDTs

Parameter	GHSE 750-1000
Nominal Input Voltage	24 VDC, 30 mA
Full Scale Output	0 to 10 VDC
Linearity Error	$\leq \pm$ 0.10% of FSO
Repeatability Error	< 0.000025 inch (0.64 μm)
Operating Temperature	-0°F to +160°F (-17.8°C to +71°C)
Thermal Coefficient of Scale Factor	-0.015%/°F (-0.027%/°C)

All instrumentation was installed in the replacement PCC sections much like it was originally installed on the Ohio SHRP Test Road, and on other test pavements around Ohio and New York. Strain gauges were wired to steel chairs specially fabricated for each project and anchored to the top of the exposed base material, as shown in Figure 3.2. Tokyo Sokki Kenkyujo gauges are in the left portion of the figure and Vishay gauges are on the right.

Holes were drilled in the subgrade, plastic pipes were inserted to line the holes, and steel reference rods were inserted in the pipes and anchored to the bottom of the holes with grout. The holes were capped and base layers for the pavement were placed on lime-stabilized subgrade. Core holes were drilled through the base layers to the capped holes. The caps were removed and fixtures to hold the LVDTs, shown in Figure 3.3, were dropped into the holes and epoxied to the 301 base. After pavement concrete was placed around the fixtures, LVDTs were fastened in the fixtures so the moveable cores rested on the end of the steel rods. This arrangement allowed pavement deflections to be measured with respect to the bottom of the steel rods.

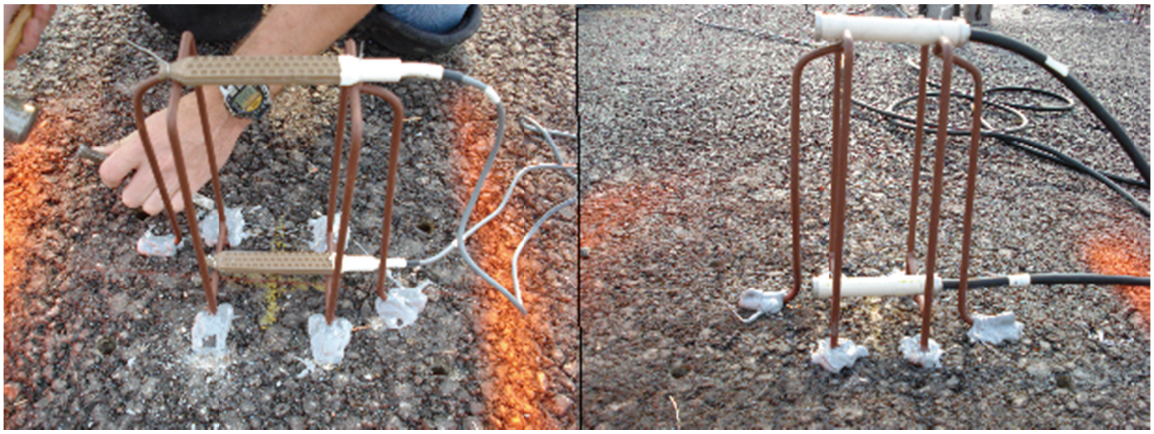


Figure 3.2 Strain Gauges Mounted on Chairs

Figure 3.3 Fixture to Hold LVDT

Pressure cells were mounted in the top of the lime stabilized subgrade by removing a few inches of the subgrade material and placing the cells on a cushion of sand to provide uniform support. Base and pavement layers were carefully placed over the cells while taking care not to have heavy wheels run over the cells. Thermocouples were attached to steel rods inserted in the 301 base with the sensors pulled away from the rod to avoid problems from different coefficients of thermal conductivity in the asphalt concrete and steel rods.

3.5 Data Acquisition

Two types of data acquisition system were used to record data. A Yokogawa system continuously recorded environmental data over time and a Megadac system was used to collect dynamic responses during FWD and controlled vehicle testing.

Yokogawa

Model MW100 Yokogawa systems used to record environmental factors were capable of recording data up to one sample per second. For this project, pavement temperatures were recorded every hour, except during the first week after concrete placement, when data were recorded every 30 minutes to monitor changes as the concrete cured.

Megadac

Four Megadec Digital Data Acquisition & Signal Conditioning Systems were used to record environmental and dynamic response data. These systems were capable of recording a total of 2500 samples per second; although previous tests showed that 1200 samples per second were sufficient to identify peak responses. LVDT and strain gauge outputs were recorded every half hour during the first 24 hours after placement of the concrete to monitor movement during the curing. For around 30 days after placement in August and September, data were collected every hour. Hourly data were also collected at the beginning and end of November to determine total slab deformation after four months. During the FWD and controlled vehicle tests, data were collected at a rate of 1200 samples per second to determine peak responses as dynamic loads were applied to the pavement.

3.6 Early Concrete Temperature Data

Figures 3.4 – 3.8 show average temperature gradients measured between centerline thermocouples TC1CL and TC4CL starting immediately after concrete was placed in Sections 268, 269, 270, 271 and 272, respectively; these were computed by taking the difference between the two temperatures, those closest to the top and bottom of the slab, and dividing by the distance between the thermocouples, which was 8 in (20 cm). In August, gradients are normally positive (top warmer than bottom), quite large in the afternoon as the hot sun heats the pavement surface, and near zero at night as the surface cools. When the effects of internal warming from hydration of newly placed concrete are added to these cycles, the net effect is to shift the daily cycles down and have negative gradients at night and minimal gradients during the day. As the hydration heat dissipates, the daily cycles rise back to normal. In Sections 268, 269 and 270, five to six days were required for this process to be completed. No obvious signs of hydration appeared in Sections 271 and 272.

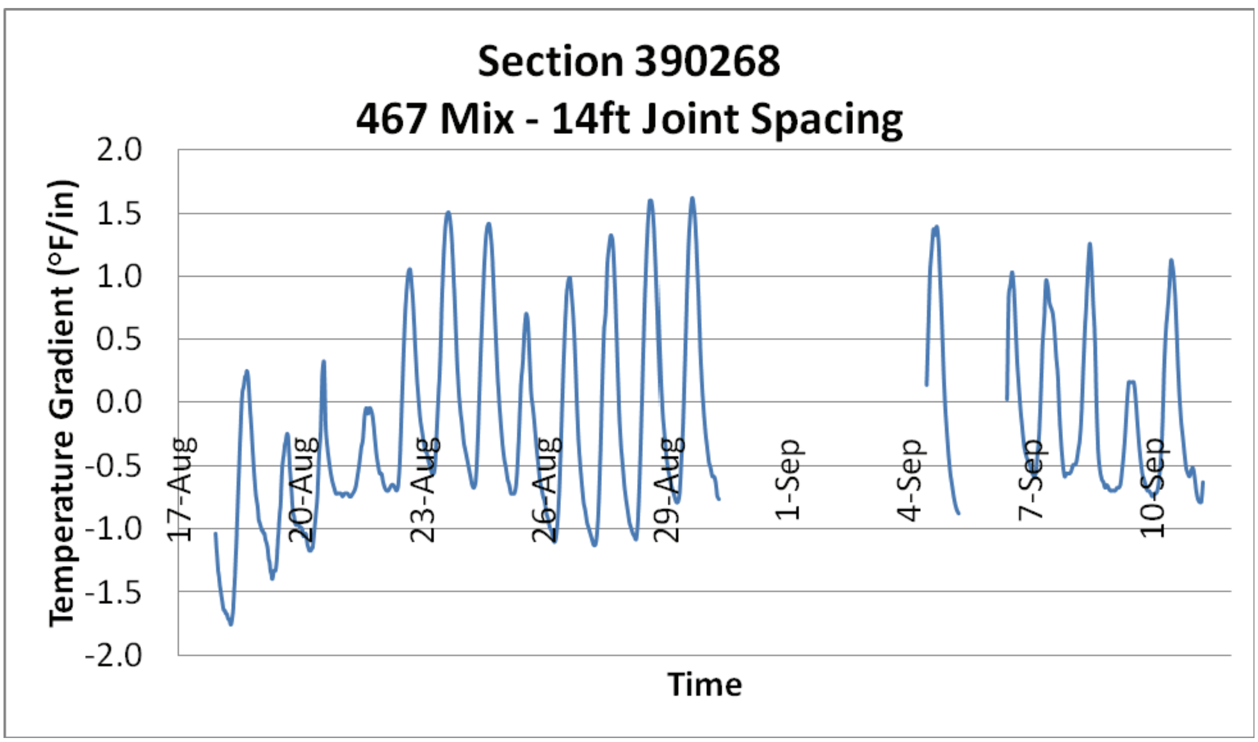


Figure 3.4 – Early Temperature Gradients in Section 268, August-September 2007.

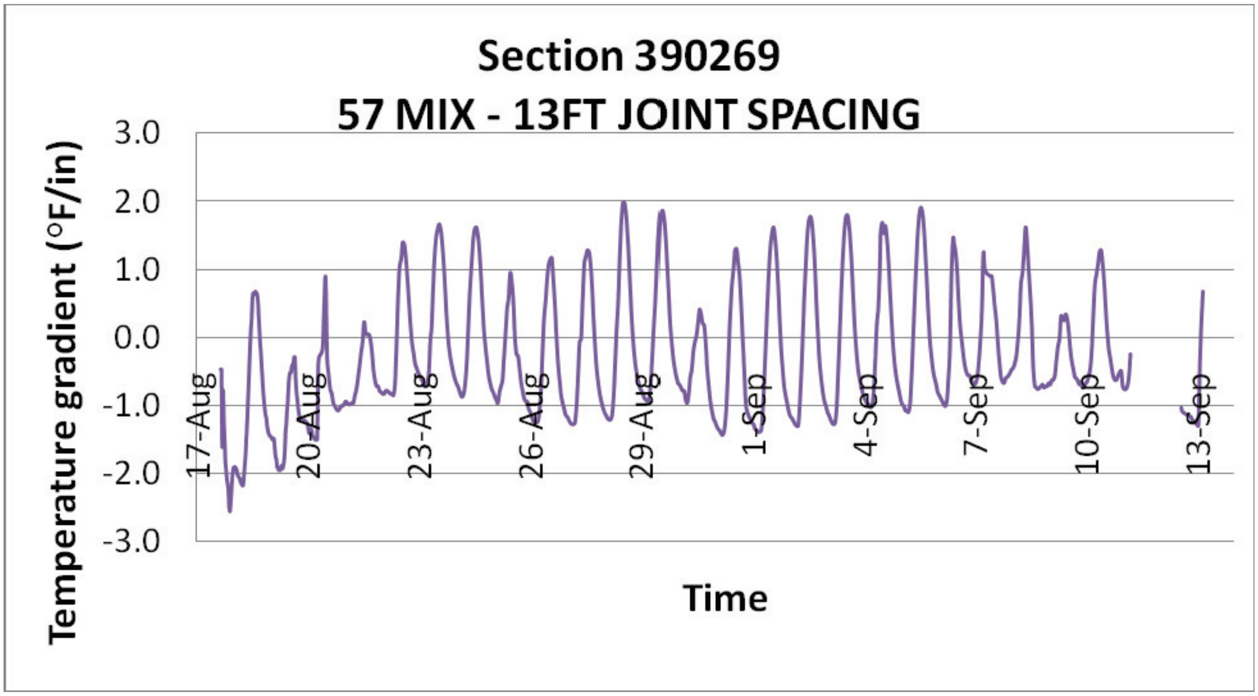


Figure 3.5 – Early Temperature Gradients in Section 269, August-September 2007.

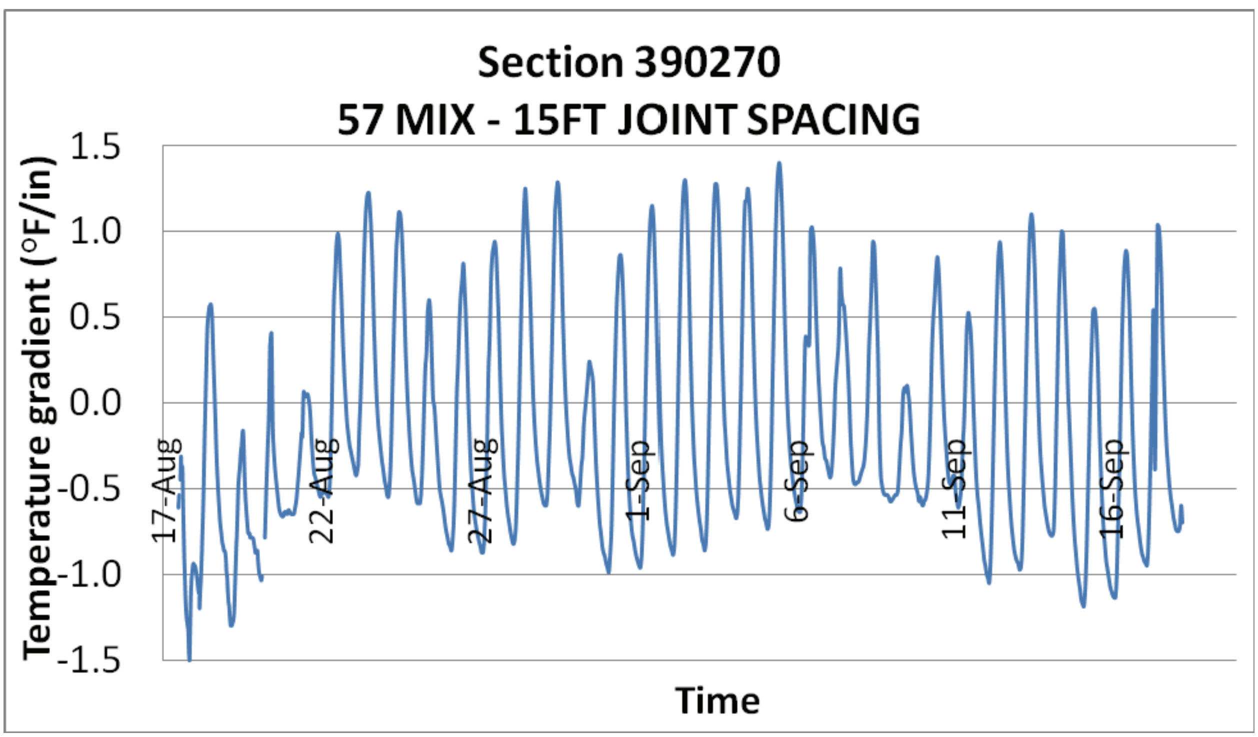


Figure 3.6 – Early Temperature Gradients in Section 270, August-September 2007.

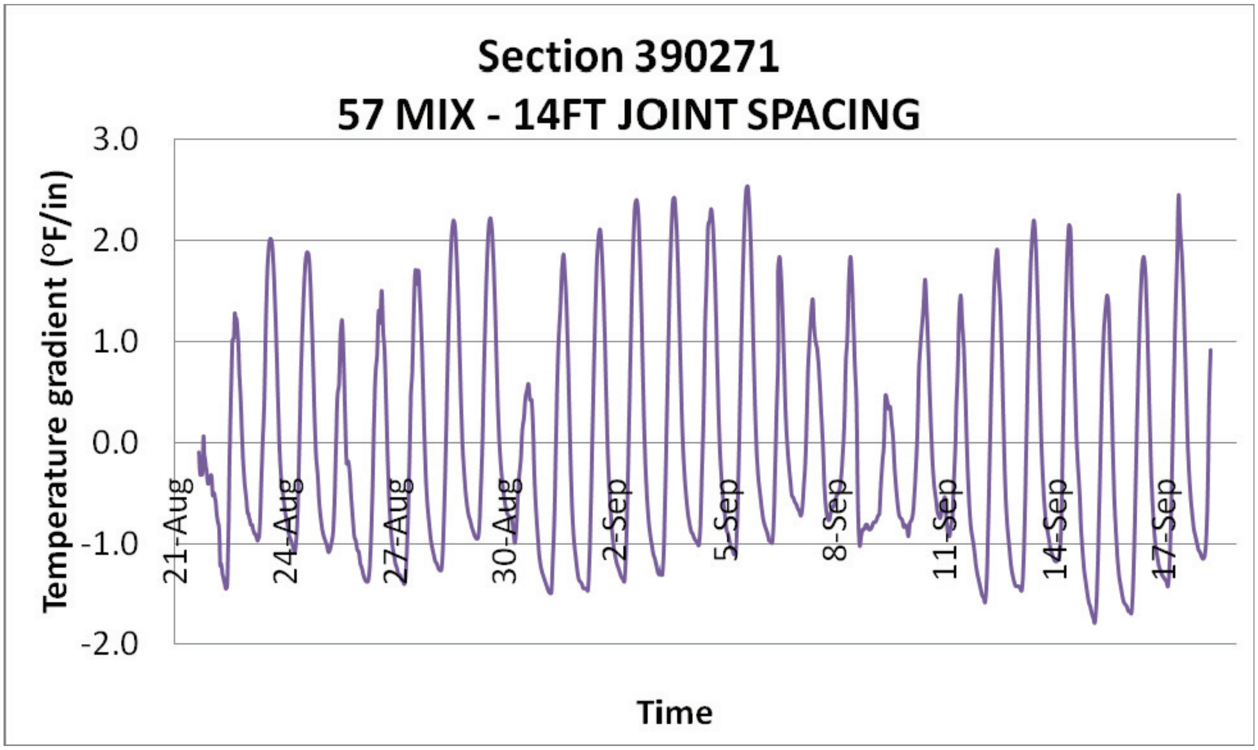


Figure 3.7 – Early Temperature Gradients in Section 271, August-September 2007.

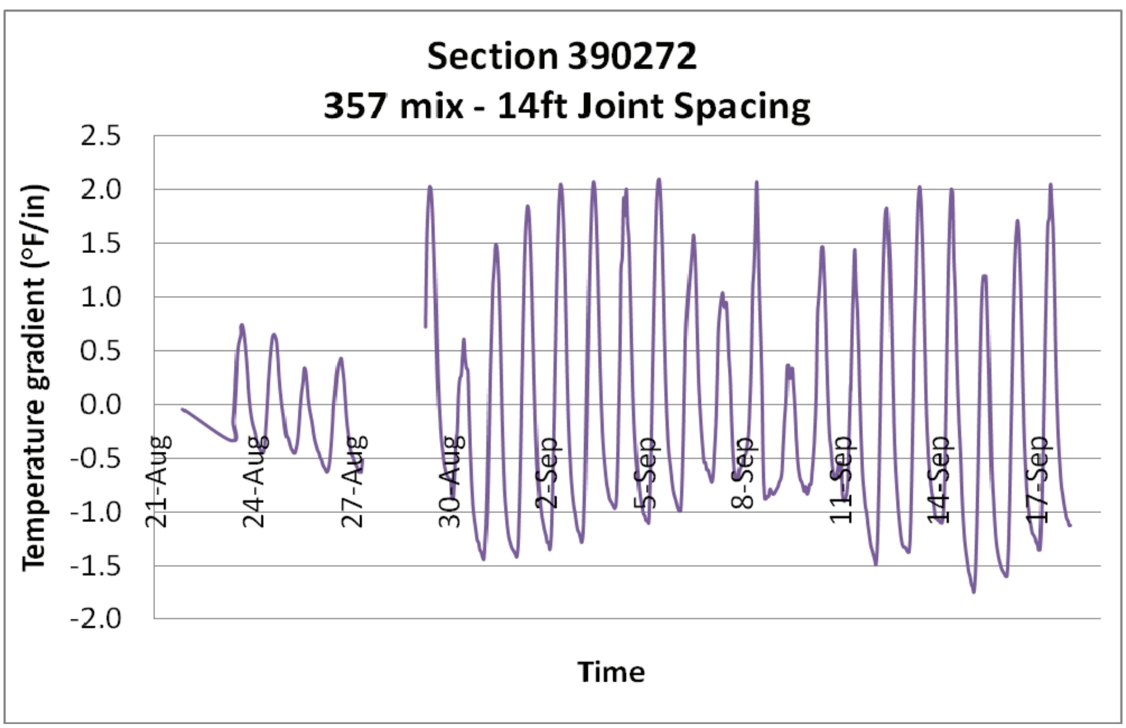


Figure 3.8 – Early Temperature Gradients in Section 272, August-September 2007.

3.7 Controlled Vehicle Tests

Heavily loaded single and tandem axle dump trucks were run at 5, 25 and 55 mph (8.0, 40.2 and 88.5 kph) on September 25 and 26, 2007. Similar runs were made on October 1, 2007 with a smaller load just prior to the road being opened to traffic on October 2, 2007. Prior to running these tests, the front truck tires were adjusted to 100 psi, the rear tires were adjusted to 120 psi, the trucks were loaded with an appropriate amount of aggregate, and weighed and measured at the ODOT Delaware County Garage. This was the tenth series of controlled vehicle tests at the DEL-23 site.

Tests were conducted by running the trucks continuously in a circular pattern on the test road, traveling north over the instrumented PCC replacement sections and returning on the southbound AC lanes. Traffic was diverted to the adjacent service road during the tests. The two trucks were spaced so there was about equal time between truck passes, which was sufficient to measure the offset distances, smooth out the sand used to record the lateral position of the truck with respect to the wheelpath sensors, and prepare the data acquisition systems for the next pass.

Figure 3.9 shows an imprint of a set of dual tires in sand spread across the right wheelpath at the end of an instrumented section to show the lateral position of trucks as they passed over the sections. The line between the tires was drawn with a finger to show the line of wheelpath sensors. Lateral offsets were measured from that line to the outside edge of the right dual tire. In this case, the offset was 10.25 inches (26.0 cm), which was ideal since the goal was to straddle the line of sensors with the dual tires. Offsets measured during this tenth series of tests are summarized in Appendix A. Figure 3.10 shows the geometry of the axles and tires on the trucks and Figure 3.11 shows individual tire weights. Dimensions in Figure 3.10 show the outside dual tire essentially overlapped the front tire on both trucks. On the single-axle truck, the right front tire covered a path 37.0 - 47.0 inches (92.5 - 117.5 cm) from the centerline of the truck and the right outside dual tires covered a path 38.5 - 47.3 inches (97.8 - 120.1 cm). On the tandem-axle truck, these distances were 34.1 - 46.4 inches (86.6 - 117.9 cm) for the right front tire and 38.8 - 47.1 inches (98.6 - 119.6 cm) for the right outside dual tires. For these geometries, ideal offsets for the sensors to fall between the dual tires were 8.75 - 13.50 inches (22.2 - 34.3 cm) for the single-axle truck and 8.38 - 13.38 inches (21.3 - 34.0 cm) for the tandem-axle truck.

Considering the stiffness of these concrete sections, little difference in response would be expected with the sensors being located anywhere between or under the dual tires.

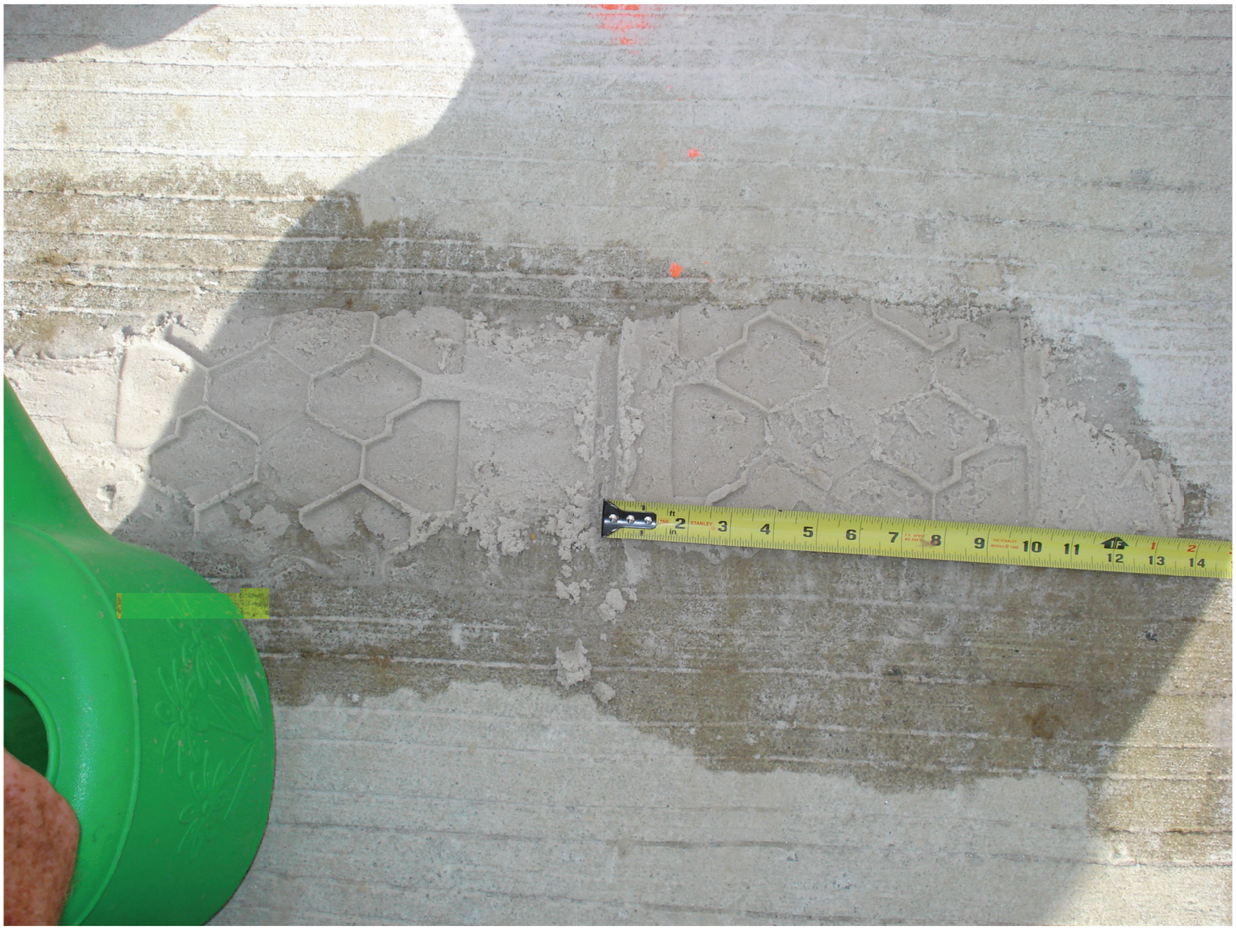


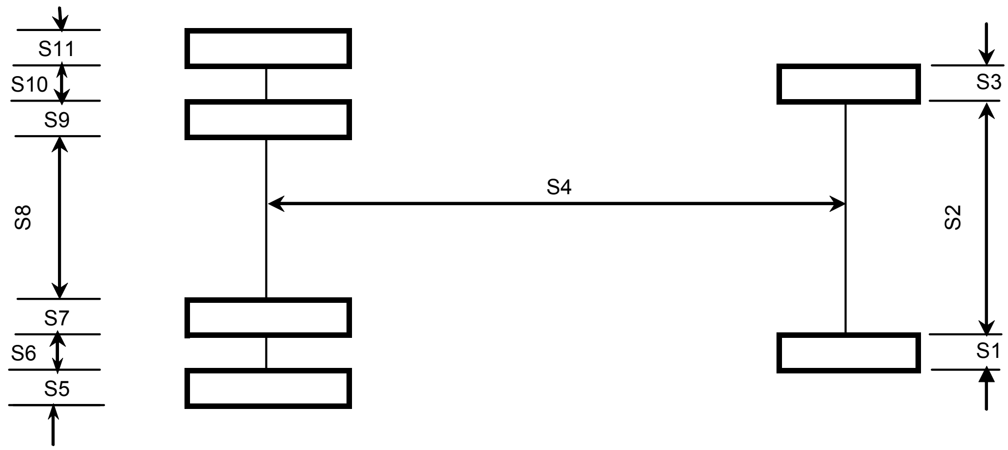
Figure 3.9 – Tire Imprints in Sand

Spacing between the two axles on the single-axle dump truck was 14.2 feet (4.33 m) and the distance between the steering axle and the front tandem axle was 14.9 feet (4.53 m) on the tandem-axle dump truck. Consequently, differences in longitudinal strain might be expected on the 13, 14 and 15 foot (3.96, 4.27 and 4.57 m) long slabs instrumented for these tests. On the 13-foot (3.96 m) slabs, tires on the steering axle would essentially be off the slabs before tires on the next axle begin to roll on. On the 15 foot (4.57 m) slabs, tires on these two axles would be expected to generate a convex shape and high tensile longitudinal strains near the midslab pavement surface when they were on opposite ends of the slabs at the same time. The 14 foot (4.27 m) slabs would fall somewhere between these two situations as there would be some, but less than half, of the tire areas on a slab at the same time. Pavement responses on 13-foot (3.96 m) and 15 foot (4.57 m) slabs are shown in the following discussion.

DEL 23 Controlled Vehicle Testing - Series 10, September 2007
PCC Replacement Sections - Dump Truck Axle Weights in Pounds

Single-Axle Dump Truck

Date: 9/24/2007

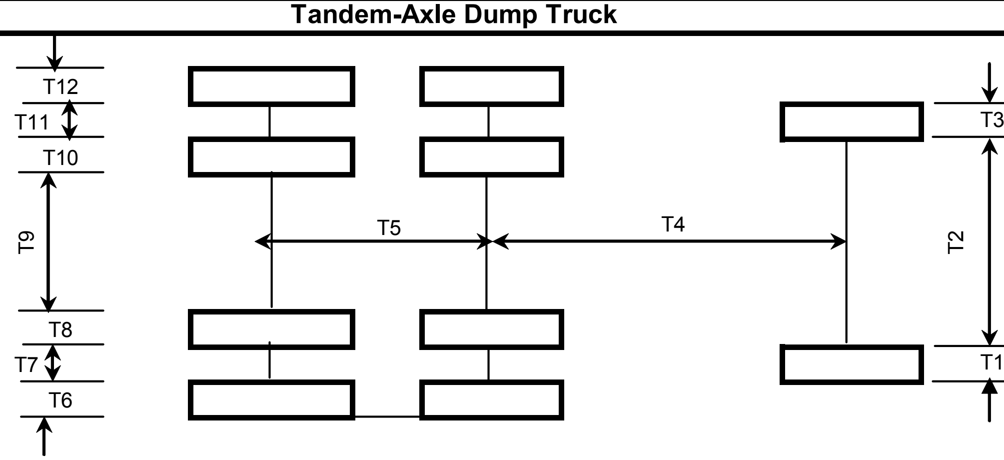


Truck ID: 2544343
Truck Lic. T 6 596

Test Series	Dimensions on Single-Axle Dump Truck (in.)										
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**
10	10.0	74.0	10.0	170.5	8.75	4.75	8.75	50.0	8.25	5.0	8.25

1 inch = 2.54 cm. = 0.0254 m

Tandem-Axle Dump Truck



Truck ID: 2560224
Truck Lic. T 6 925

Test Series	Dimensions on Tandem-Axle Dump Truck (in.)											
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**T11**	**T12**
10	12.25	68.25	12.38	178.5	53.5	8.38	5.0	8.38	50.75	8.38	5.0	8.38

1 inch = 2.54 cm. = 0.0254 m

Figure 3.10 – Dump Truck Geometry

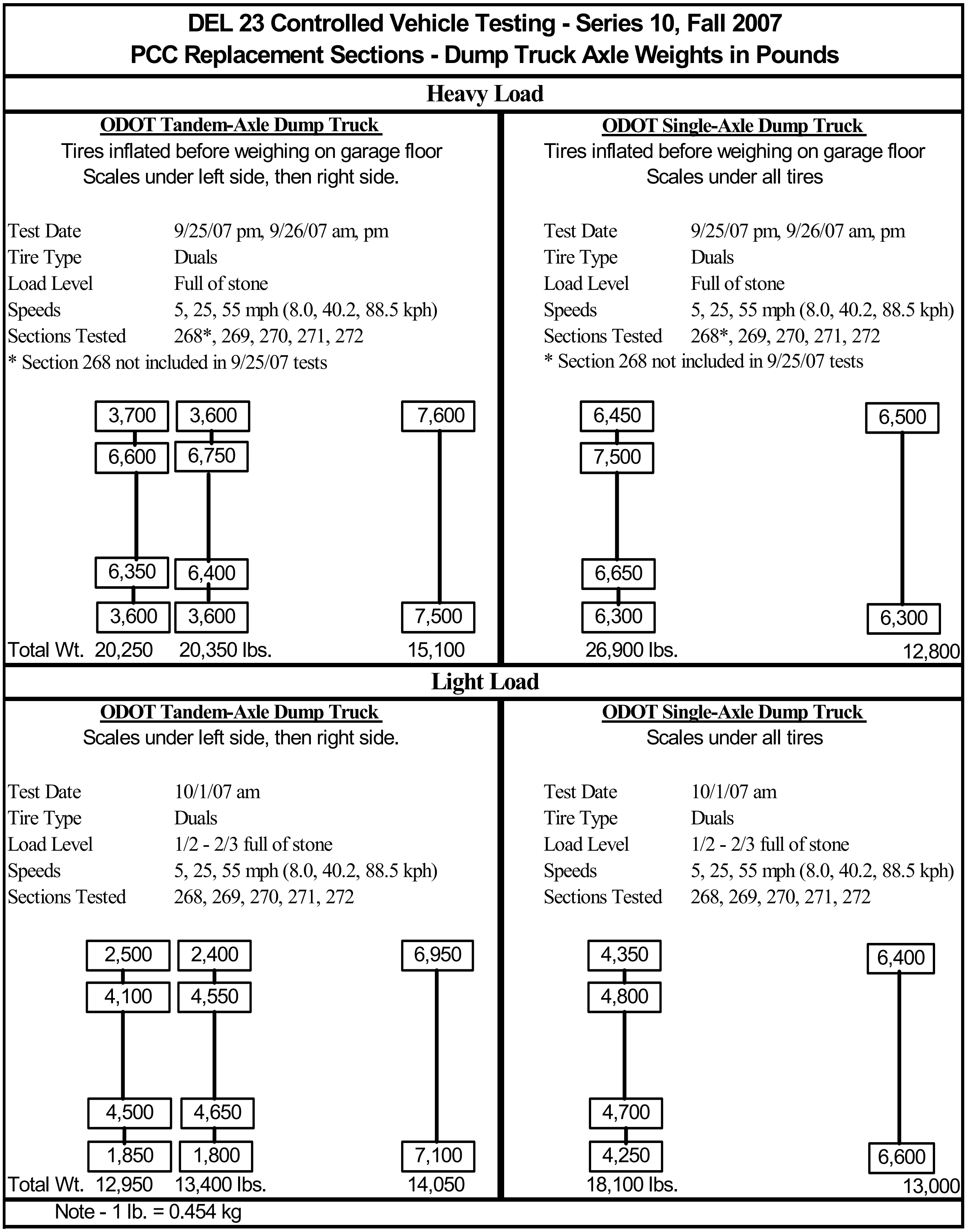


Figure 3.11 – Dump Truck Wheel Weights

These tests comprised the tenth set of controlled vehicle tests at the DEL 23 site since it was opened in August 1996 and were divided into three general series of runs, as follows: A) heavy loads in the morning of 9/25/07, B) heavy loads in the afternoon of 9/26/07 to measure the effects of temperature, and C) light loads in the morning of 10/1/07 to measure the effects of load. Each truck made three runs at 5, 25 and 55 mph (8.0, 40.2 and 88.5 kph) in each series of tests to measure the effects of load and speed on dynamic response. Each truck made 9 runs over two sections and 10 runs over two other sections in the Group A tests, 27 runs over five sections in the Group B tests, and 11 runs over five sections in the Group C tests for a total of 456 section tests, more than 13,000 sensor traces, and more than 34,000 axle responses. A list of individual truck runs showing speed and lateral offsets is included in the appendix and measured responses are on a CD attached to this report. Pressure at the subgrade surface was measured only in Section 268.

Table 3.9 shows pavement temperature data collected during the controlled vehicle tests with gradients calculated as the difference between TC1, one inch (2.54 cm) below the pavement surface, and TC4, one inch (2.54 cm) above the bottom of the pavement. While the data are not complete, a moderate positive gradient was observed in the afternoon of 9/25/07, and a small negative gradient changing to a small positive gradient was noted on 9/26/07 and 10/1/07.

Figure 3.12 shows the relationship between weight and spacings for the first and second axles on 16,800 trucks recorded during four different weekdays in 1998 – 2001 with weigh-in-motion scales on the Ohio SHRP Test Road, where 75-80% of the trucks were Class 9. The two bars above each spacing integer along the x-axis show the average weights for each axle falling within the one foot range in spacing for that integer (i.e., 11=11.00-11.99, 12=12.00-12.99, etc.). With recent concerns about high longitudinal tensile stresses being generated near slab surfaces when tires on adjacent truck axles are on opposite ends of a slab, 13 ft. (4.0 m), 14 ft. (4.3 m), and standard 15 ft. (4.6 m) long replacement PCC slabs were constructed and instrumented on the test road in 2006-07 to measure dynamic responses as a single-axle dump truck having an axle spacing of 14.2 ft. (4.33 m) and a dual-axle dump truck having a spacing of 14.8 ft. (4.51 m) between the first and second axles were run across the slabs at different loads and speeds. Figures 3.13 and 3.15 show typical midslab strain histories measured in the RWP with the single-axle dump truck traveling left to right at a nominal speed of 5 mph (8 kph) over 13 and 15 foot (4.0 and 4.6 m) long slabs, and Figures 3.14 and 3.16 show similar results for deflection measured with deep LVDTs in the LWP. All traces were recorded on the same pass when loads and temperatures were the same.

Table 3.9

Pavement Temperature During Controlled Vehicle Testing

Date	Time	Section	Pavement Temperature									
			°F					°C				
			TC1	TC2	TC3	TC4	TC1-TC4	TC1	TC2	TC3	TC4	TC1-TC4
9/25/07												
	4:50 pm	270	92.3	87.8	84.2	81.5	+ 10.8	33.5	31.0	29.0	27.5	+ 6.0
9/26/07	9:15 am	268	72.3	73.4	74.5	75.6	- 3.3	22.4	23.0	23.6	24.2	- 1.8
	10:00 am		74.8	75.2	76.6	77.5	-2.7	23.8	24.0	24.8	25.3	- 1.5
	11:15 am		77.0	76.3	76.6	77.4	- 0.4	25.0	24.6	24.8	25.2	- 0.2
	11:48 am		79.2	78.4	78.4	79.0	+ 0.2	26.2	25.8	25.8	26.1	+ 0.1
	3:10 pm		80.8	80.2	78.8	78.4	+ 2.4	27.1	26.8	26.0	25.8	+ 1.3
	4:05 pm		79.7	78.6	78.3	78.3	+ 1.4	26.5	25.9	25.7	25.7	+ 0.8
10/1/07	10:40 am	268	68.4	68.9	70.9	72.0	- 3.6	20.2	20.5	21.6	22.2	- 2.0
	11:25 am		71.4	69.4	69.6	71.4	0.0	21.9	20.8	20.9	21.9	0.0
	11:47 am		72.5	71.2	71.1	72.0	+ 0.5	22.5	21.8	21.7	22.2	+ 0.3
	12:26 am		*74.3*	72.1	72.3	73.0	+ 1.3	23.5	22.3	22.4	22.8	+ 0.7

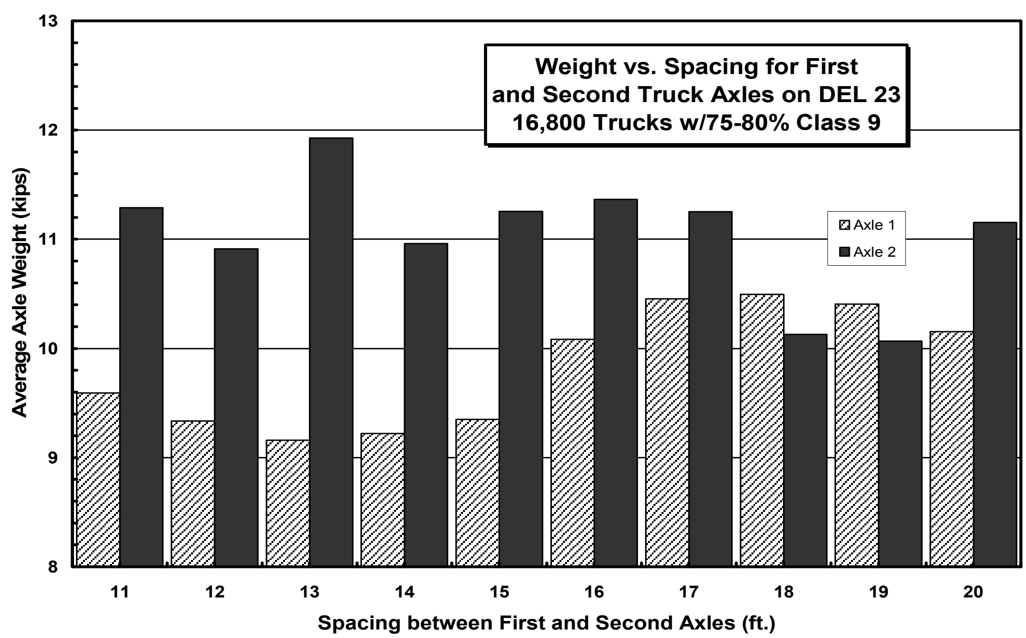


Figure 3.12 – Weight vs. Spacing for First and Second Truck Axles (1 ft = 0.30m, 1 kip=4.5kN)

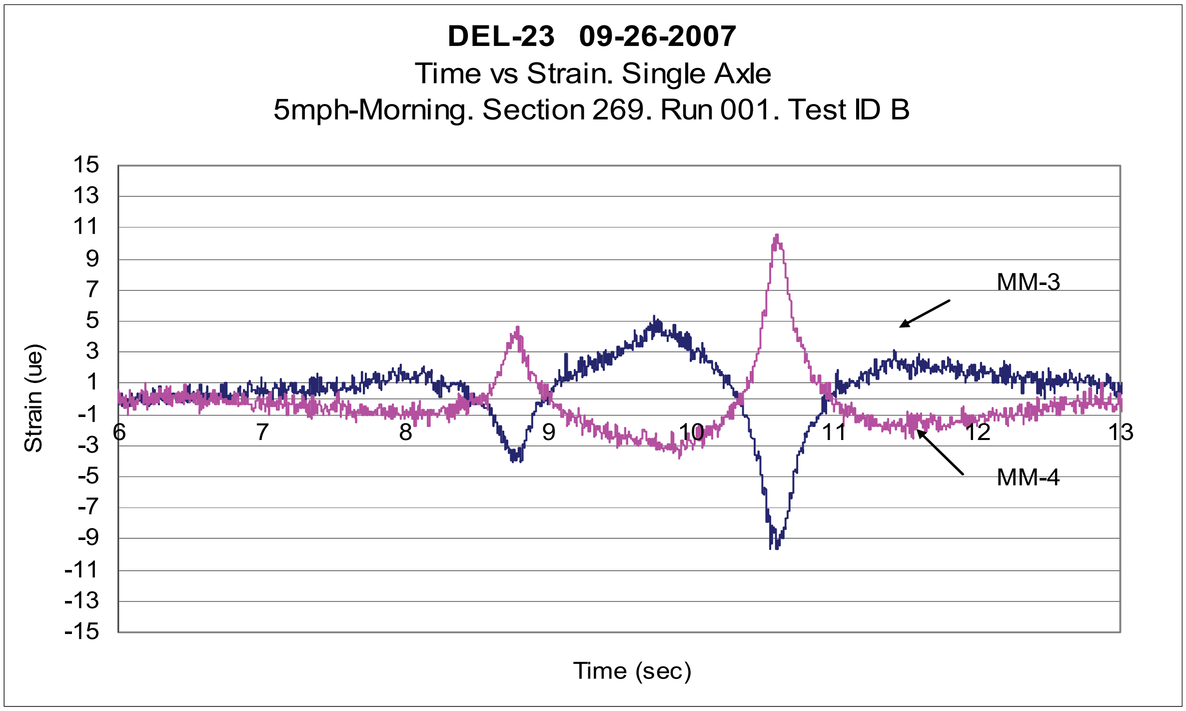


Figure 3.13 – Longitudinal Strain on 13-foot (4.0 m) Long Slab

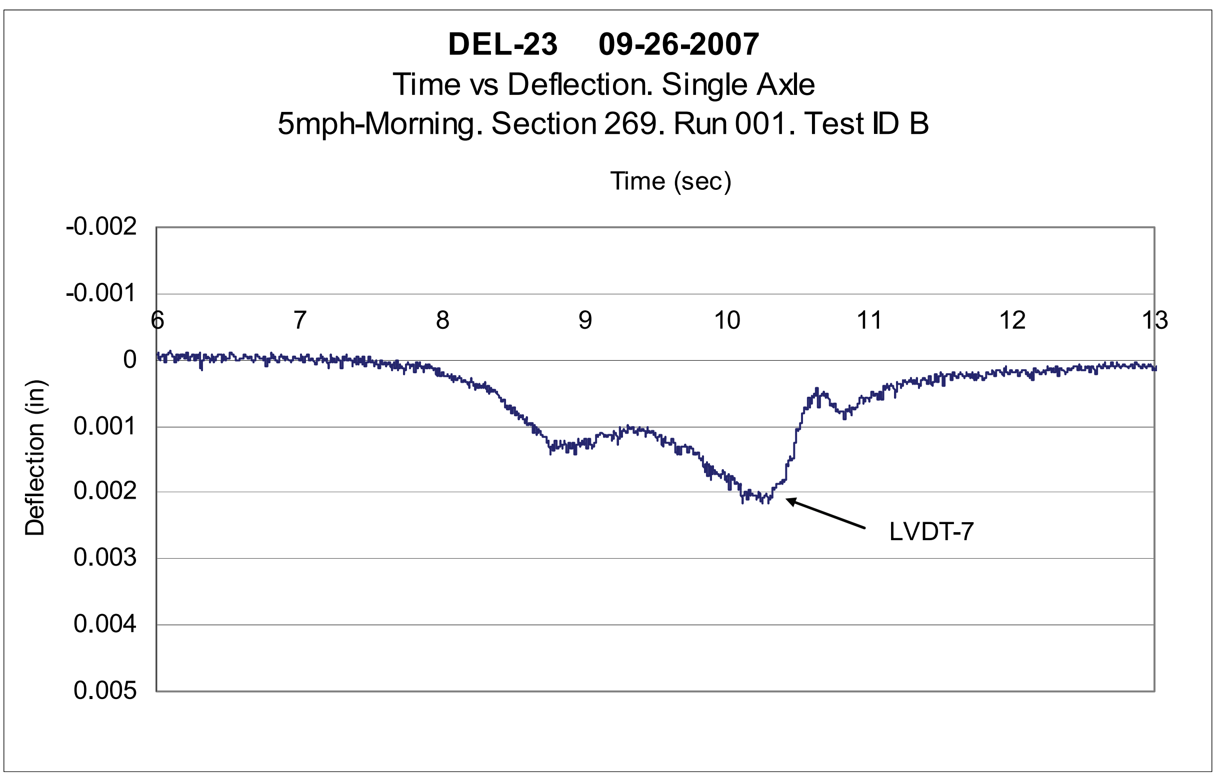


Figure 3.14 –Deflection on 13-foot (4.0 m) Long Slab

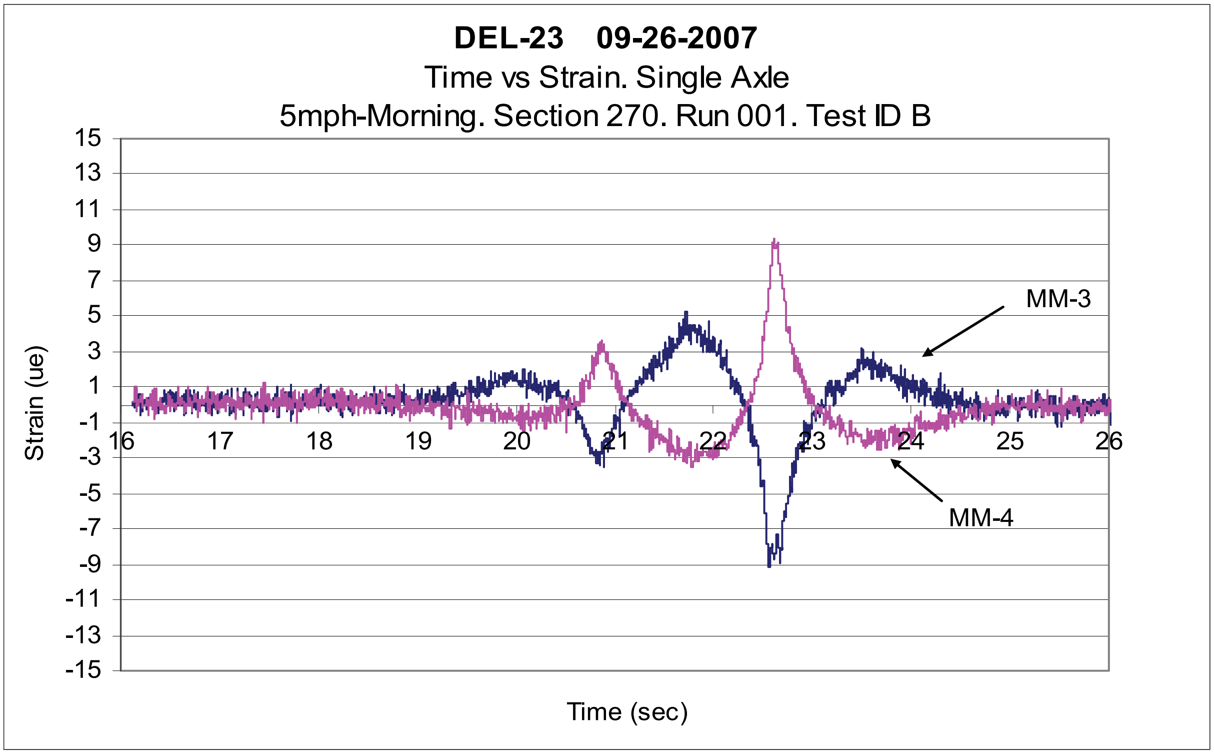


Figure 3.15 - Longitudinal Strain on 15-foot (4.6 m) Long Slab

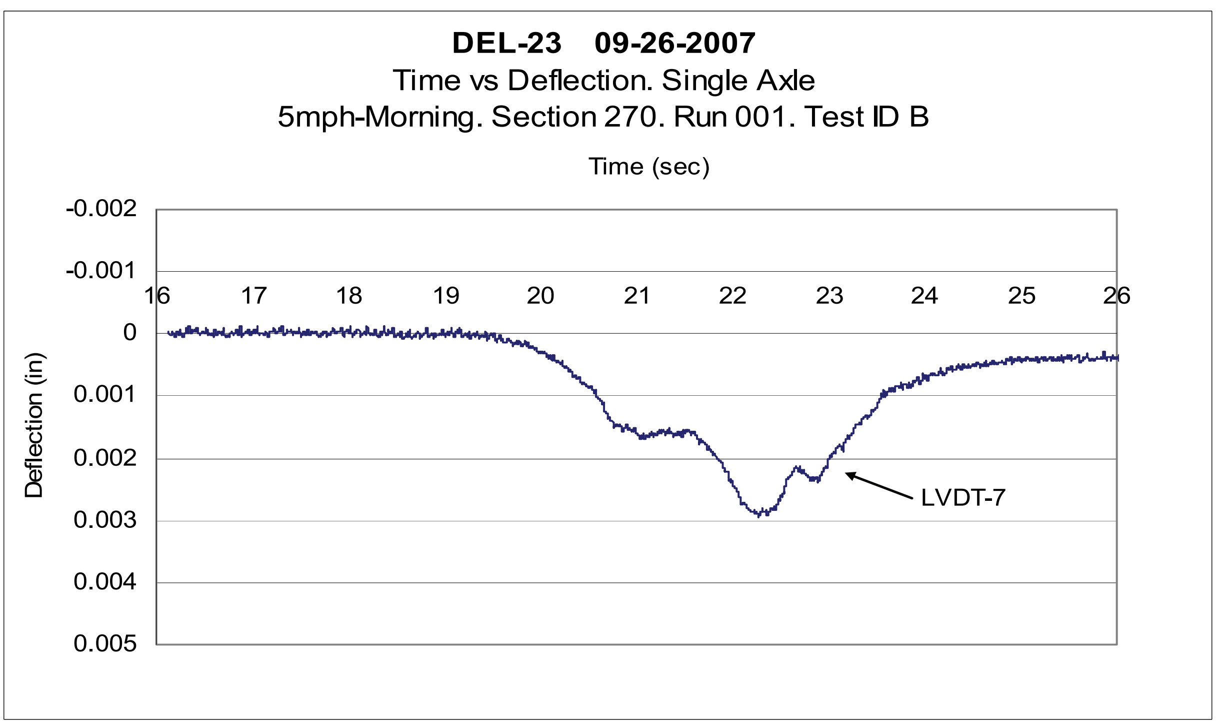


Figure 3.16 - Deflection on 15-foot (4.6 m) Long Slab

When jointed PCC pavements are new and load transfer at transverse contraction joints is high, multiple slabs act as a continuous strip with responses under traffic loading being relatively uniform in the longitudinal direction. As dowel bars become loose and load transfer is lost, joints begin to act as hinges, thereby requiring slab ends to carry more load and allowing joint deflections to increase under dynamic loading. This process of increasing deflection around the joints further reduces support under the joints through additional compaction of unbound base material and/or pumping of fine material from the base which accelerates the loss of load transfer. As joint deflections rise, slab curvature and internal slab stresses also rise accordingly. Upward curling of the slab ends from negative temperature gradients exacerbates the problem of increasing dynamic joint deflections even more through the loss of base support.

As was stated earlier, 13 ft. (4.0 m), 14 ft. (4.3 m), and standard 15 ft. (4.6 m) long slabs were constructed to evaluate dynamic responses caused by moving single-axle and tandem-axle dump trucks with spacings of 14.2 feet (4.3 m) and 14.9 feet (4.5 m), respectively, between the first and second axles. Tires from both axles will be on the 15 ft. (4.6 m) slabs for a short time, only tires from one axle can fit on the 13 ft. (4.0 m) slabs, and partial tire coverage will occur on the 14 ft. (4.3 m) slabs. Dynamic responses would be expected to be similar on the different slab lengths when the pavement is new and load transfer is high, but differences should begin to appear as load transfer degrades.

At 5 mph or 7.3 feet per second (8 kph or 2.2 meters per second), approximately two seconds will be required between pulses generated by tires on the first and second axles on both dump trucks. Since the actual time was slightly more than one second, the trucks were traveling faster than 5 mph (8 kph). Maximum strains in Figures 3.13 and 3.15 were essentially the same in both slabs, but maximum deflection was about 50% higher on the 15 foot (4.6 m) slab in Section 270. While strain looked quite smooth over the entire length of the traces, deflection on both slabs had an unexpected pulse soon after the rear axle passed the LVDT. The timing of this pulse suggests it may have been caused by the rear tires crossing the transverse contraction joint to the next slab. The similarity in trace responses on the two slabs was probably due to excellent load transfer (~86%) measured with the FWD. With reduced load transfer, all traces may well show a spike as the tires cross joints on both ends of the slab, and top tensile strain on the longer slab may be higher between the two axles. Maximum deflection under the tires would also be expected to rise over time as load transfer drops off.

3.8 Profiles

A rolling wheel profilometer was designed and fabricated by ORITE primarily to record transverse profiles across wheelpaths and measure rut depths on AC pavements in the APLF. The profiler has also been used in the field to measure ruts on AC pavements, and curling and warping deformations on PCC pavements. In a typical profile, 210 elevations are recorded at intervals of 0.536 in. (1.36 cm) for a total profile length of 112.5 inches (2.86 m). The profiler frame is approximately 10 feet (3.05 m) long and profiles can be concatenated end to end to achieve longer lengths of pavement.

Five of the seven PCC replacement sections on DEL 23 contained dynamic response instrumentation in two adjacent slabs. Two longitudinal profiles and six transverse profiles were run on these instrumented slabs before they were opened to traffic on four hot days in August 2007. These profile paths are shown in Figure 3.17.

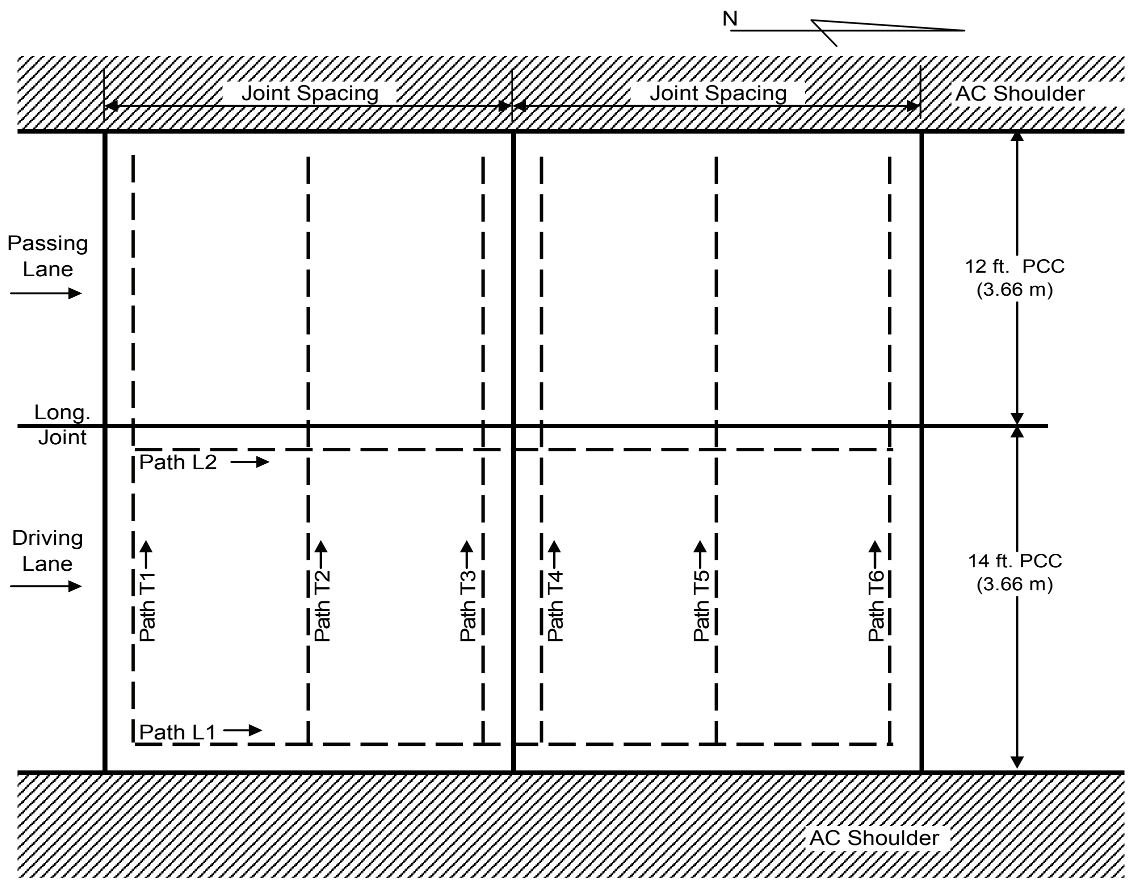


Figure 3.17 – Profile Paths on DEL 23 Replacement Sections

Individual profiles were referenced to an arbitrary datum and coded in the form of BL12A, etc., where B is the section ID, L is for longitudinal or T is for transverse, 1 is the profile path shown in Figure 3.17, 2 is the number of the profile recorded along the path, and A is the profile series on the section. On transverse profiles, the first two profiles were end to end starting at the east pavement edge, and a third profile had an overlap of 46 inches (117 cm) over the second profile making a total profile length of about 313 inches (7.95 m) across the 14 and 12 foot (4.27 and 3.66 m) lane widths. Each of the two longitudinal profiles consisted of three concatenated profiles starting at the south end and extending across the two instrumented slabs. Section IDs correspond to the following SHRP numbers assigned to the instrumented PCC replacement sections:

Table 3.10

Profile Sections vs. Project Sections

Profile Section ID	SHRP Section Number	Joint Spacing (ft.) (m)
A	268	14 (4.27)
B	269	13 (3.96)
C	270	15 (4.57)
D	271	14 (4.27)
E	272	14 (4.27)

Multiple series of profiles were taken in Sections A, B and C to check for repeatability and the effects of temperature gradients on slab curling and warping. Unfortunately, the similarities of temperatures on the days the profiles were recorded made it difficult to detect any curling and warping deformations. Table 3.11 summarizes dates and times the various profile series were run.

Table 3.11

Profile Timing

Profile Section ID	Profile Series	Date	Time	Profile Section ID	Profile Series	Date	Time
A	A	8/15/07	11:11-11:53 am	C	A	8/21/07	4:00-4:30 pm
A	B	8/16/07	4:09-5:00 pm	C	B	8/22/07	3:01-3:36 pm
A	C	8/21/07	1:16-1:50 pm	D	A	8/22/07	5:01-5:27 pm
B	A	8/21/07	3:09-3:46 pm	E	A	8/22/07	5:37-6:04 pm
B	B	8/22/07	2:01-2:34 pm				

Figures 3.18-3.22 show profiles for Paths L1, L2, T2 and T3 measured during the various series of runs on the five instrumented sections. These profiles were selected because they represent longitudinal paths along a joint and the pavement edge, and transverse paths across midslabs and along a joint. Because profiles have an arbitrary datum, repeated runs for the different series of tests in the same path were adjusted to the same initial elevation in Series A. Software is needed to model the entire slab surface by reconciling differences in elevation at points where the profiles cross.

Transverse profiles show very straight cross slopes from the outside edges of the pavement to the longitudinal joint, which would be expected since the concrete was placed with a slipform paver. Longitudinal profiles had less average slope across slabs, but were more erratic in shape, especially in Sections 268 and 272. An extended longitudinal profile was measured north along the longitudinal joint from Section 268, as shown in Figure 3.19. The average slope over this 168 feet (51.2 m) length was 0.34% or 0.34 feet (10.4 cm) of elevation per 100 feet (30.5 m) of length.

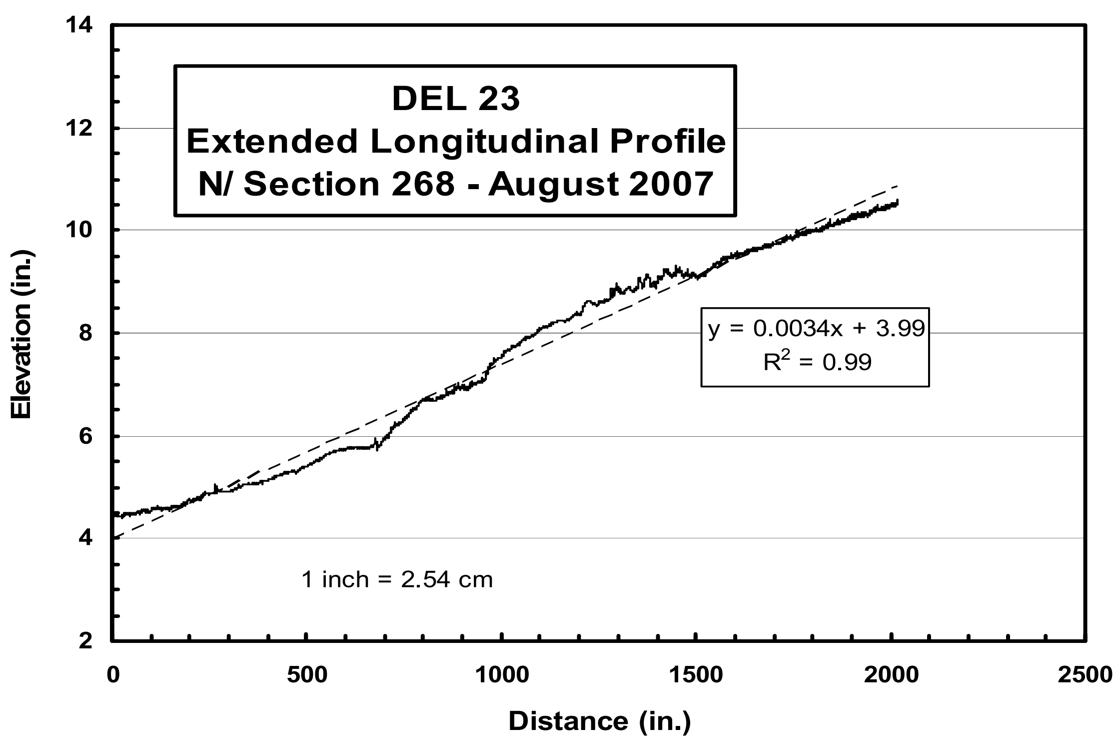
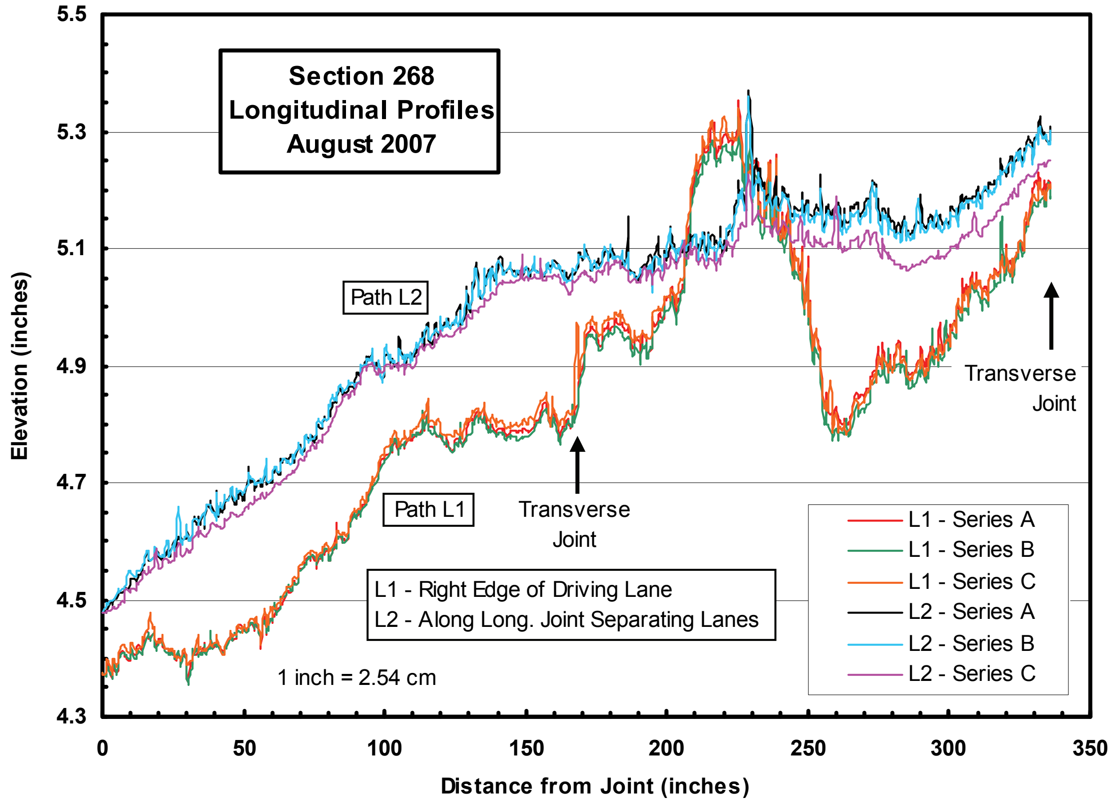


Figure 3.18 – Extended Longitudinal Profile North of Section 268



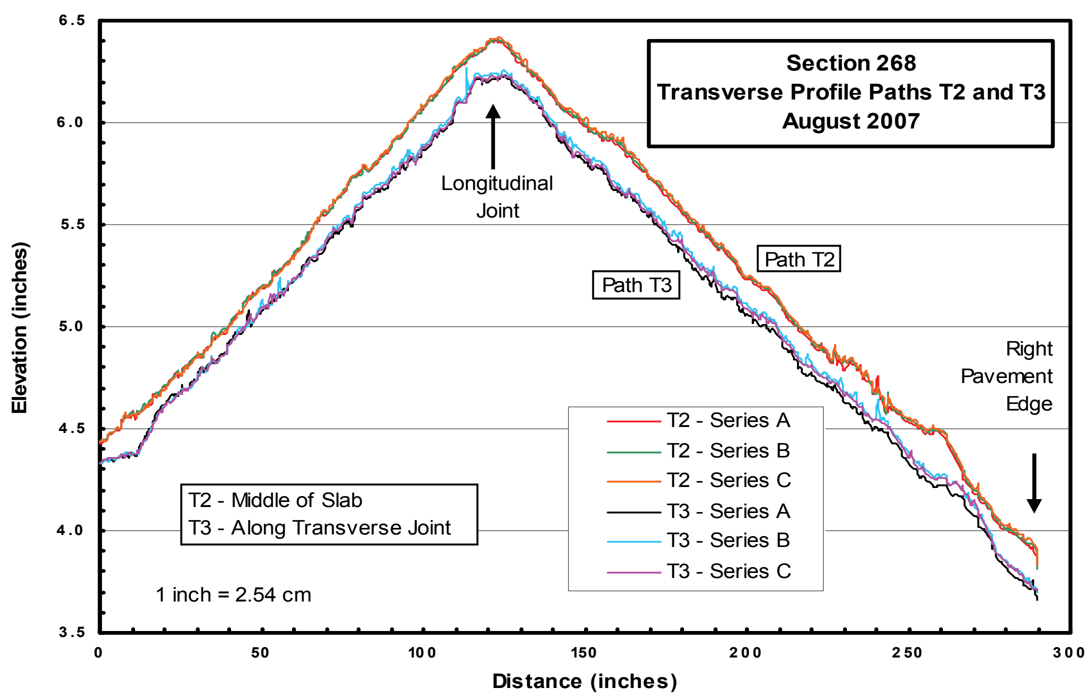
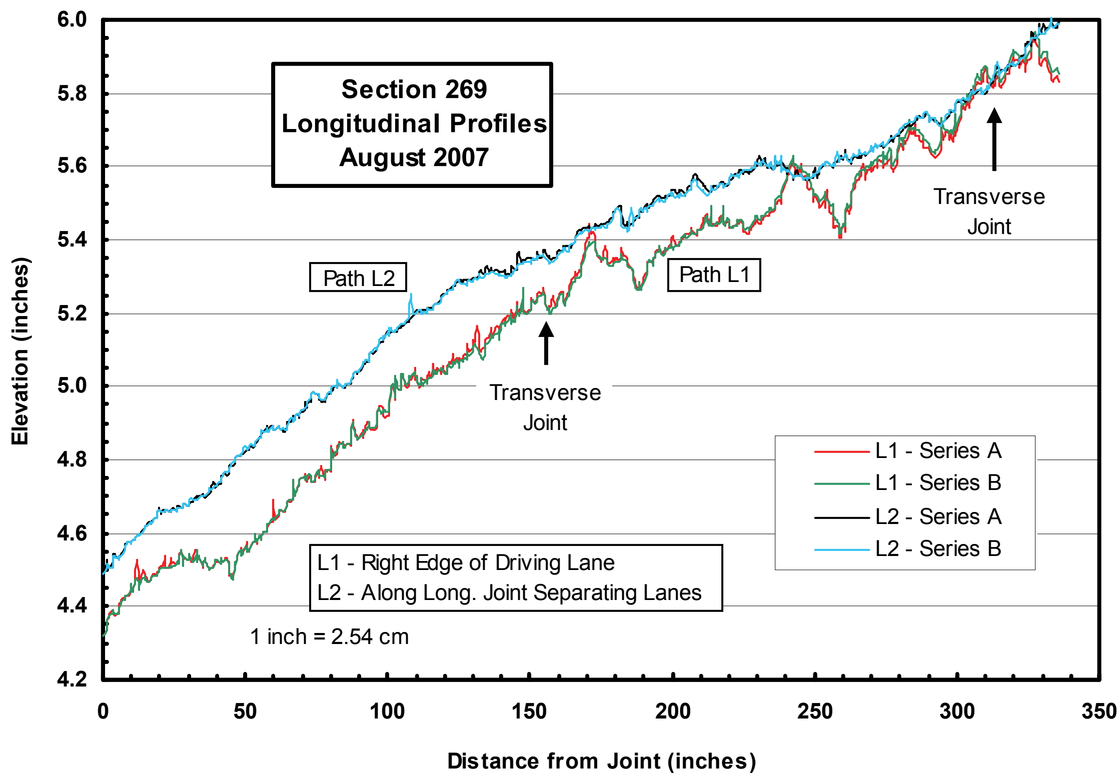


Figure 3.19 – Longitudinal and Transverse Profiles on Section 268 (1 in = 2.54 cm)



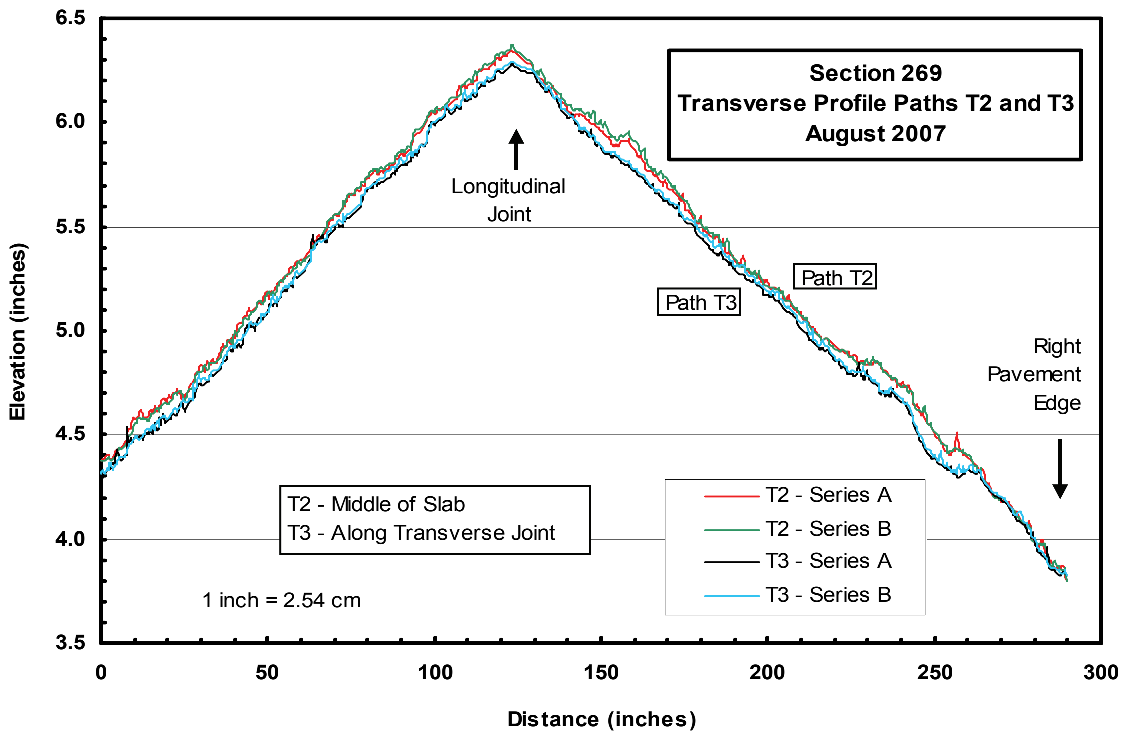
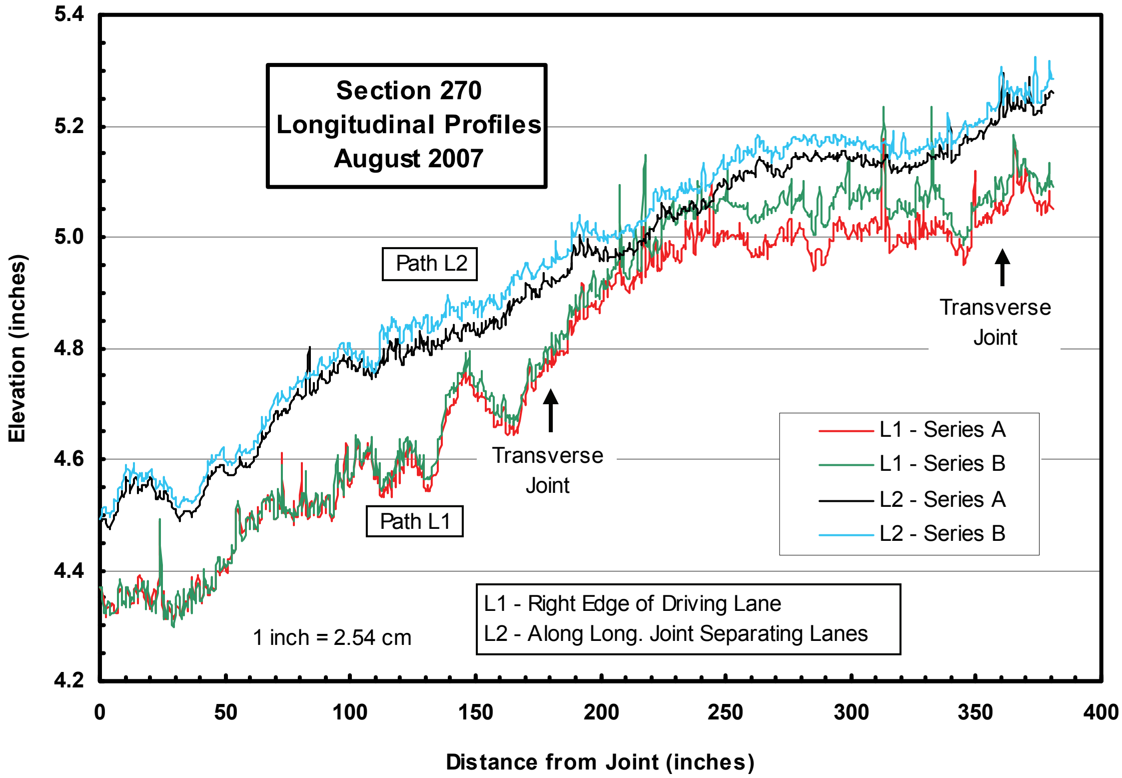


Figure 3.20 – Longitudinal and Transverse Profiles on Section 269 (1 in = 2.54 cm)



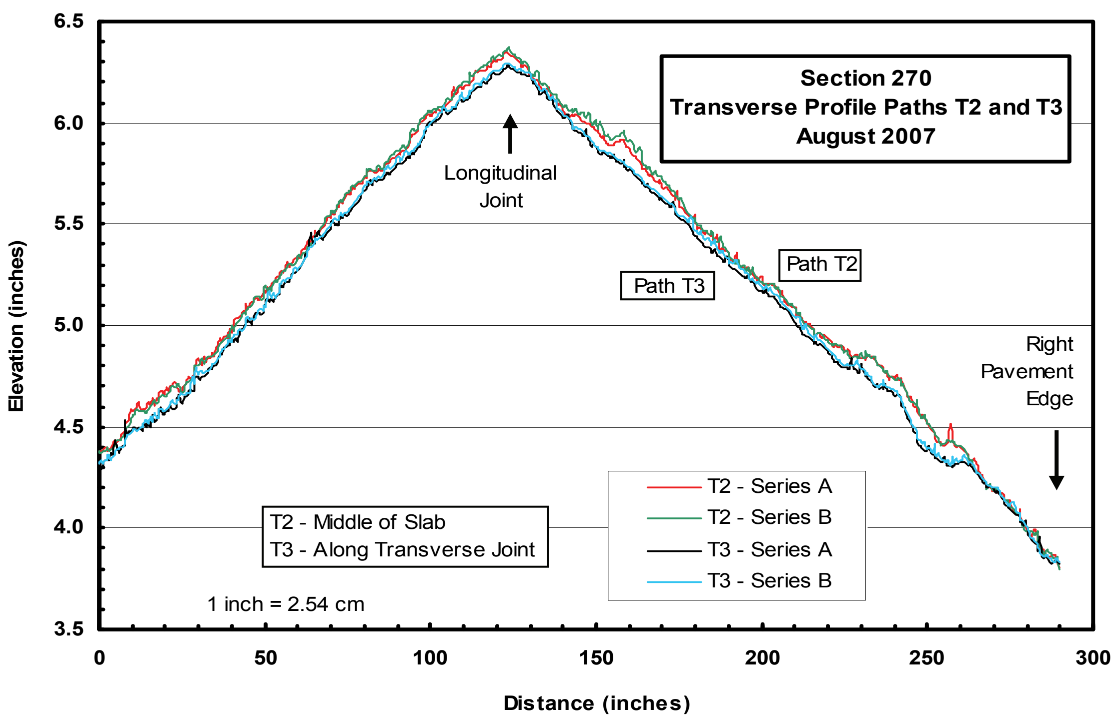
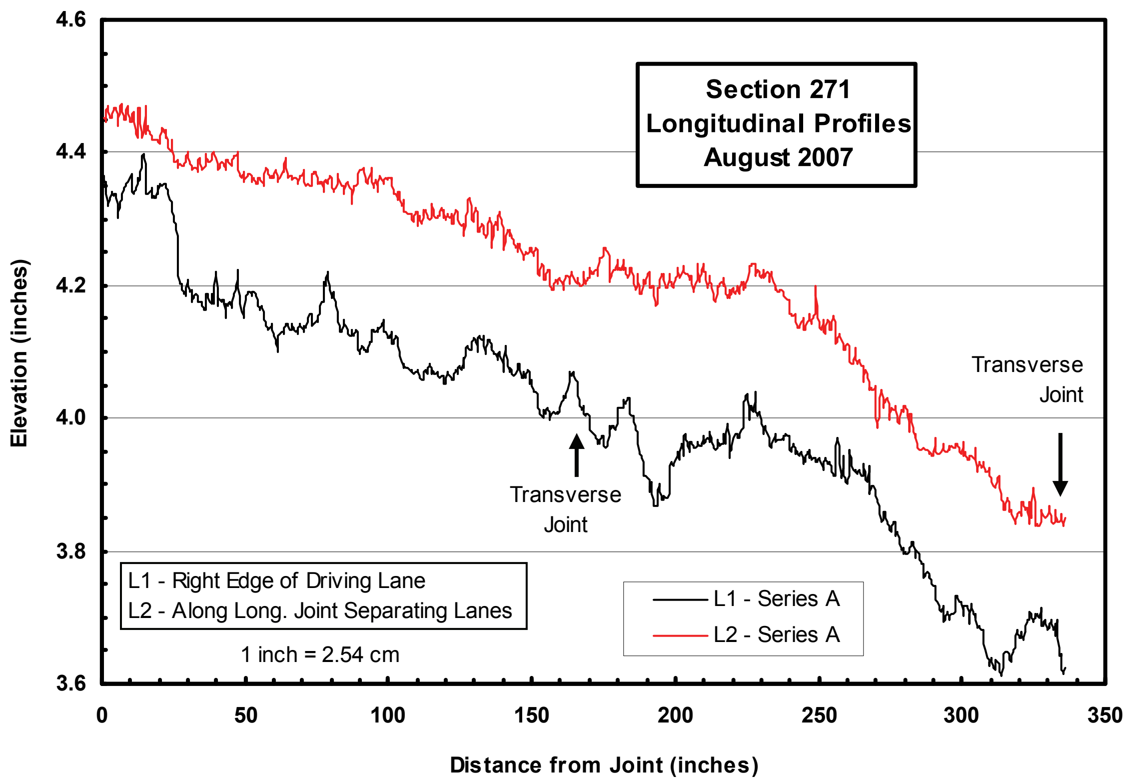


Figure 3.21 – Longitudinal and Transverse Profiles on Section 270 (1 in = 2.54 cm)



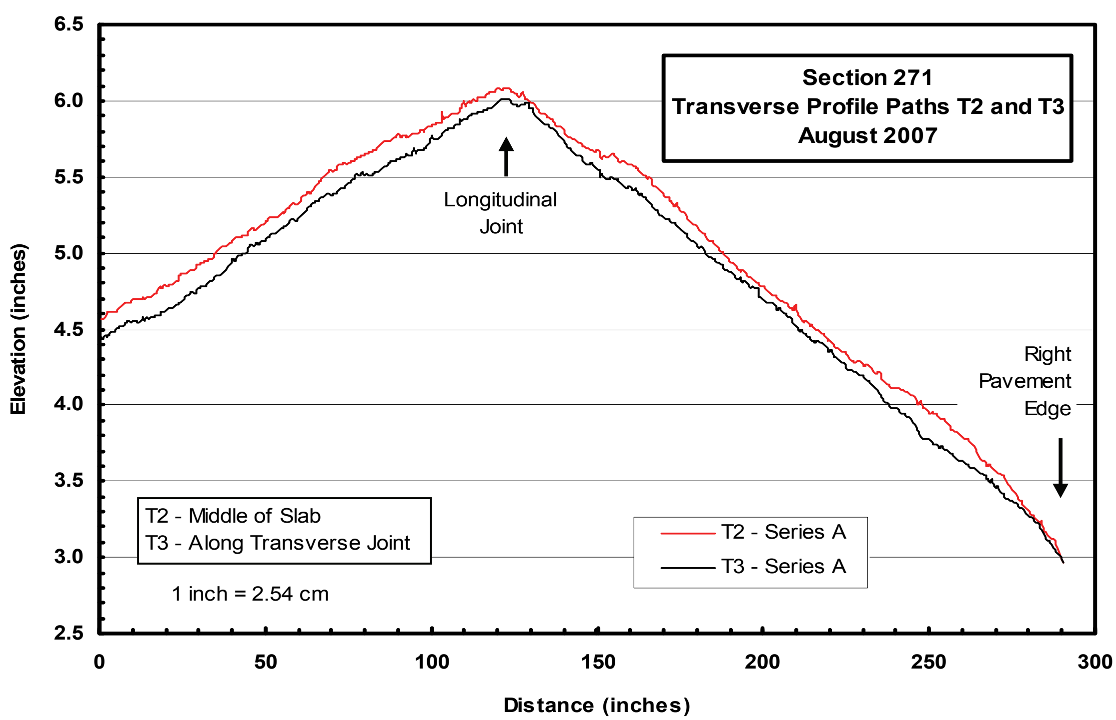
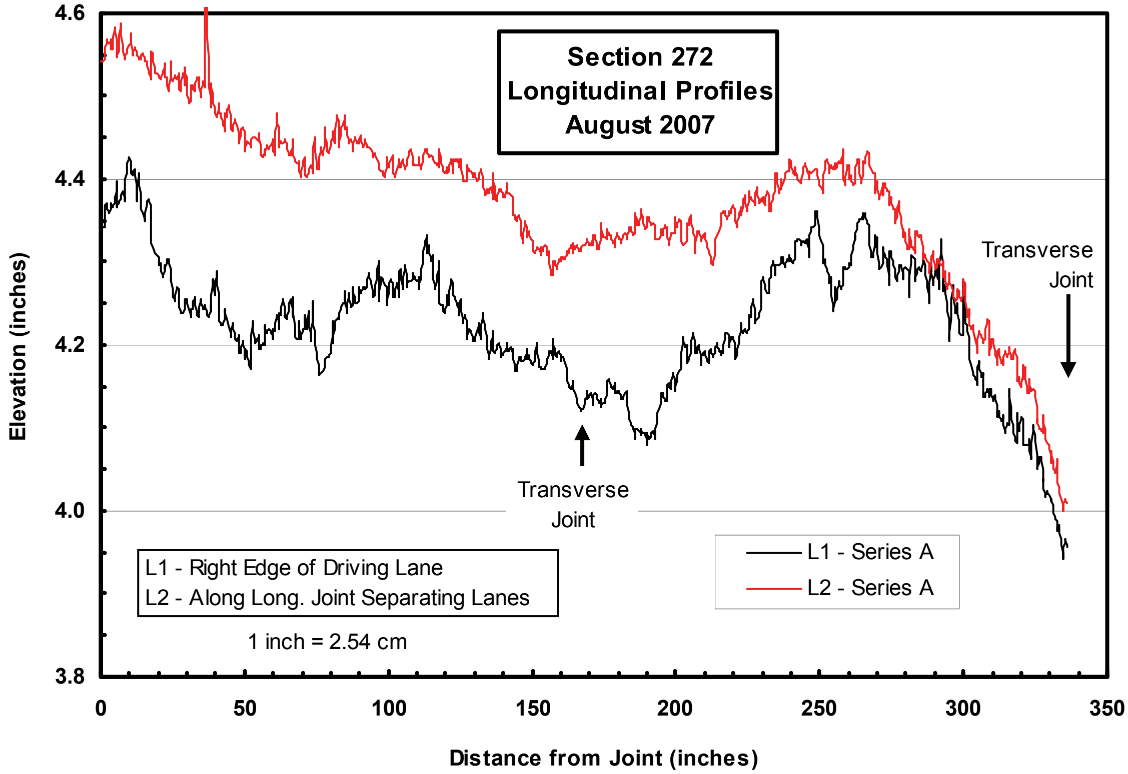


Figure 3.22 – Longitudinal and Transverse Profiles on Section 271 (1 in = 2.54 cm)



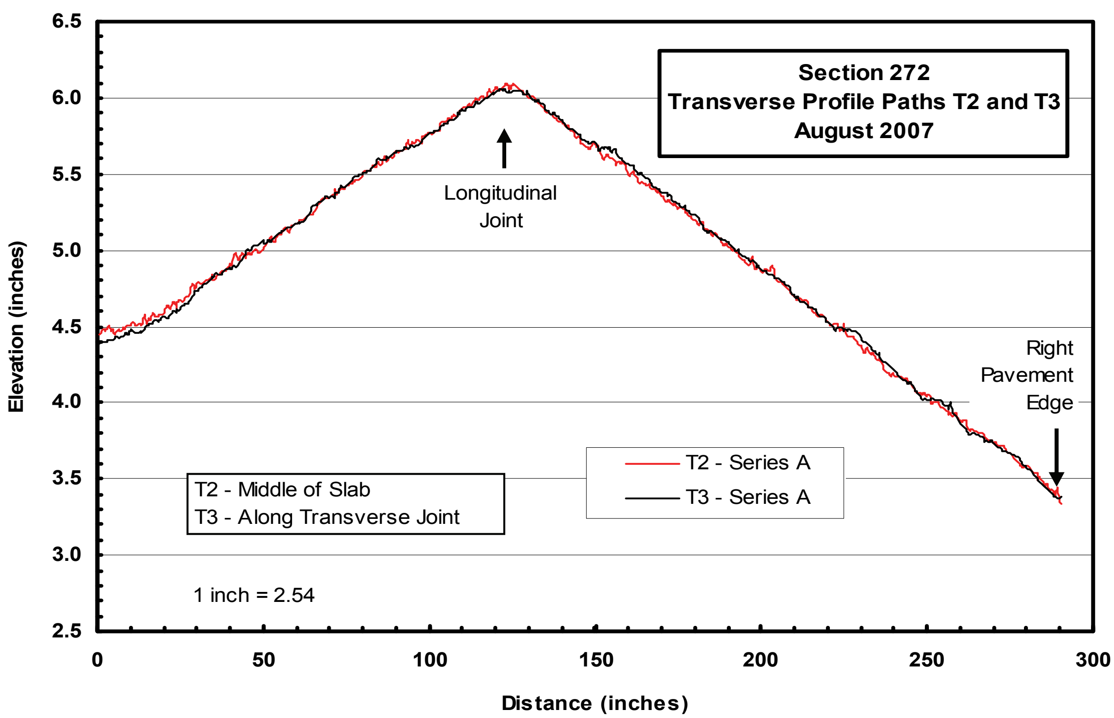


Figure 3.23 – Longitudinal and Transverse Profiles on Section 272 (1 in = 2.54 cm)

3.9 Water Tables

Nine piezometers were installed during construction of the Ohio SHRP Test Road in 1994-96, three ceased to function after a short time, and six have been monitored periodically since that time. Figure 3.24 provides a pictorial summary of the data. The piezometer in Section 102 was abandoned in September 1997, and the units in Sections 103 and 108 were no longer functional after June 2003. Of the six remaining piezometers, those in Sections 104, 108 and 201 consistently had the highest water tables. All piezometers showed typical annual cycles with the lowest levels being recorded in late fall to early winter months (September–February) and the highest levels showing up in late winter to early summer (March-June). As the number of observations decreased during 2003 – 2005, the annual cycles became less well defined.

3.10 TDR Measurements of Subgrade Moisture

A Time Domain Reflectometry (TDR) system was installed at Section 272 to monitor the moisture in the soil at the new sections. Results are shown in Figure 3.25, covering measurements made in July 2007 (average of three readings), August 2007 (average of three readings), and November 2007 (one reading). The top sensor was in the base. Below that the recorded moisture content lies in the 30%-40% range at all times recorded, with a few occasional outliers. Sensors 2 (depth 23 in (0.58 m)) and 8 (depth 59 in (1.50 m)) did not return any usable readings, and Sensors 5 (depth 41 in (1.04 m)) and 6 (depth 47 in (1.19 m)) gave readings only in November. The outlier for Sensor 4 (depth 35 in (0.89 m)) for August represents a single reading.

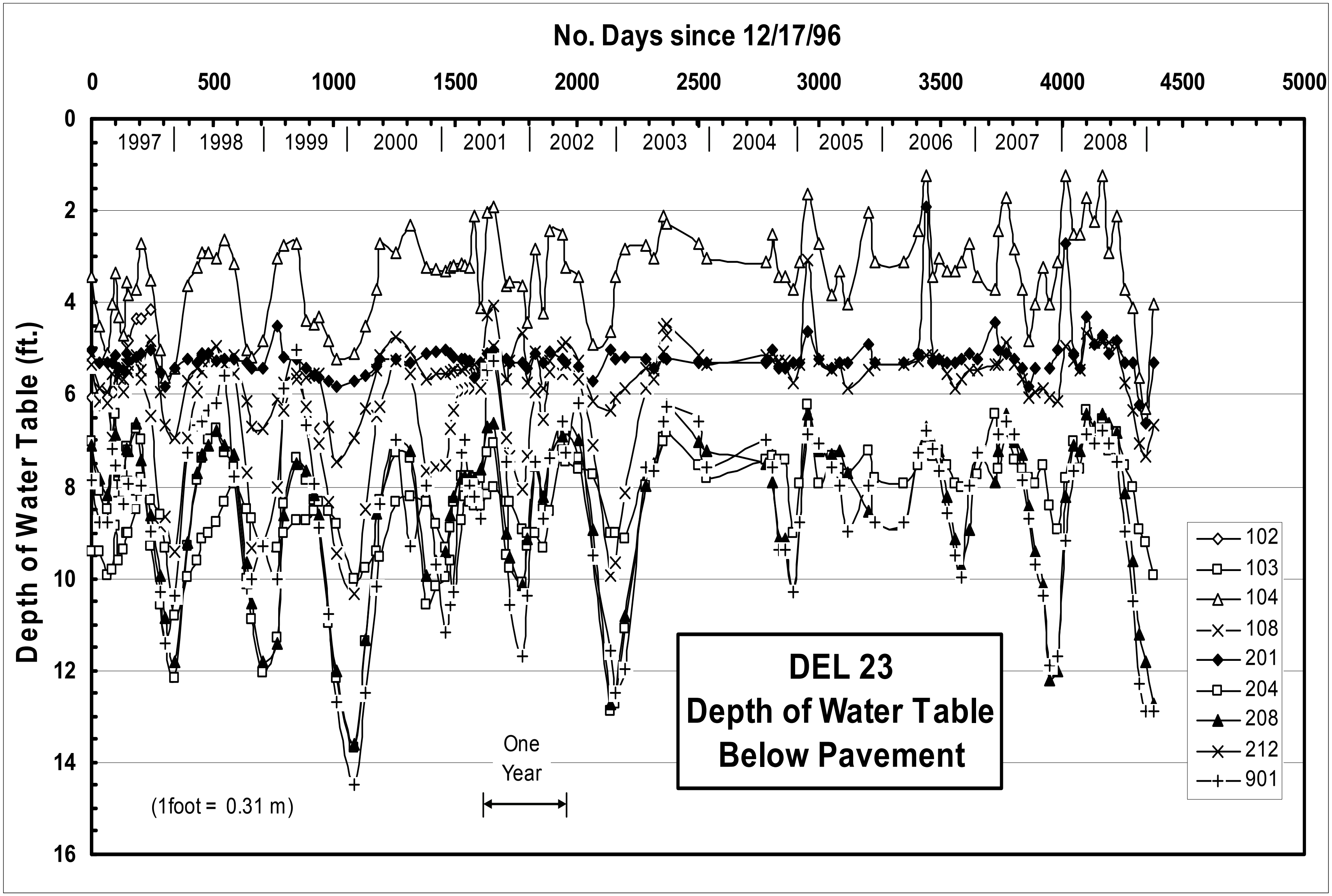


Figure 3.24 – Water Tables on DEL 23 (1 ft = 0.30 m)

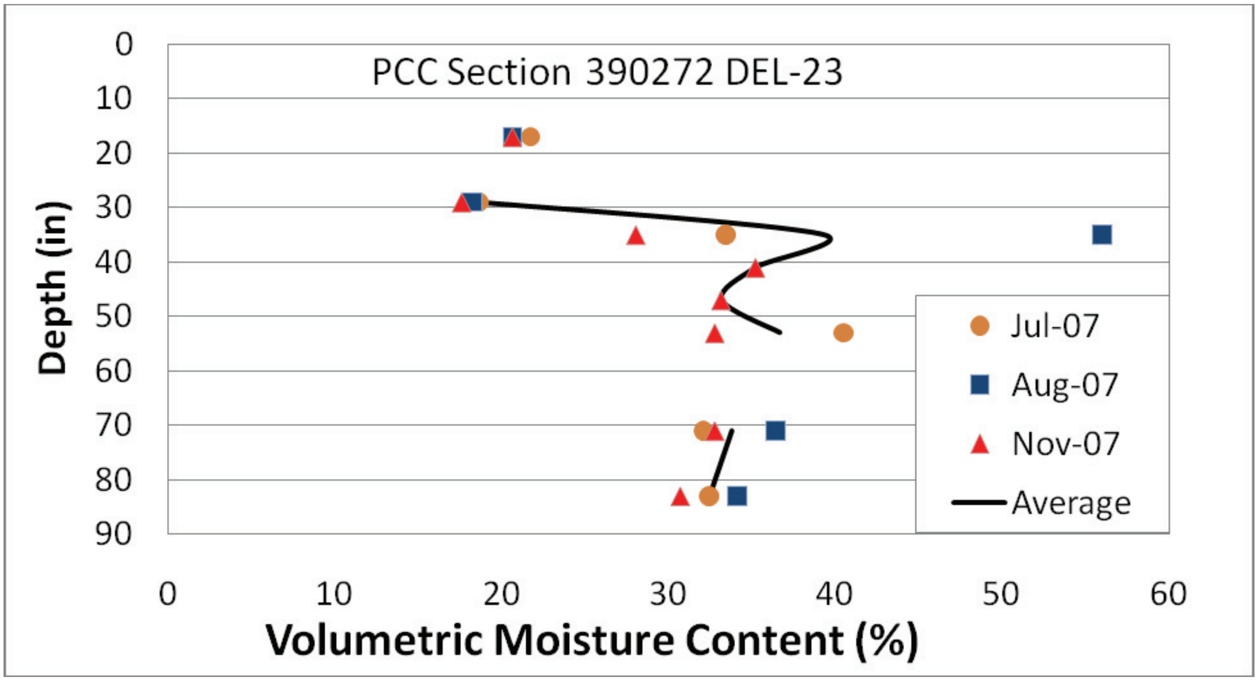


Figure 3.25 – Soil volumetric moisture content measured by TDR as a function of depth under PCC pavement at Section 390272 (1 in = .0254 m).

3.11 Distress Surveys and Forensic Analysis

Distress surveys were made of the instrumented slabs on DEL23 on June 13, 2007 and August 22, 2007, as noted in Appendix C. In June one crack was observed at Station 402+70, between Sections 208 and 207, and in August another crack was observed, at Station 325+00.

Visual inspection of the new sections on DEL-23 in June 2009, two years after construction, confirmed that the concrete had experienced premature distresses. Longitudinal cracks approximately two ft (0.61 m) from the longitudinal joints were identified in Sections 390268, 390270, and 290271. Figure 3.26 shows longitudinal cracks in each of those sections. Figure 3.27 shows some additional observed damage, including spalling and transverse cracking on Section 270 and a patch applied on Section 271 at a damaged joint.

Section 390268 Section 390270 Section 390271

Figure 3.26 – Longitudinal Cracking on PCC Slabs on DEL-23

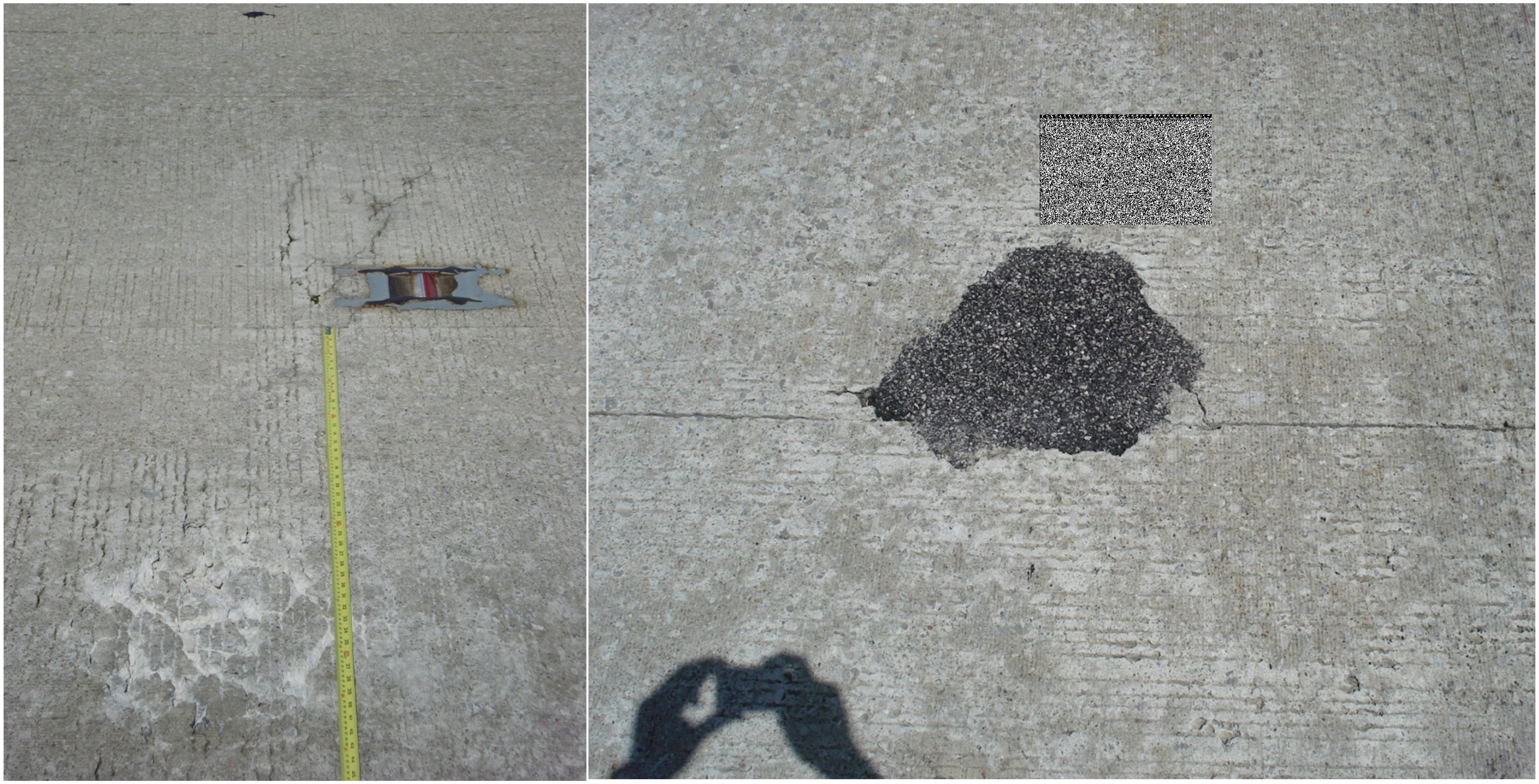


Figure 3.27 – Additional damage on DEL-23. At left spalling in front and cracking behind reflector on Section 270, at right a patch placed at a joint on Section 271

Three core samples were collected from a cracked slab in one of the damaged sections. The first sample came from the longitudinal joint. The core revealed that the saw cut was only 2 in (5.1 cm) deep, with no cracking at the base of the cut. The core showed that the thickness of the pavement was 12 in (30.5 cm). The second sample was taken from the longitudinal crack, located 1.5 ft (46 cm) from the longitudinal joint. Here the core showed that the pavement was 11.25 in (28.6 cm) thick. The third core was near the edge of the pavement, 1 ft (30 cm) from the outside shoulder. The pavement thickness as indicated by this concrete core was 12.25 in (31.1 cm). The compressive strength of this specimen was 5.24 ksi (36.1 MPa). Figure 3.28 shows the three cores.

Figure 3.28 – Concrete Cores from a Cracked Slab on DEL-23

Three samples were taken from a slab in the same section that did not have the surface cracking. The first concrete core came from the longitudinal joint. A 45 degree crack was found under the 2.25 in (5.71 cm) saw cut in the 11.25 in (28.6 cm) thick pavement. The second core, extracted from the middle of the slab, was 11 in (27.9 cm) deep. The compressive strength was 5.45 ksi (37.6 MPa). Finally, the third core, which was 1 ft (30 cm) from the outside shoulder, showed that the pavement was 12 in (30.5 cm) thick. The compressive strength of this specimen was 6.55 ksi (45.2 MPa). Figure 3.29 presents these cores; notice in the left core the crack at 45 degrees starting at the bottom of the saw cut.

Figure 3.29 – Concrete Cores from a Non-Cracked Slab on DEL-23

<u>3.11.1 Conclusions of the Forensic Analysis</u>

During the visual inspection of the new PCC sections on DEL-23 performed in June of 2009, longitudinal cracks were observed in Sections 390268, 390270, and 390271. The subsequent forensic investigation revealed that the concrete was not uniform in thickness. Also, the depths of the saw cuts at the longitudinal joints were inconsistent, and some did not have the required depth. For an 11 in (27.9 cm) thick pavement, the ODOT standard design stipulates that the saw cut must have a minimum depth of one-third of the design pavement thickness, which is 3.667 in (9.31 cm). The cuts along the longitudinal joint were not deep enough to force crack formation at the joint, and in addition, the length of the cores taken showed that the concrete at the longitudinal joint was almost 1 in (2.54 cm) thicker than at the location of the crack. In other words, the concrete found a weaker place to crack, where the pavement was thinner and there was no presence of restraining tie bars.

In section 390269, the crack was under the saw cut. The concrete pavement was 0.75 in (1.9 cm) thinner than at the inner wheel path (where the crack appeared on the other sections). Also the depth of the cut was 2.25 in (5.71 cm), 0.25 in (6.4 mm) more than in the cracked slab. These mistakes made during the construction, such as the non-uniform pavement thickness and the shallow cuts on the longitudinal joints, caused the observed longitudinal surface cracking.

The longitudinal cracks in the test sections were the result of improper construction techniques that were not but should have been discovered during routine construction inspections. The shallow saw cuts and the varying concrete thickness along the project created these longitudinal cracks. A "soft saw" saw was used to cut the longitudinal joints. Further investigation needs to be done to reveal if this was the right method for the type of concrete mixes used in DEL-23. Another likely source of the problem that needs to be clarified was the timing of the saw cut. During the first hours after placing the concrete, tensile stresses develop, if these stresses surpass the tensile strength of the concrete, cracks will start to appear. Therefore, it is crucial to make the saw cuts at the right time in order to control cracking in the slabs.

After eight months, the data from strain gauges at the top of the slab showed that Section 390269, the non-cracked section, was the only section where the compressive stresses were similar to the tensile stresses. The other sections did not have this symmetry around the neutral axis due to the early cracking.

3.12 Summary

Much of the data collected for this project has been incorporated into a computerized database, a copy of which has been placed on a DVD and attached to this report. Among the items included in the database are the following:

1. Detailed crack surveys of the AC test sections
2. Detailed crack surveys of the PCC test sections
3. Detailed water table depths from the piezometers
4. Dynamic response data from controlled vehicle tests
5. Climatic data from the on-site weather station

In reviewing FWD measurements obtained for the various pavements in this research, it became apparent that the ratio of the first and seventh geophone readings (Df1/Df7) was related to performance, especially on AC pavements. While not a precise measure of performance, Df1/Df7 can be used in the field to make a quick assessment of pavement condition as the FWD measurements are being recorded. To investigate this ratio further, FWD measurements made on the 40 AC and PCC test sections on the DEL-23 test pavement before they were opened to traffic were analyzed, and the results are shown in Appendix B. These 40 sections represent different levels of performance. On AC pavements, Df1/Df7 $\leq$ 5.0 indicates good performance, between 5.0 and 7.0 indicates fair performance, and > 7.0 indicates poor performance. Df1/Df7 is typically about 2.5 – 3.0 for PCC pavements and high level AC pavements.

The forensic analysis of the premature distresses observed on the new PCC sections on DEL-23 was conducted in June of 2009, after the original project data had been collected. Longitudinal cracking in particular was observed on Sections 390268, 390270, and 390271, and this was determined to be due primarily to a combination of insufficiently deep saw cuts at the longitudinal joint and reduced thickness under the inner wheel path where the cracking generally occurred.

Chapter 4
Other Instrumented Pavements in Ohio

4.1 ATH 33 - Nelsonville

A test of concrete maturity and durability was conducted on a segment of US Route 33 during a road reconstruction project in Nelsonville, Ohio. Three different mixes were compared: Mix A had 30% blast furnace slag and used #57 aggregate; Mix B had 30% blast furnace slag and used #357 aggregate; and Mix C was a standard ODOT mix with no slag and #57 aggregate. Sections of 1000 ft (305 m) were constructed using each mix. Half of each section was cured using wet burlap and the other half was cured using a spray-on membrane. In one slab in each half section, thermocouples were installed at the center and at one corner to monitor temperatures during curing.

The Mix C sections were first to be placed on April 23rd 2003. Air temperature on the evening of April 23rd and the morning of April 24th varied from 54° F (12° C) at midnight on April 23rd to a low of 37° F (3° C) at 6AM on April 24th. Air temperature reached 54° F (12° C) at noon on April 24th and continued to rise. Mix A and Mix B sections where placed on May 2nd 2003. Air temperature varied between 57 - 66° F (14 - 19 ° C) during placement of the concrete and the subsequent 12 hour period.

FWD measurements were obtained on this PCC pavement to determine vertical deflection of the slab ends and load transfer across the joints in the morning and afternoon of March 24, 2004. One set of measurements was run in the morning while the pavement temperature was uniform, and a second set of measurements was run in the afternoon after the pavement surface had warmed and a positive temperature gradient had built up in the pavement. The morning run started at 8:22 am and the afternoon run started at 2:34 pm. Both runs required about two hours to complete. Infrared thermometer readings indicated the surface temperature ranged from 42 – 44º F (6 -7° C) in the morning and from 60 – 61º F (16° C) in the afternoon.

Table 4.1 summarizes the normalized maximum deflection (Df1) in mils/kip and load transfer (LT) in percent as the FWD load plate was placed in the approach and leave positions at five joints in each of the six test sections. In the approach position, the load plate was located behind the joint and load transfer was calculated as Df3/Df1. In the leave position, the load plate was located just beyond the joint and load transfer was calculated as Df2/Df1. Geophone Df1 was at the center of the 300 mm (11.8 in.) diameter load plate, Geophone Df2 was 305 mm (12 in.) behind the center of the load plate, and Geophones Df3 was 305 mm (12 in.) in front of the center of the load plate, followed by Geophones Df4 – Df7. Subsequent FWD measurements were not possible because of problems maintaining traffic on US-33 through Nelsonville.

In general, maximum deflection and load transfer were about the same on all test sections when measured in the approach and leave positions. Data were quite consistent between the morning and afternoon runs, in that individual joints showing high or low readings in the morning showed similar trends in the afternoon. Load transfer was essentially the same on all sections and during both runs. Maximum deflection was higher on the water cured portion of Section A, about the same on both portions of Section B, and higher on the membrane cured portion of Section C. As would be expected, deflections consistently dropped in the afternoon as the surface warmed and the slab ends curled downward to improve support under the PCC slabs. The percent decrease in deflection from morning to afternoon was highest on the five water cured joints in Section A and on all ten joints in Section C. Individual joints with the most drop in deflection were Joints 8, 9 and 10 in Section A, and Joints 4, 7, 8, 9 and 10 in Section C. Some transverse cracking appeared at business entrances where high early strength concrete was used to accelerate curing and shorten the time to opening.

4.2 ATH 50 – Dowel Bars

In 1997, an experimental high-performance jointed concrete pavement was constructed on US-50 east of Athens Ohio. In this pavement, 25% of the Portland cement was replaced with ground granulated blast furnace slag and epoxy coated steel dowel bars were used at most joints. Stainless steel tubes filled with concrete were used in seven joints and fiberglass dowel bars were used in a six joints to compare their performance with seven joints of standard epoxy-coated steel bars. Figures 4.1 and 4.2 show how FWD deflection and load transfer in the right wheelpath have varied on these dowel bars since they were installed in 1997. Deflections at the three types of dowel bars varied widely over time, probably due to different temperature gradients in the pavement. Load transfer in the fiberglass bars was consistently 15-20% lower than the stainless tubes and epoxy-coated steel bars over the first six years of service, but then dropped dramatically to about 30% by late 2006 and remained at that level in 2008.

Table 4.1

FWD Measurements on ATH-33 (Nelsonville) – 3/24/04 (English units)

Maximum Deflection and Load Transfer on ATH-33 (Nelsonville) – 3/24/04										
Section	Curing	Joint	Morning				Afternoon			
			Approach		Leave		Approach		Leave	
			$Df1_A$ (mils/kip)	LT_A (%)	$Df1_L$ (mils/kip)	LT_L (%)	$Df1_A$ (mils/kip)	LT_A (%)	$Df1_L$ (mils/kip)	LT_L (%)
A	Membrane	1	0.42	93.9	0.39	100.7	0.42	93.3	0.40	96.5
		2	0.44	90.1	0.44	89.6	0.38	93.9	0.38	92.8
		3	0.51	86.3	0.52	85.1	0.51	82.7	0.44	89.1
		4	0.38	91.1	0.38	92.1	0.32	91.1	0.31	88.0
		5	0.41	92.8	0.43	87.3	0.36	98.3	0.42	82.4
		Avg.	0.43	90.8	0.43	91.0	0.40	91.9	0.39	89.8
	Water	6	0.45	86.4	0.42	89.1	0.40	94.4	0.42	86.4
		7	0.46	91.1	0.44	91.6	0.40	96.2	0.43	90.2
		8	0.66	91.5	0.78	79.1	0.58	81.6	0.51	91.0
		9	0.51	90.1	0.56	81.0	0.38	86.8	0.40	81.7
		10	0.60	86.3	0.56	89.2	0.43	96.0	0.48	85.8
		Avg.	0.54	89.1	0.55	86.0	0.44	91.0	0.45	87.0
B	Water	1	0.36	96.8	0.36	94.5	0.31	94.8	0.32	92.0
		2	0.43	92.0	0.41	94.3	0.37	92.9	0.36	100.0
		3	0.38	96.9	0.40	90.0	0.32	97.1	0.33	96.0
		4	0.38	92.0	0.36	96.7	0.32	94.2	0.32	92.9
		5	0.37	90.5	0.34	101.5	0.29	94.3	0.28	95.0
		Avg.	0.38	93.6	0.37	95.4	0.32	94.7	0.32	95.2
	Membrane	6	0.31	90.5	0.29	95.9	0.28	89.6	0.26	93.4
		7	0.32	92.4	0.31	93.3	0.28	95.6	0.29	88.5
		8	0.35	90.0	0.35	87.3	0.35	92.4	0.35	87.9
		9	0.37	93.2	0.38	91.8	0.35	94.3	0.33	93.6
		10	0.35	95.4	0.36	88.2	0.35	92.4	0.34	93.9
		Avg.	0.34	92.3	0.34	91.3	0.32	92.9	0.31	91.5
C	Water	1	0.49	87.8	0.49	87.0	0.41	92.3	0.42	89.6
		2	0.41	87.7	0.38	92.9	0.35	90.5	0.33	94.8
		3	0.34	92.7	0.34	89.4	0.30	92.6	0.30	91.5
		4	0.49	94.7	0.52	89.0	0.38	95.1	0.39	90.9
		5	0.30	96.1	0.33	87.8	0.26	93.8	0.27	90.3
		Avg.	0.41	91.8	0.41	89.2	0.34	92.9	0.34	91.4
	Membrane	6	0.44	91.8	0.45	87.9	0.40	92.6	0.39	92.2
		7	0.52	92.3	0.50	93.7	0.43	94.1	-	-
		8	0.52	93.3	0.53	89.0	0.44	90.0	0.45	89.6
		9	0.58	97.8	0.62	88.6	0.41	98.8	0.45	90.5
		10	0.59	94.4	0.61	89.9	0.44	96.9	0.49	91.1
		Avg.	0.53	93.9	0.54	89.8	0.42	94.5	0.45	90.9

Table 4.1 (continued)

FWD Measurements on ATH-33 (Nelsonville) – 3/24/04 (metric units)

Maximum Deflection and Load Transfer on ATH-33 (Nelsonville) – 3/24/04										
			Morning				Afternoon			
			Approach		Leave		Approach		Leave	
Section	Curing	Joint	$Df1_A$ (mm/MN)	LT_A (%)	$Df1_L$ (mm/MN)	LT_L (%)	$Df1_A$ (mm/MN)	LT_A (%)	$Df1_L$ (mm/MN)	LT_L (%)
A	Membrane	1	2.40	93.9	2.23	100.7	2.40	93.3	2.28	96.5
		2	2.51	90.1	2.51	89.6	2.17	93.9	2.17	92.8
		3	2.91	86.3	2.97	85.1	2.91	82.7	2.51	89.1
		4	2.17	91.1	2.17	92.1	1.83	91.1	1.77	88
		5	2.34	92.8	2.46	87.3	2.06	98.3	2.40	82.4
		Avg.	2.46	90.8	2.46	91	2.28	91.9	2.23	89.8
	Water	6	2.57	86.4	2.40	89.1	2.28	94.4	2.40	86.4
		7	2.63	91.1	2.51	91.6	2.28	96.2	2.46	90.2
		8	3.77	91.5	4.45	79.1	3.31	81.6	2.91	91
		9	2.91	90.1	3.20	81	2.17	86.8	2.28	81.7
		10	3.43	86.3	3.20	89.2	2.46	96	2.74	85.8
		Avg.	3.08	89.1	3.14	86	2.51	91	2.57	87
B	Water	1	2.06	96.8	2.06	94.5	1.77	94.8	1.83	92
		2	2.46	92	2.34	94.3	2.11	92.9	2.06	100
		3	2.17	96.9	2.28	90	1.83	97.1	1.88	96
		4	2.17	92	2.06	96.7	1.83	94.2	1.83	92.9
		5	2.11	90.5	1.94	101.5	1.66	94.3	1.60	95
		Avg.	2.17	93.6	2.11	95.4	1.83	94.7	1.83	95.2
	Membrane	6	1.77	90.5	1.66	95.9	1.60	89.6	1.48	93.4
		7	1.83	92.4	1.77	93.3	1.60	95.6	1.66	88.5
		8	2.00	90	2.00	87.3	2.00	92.4	2.00	87.9
		9	2.11	93.2	2.17	91.8	2.00	94.3	1.88	93.6
		10	2.00	95.4	2.06	88.2	2.00	92.4	1.94	93.9
		Avg.	1.94	92.3	1.94	91.3	1.83	92.9	1.77	91.5
C	Water	1	2.80	87.8	2.80	87	2.34	92.3	2.40	89.6
		2	2.34	87.7	2.17	92.9	2.00	90.5	1.88	94.8
		3	1.94	92.7	1.94	89.4	1.71	92.6	1.71	91.5
		4	2.80	94.7	2.97	89	2.17	95.1	2.23	90.9
		5	1.71	96.1	1.88	87.8	1.48	93.8	1.54	90.3
		Avg.	2.34	91.8	2.34	89.2	1.94	92.9	1.94	91.4
	Membrane	6	2.51	91.8	2.57	87.9	2.28	92.6	2.23	92.2
		7	2.97	92.3	2.86	93.7	2.46	94.1	-	-
		8	2.97	93.3	3.03	89	2.51	90	2.57	89.6
		9	3.31	97.8	3.54	88.6	2.34	98.8	2.57	90.5
		10	3.37	94.4	3.48	89.9	2.51	96.9	2.80	91.1
		Avg.	3.03	93.9	3.08	89.8	2.40	94.5	2.57	90.9

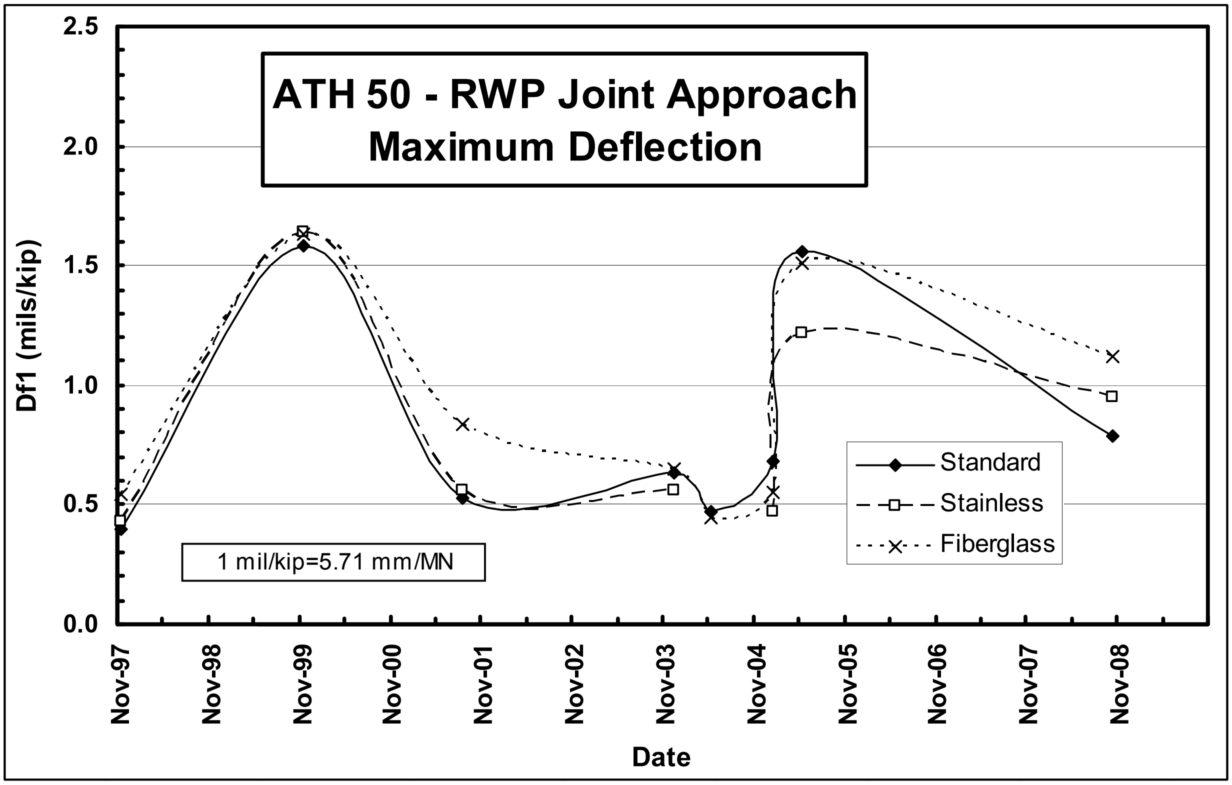


Figure 4.1 – FWD Dowel Bar Deflections on ATH-50

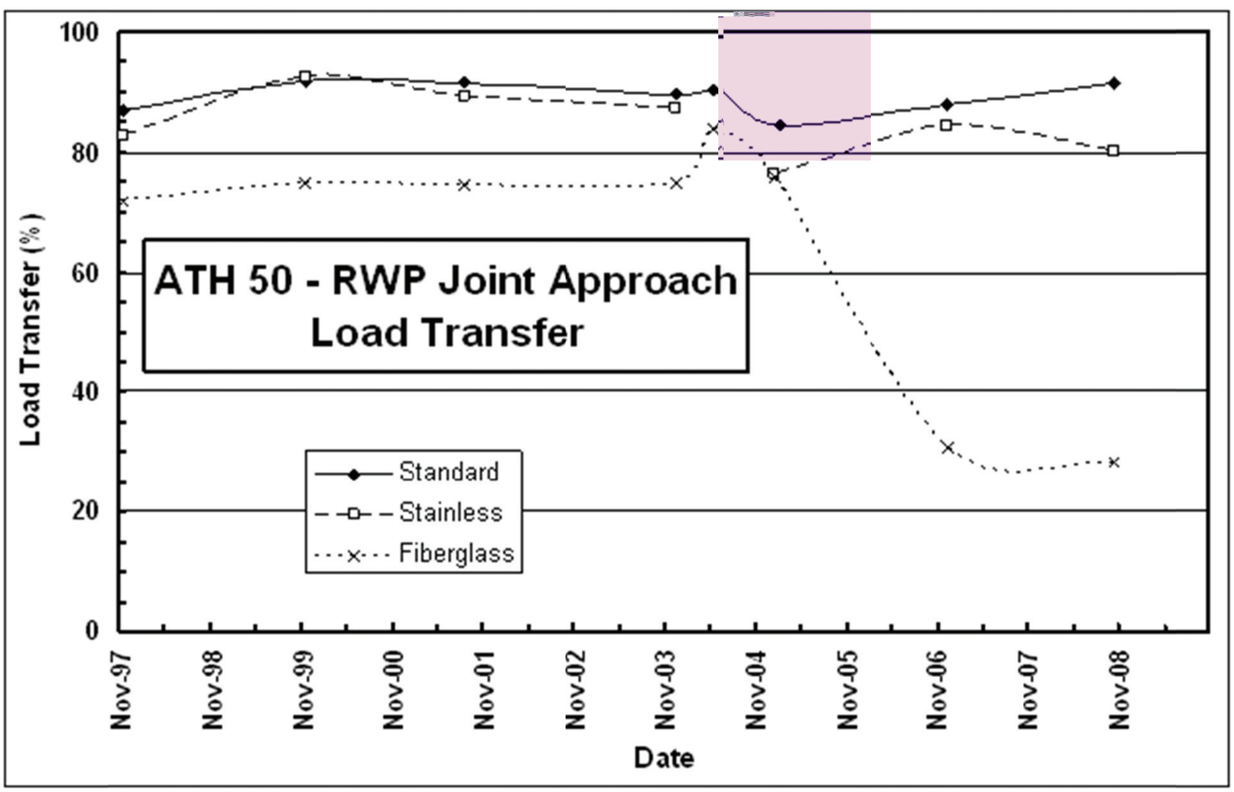


Figure 4.2 – Load Transfer of Dowel Bars on ATH-50

4.3 LOG 33

Five test sections were constructed on LOG 33 to evaluate the effects of different drainable bases on the overall performance of AC pavement. All sections had an 11-inch AC pavement thickness. Base materials included: 4 inches (10.2 cm) of asphalt-treated free-draining base (ATFDB) over 4 inches (10.2 cm) of 304 DGAB, 4 inches (10.2 cm) of cement-treated free-draining base (CTFDB) over 4 inches (10.2 cm) of 304 DGAB, ODOT 307 aggregate with a New Jersey gradation (307NJ) over 4 inches (10.2 cm) of 304 DGAB, ODOT 307 aggregate with an Iowa gradation (307IA) over 4 inches (10.2 cm) of 304 DGAB, and 8 inches (20.3 cm) of ODOT 304 aggregate. A sixth section with 6 inches (15.2 cm) of 304 DGAB was added to compare with the 8 inch (20.3 cm) DGAB section. PCR monitoring was halted after Novachip was placed on all sections after the 2001 evaluation. Additional surface treatments have been applied since 2001. Figure 4.3 shows FWD deflections, Figure 4.4 shows Spreadability, and Figure 4.5 shows Df1/Df7 measured on the six sections. LOG 33 was rehabilitated in 2009, after these measurements were made.

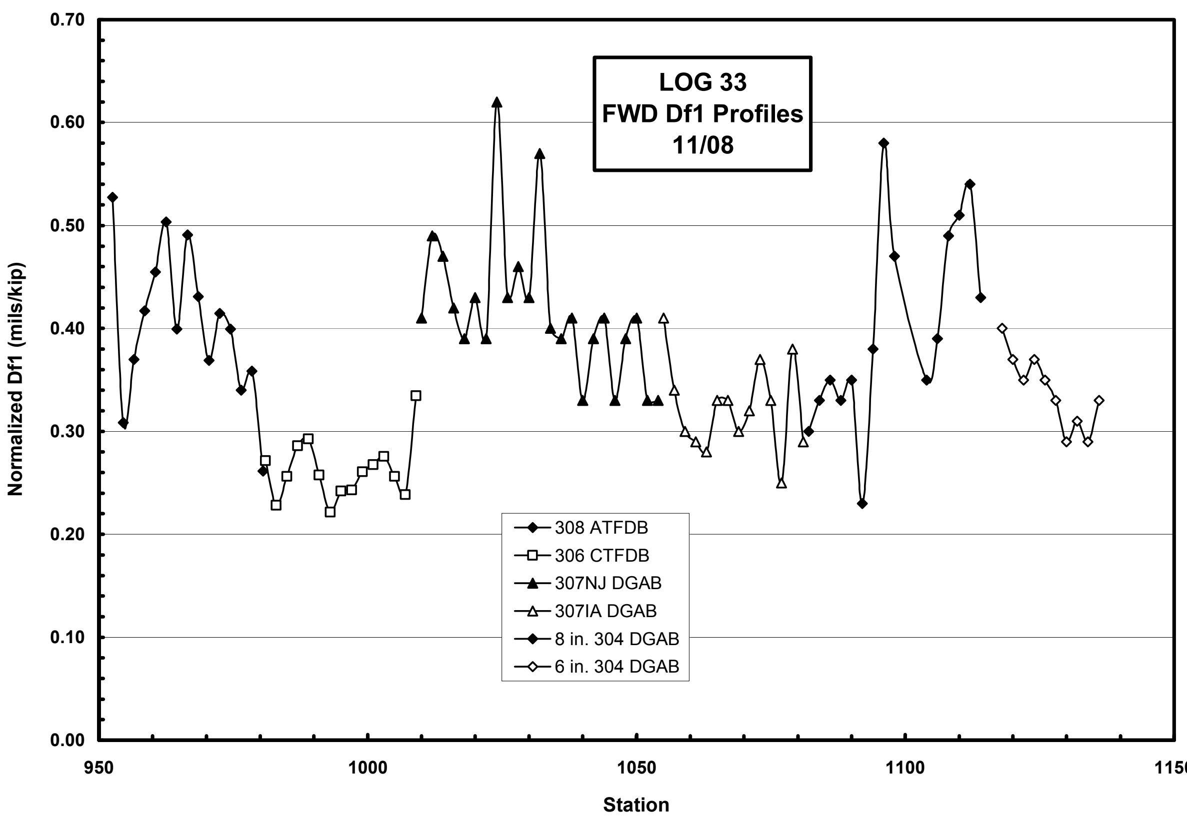


Figure 4.3 – Maximum Deflections on LOG-33

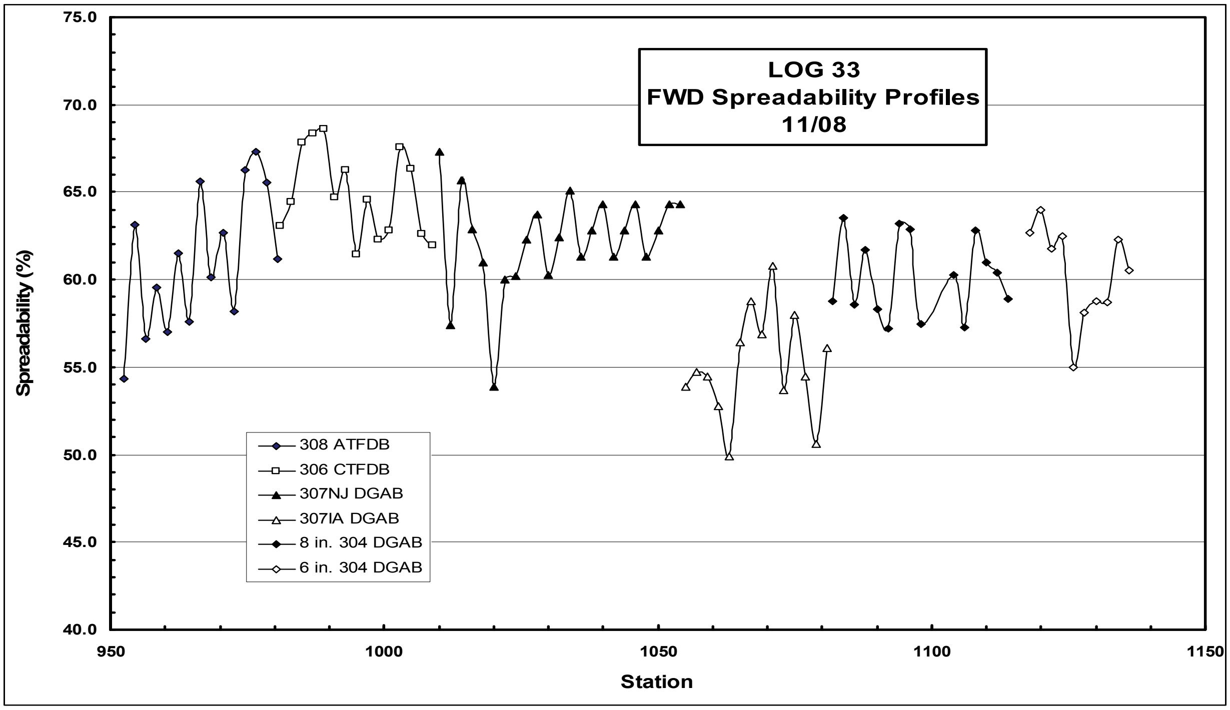


Figure 4.4 - Spreadability on LOG-33

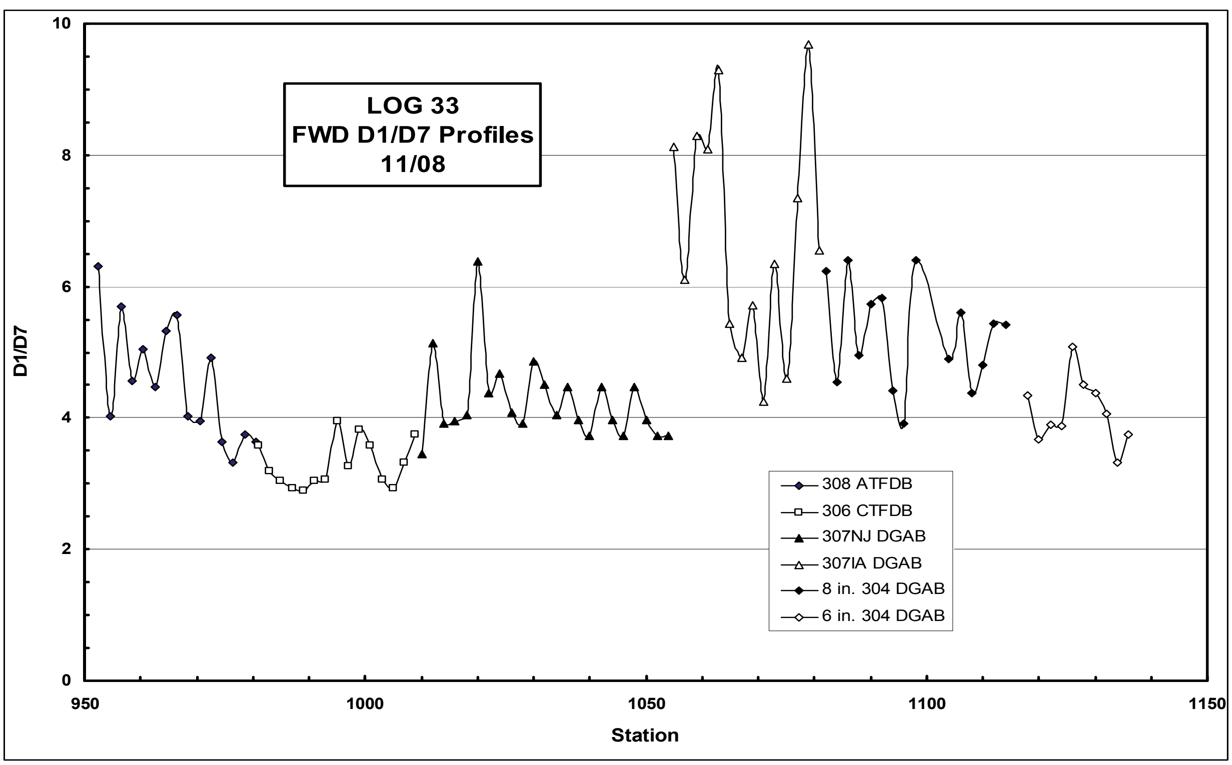


Figure 4.5 – Df1/Df7 on LOG-33

4.4 MEG 33

A 10-inch (25.4 cm) thick PCC pavement in Meigs County was constructed partly on sandy subgrade and partly on clay subgrade between Stations 1117+00 and 1465+50 in 2001. Sections were selected in both areas to evaluate the performance of sealed and unsealed joints. Intuitively, the sandy subgrade would drain better and, therefore, be expected to provide better performance. Figures 4.6 - 4.8 show plots of maximum deflection Df1, Df7 and Df1/Df7 at midslab, while Figures 4.9 and 4.10 show plots of maximum joint approach deflection and load transfer across these sections.

With the exception of a zone between Slabs 4-6 on the clay subgrade with sealed joints, most trends in FWD parameters were relatively consistent over the section lengths. Sections on the sandy subgrade had higher deflections at midslab and at joints, but a lower Df1/Df7 ratio and better load transfer than sections on the clay subgrade. The unusually high deflections around Slabs 4-6 on the clay subgrade with sealed joints, and the extremely low load transfer at Joint 5 were probably caused by a localized area of high moisture in the subgrade.

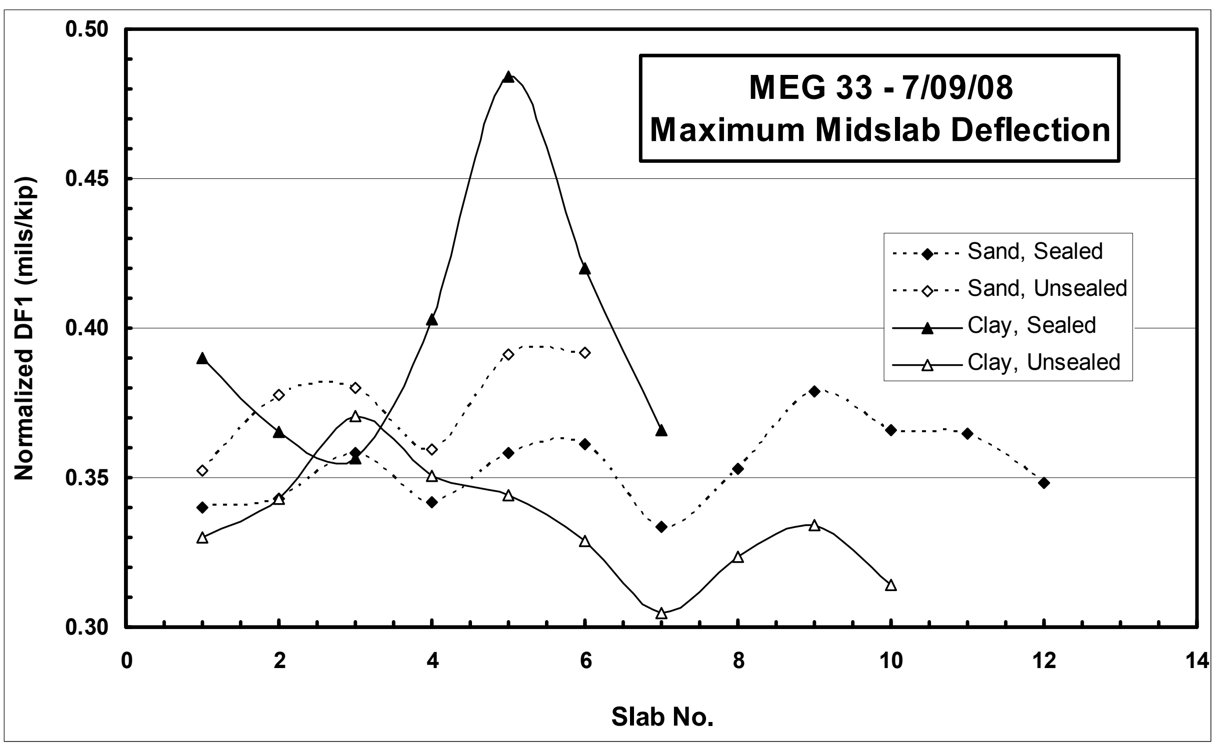


Figure 4.6 – Maximum Midslab Deflection on MEG-33

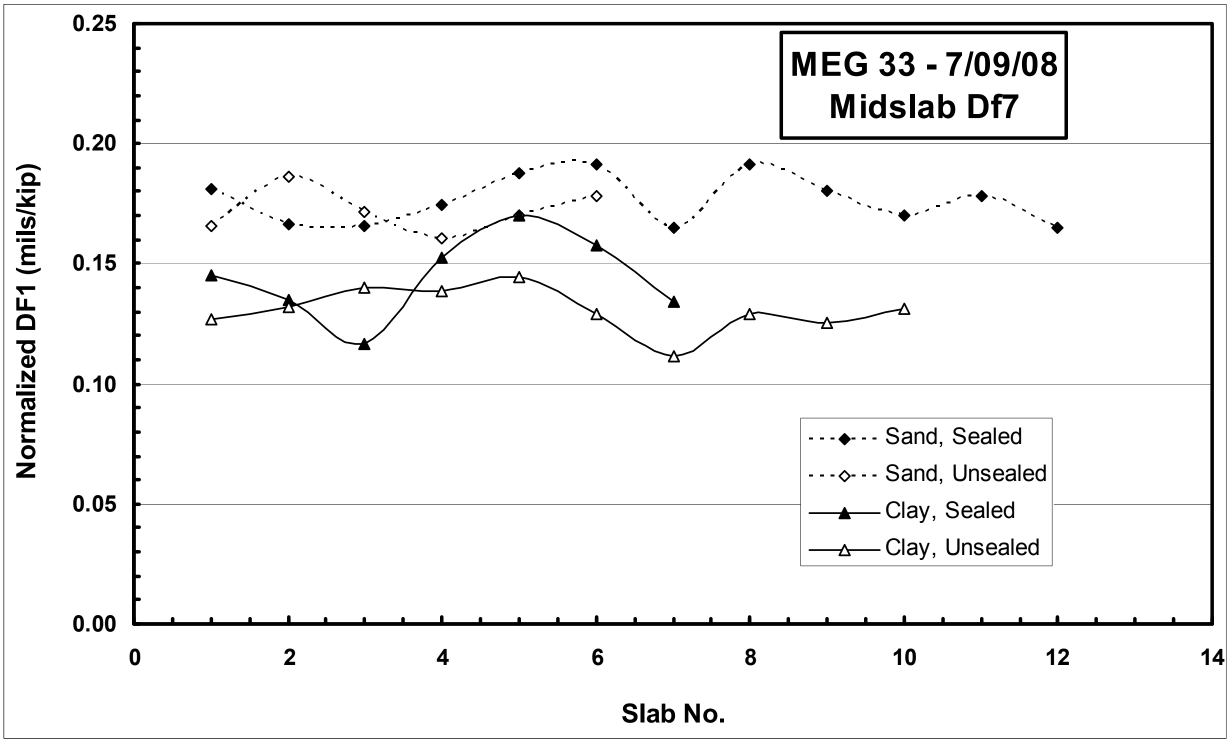


Figure 4.7 - Midslab Df7 on MEG 33

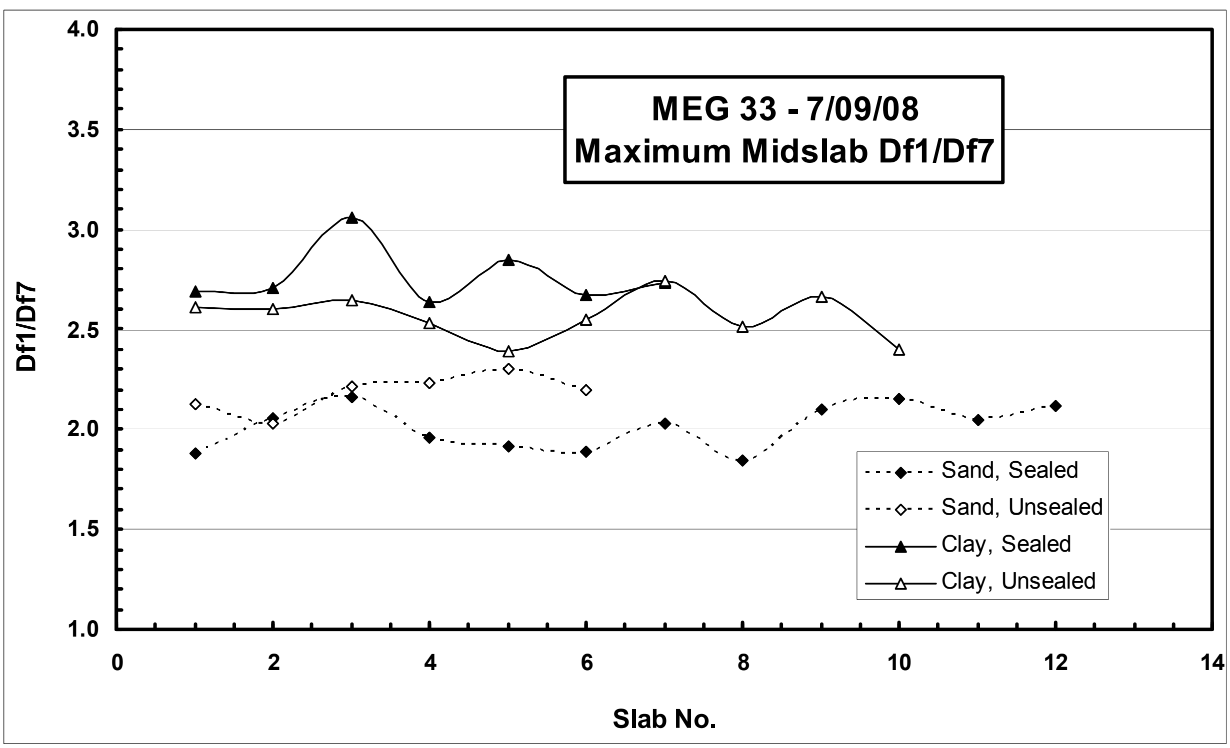


Figure 4.8 - Midslab Df1/Df7 on MEG 33

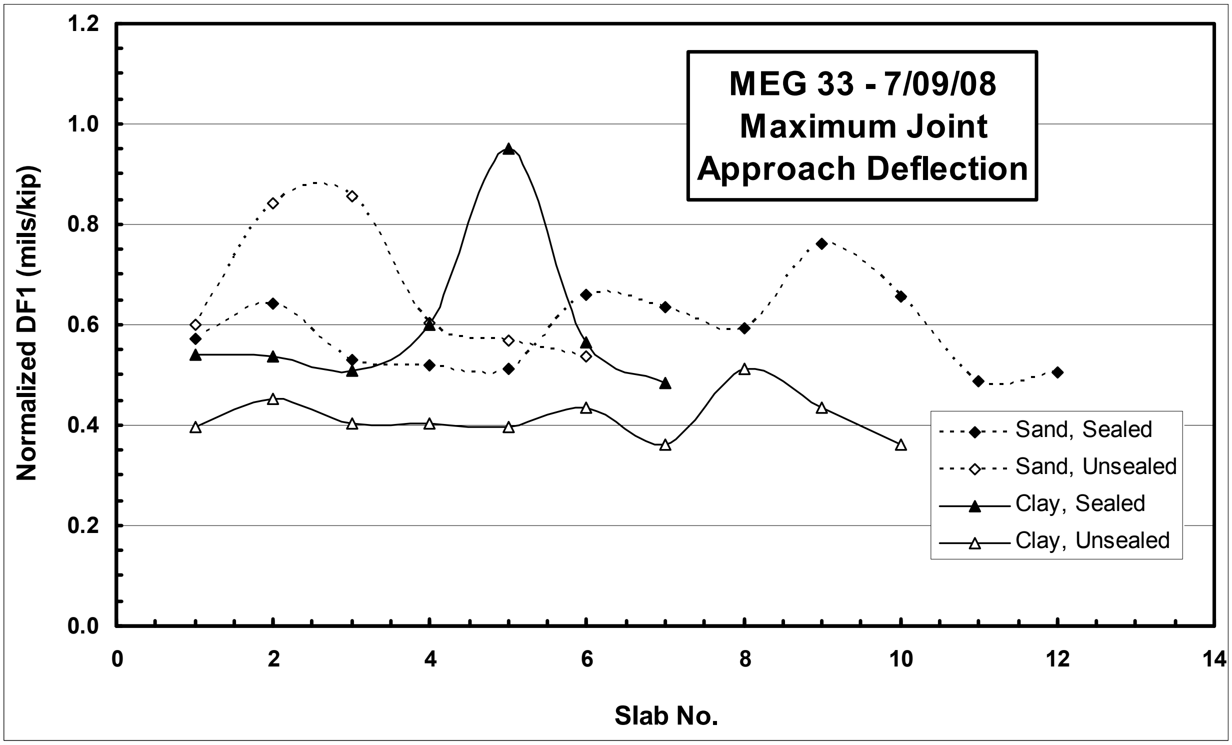


Figure 4.9 - Maximum Joint Approach Deflection on MEG 33

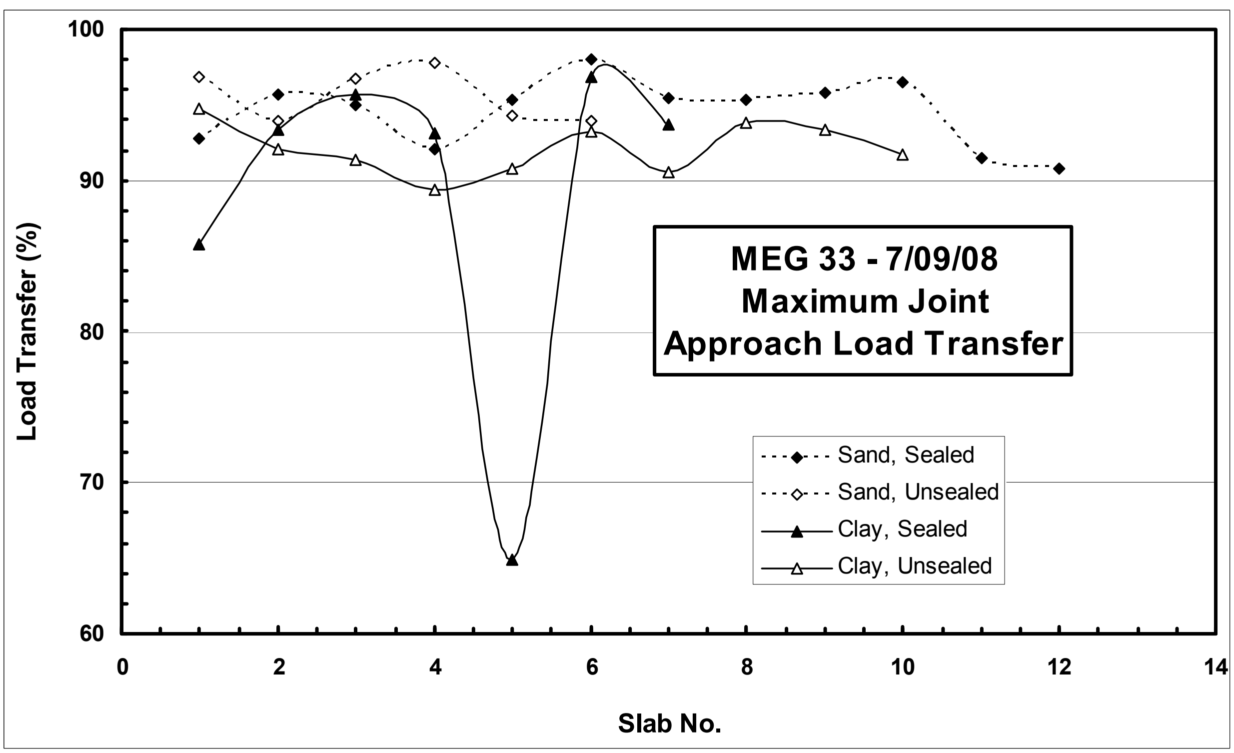


Figure 4.10 - Maximum Joint Approach Load Transfer on MEG 33

Laboratory tests were performed on samples of the sandy and clay subgrades to determine dielectric constants and volumetric moisture contents (Ref. 5). Table 4.2 gives the gravimetric moisture content of all the soil samples collected for the clayey subgrade. The gravimetric moisture content is converted into volumetric moisture content using density of the subgrade soil compacted in the box. Volumetric moisture contents are plotted against dielectric constants in Figure 4.11. The dielectric constants are obtained from the waveform traces collected at the same time the soil samples were collected to obtain the gravimetric moisture content. Table 4.3 and Figure 4.12 show the same information for the sandy subgrade.

On 4/18/08, the following conditions were noted at the MEG 33 site: some joint seals were partially removed from the joints, there was one longitudinal crack at Station 1246+90, and there were some minor surface defects between Stations 1247+00 and 1242+00.

Table 4.2

Gravimetric Moisture Content for Clay Subgrade (1 kg = 2.20 lb)

Volume of Soil			0.0191	m^3	Weight of Soil + Bucket		37.5	kg
					Weight of Bucket		4.4	kg
Bulk Density of Soil			1732.98	kg/m^3	Weight of Soil		33.1	kg
No.	**Vol. of Water (liters)**	**Wt. of Can**	**Wt. of Soil +Can (wet)**	**Wt. of Soil (wet)**	**Wt. of Soil + Can (dry)**	**Wt. of Soil (dry)**	**Gravimetric Water Content**	**Volumetric Water Content**
1	0	12.2	19.2	7.0	19.0	6.8	0.0294	0.0510
2	1	10.9	19.6	8.7	18.9	8.0	0.0875	0.1516
3	1	12.2	21.7	9.5	20.9	8.7	0.0920	0.1594
4	1	10.8	21.7	10.9	20.8	10.0	0.0900	0.1560
5	1	10.9	19.8	8.9	19.3	8.4	0.0595	0.1032
6	2	12.2	20.8	8.6	20.0	7.8	0.1026	0.1777
7	2	10.9	16.8	5.9	16.4	5.5	0.0727	0.1260
8	2	12.2	23.5	11.3	22.5	10.3	0.0971	0.1683
9	3	10.8	21.4	10.6	20.3	9.5	0.1158	0.2007
10	3	10.9	18.7	7.8	18.0	7.1	0.0986	0.1709
11	3	12.2	22.8	10.6	21.8	9.6	0.1042	0.1805
12	4	10.9	26.9	16.0	25.1	14.2	0.1268	0.2197
13	4	10.8	27.3	16.5	25.4	14.6	0.1301	0.2255
14	4	12.2	27.6	15.4	25.7	13.5	0.1407	0.2439
15	5	10.9	34.6	23.7	31.2	20.3	0.1675	0.2903
16	5	12.2	36.7	24.5	33.3	21.1	0.1611	0.2792

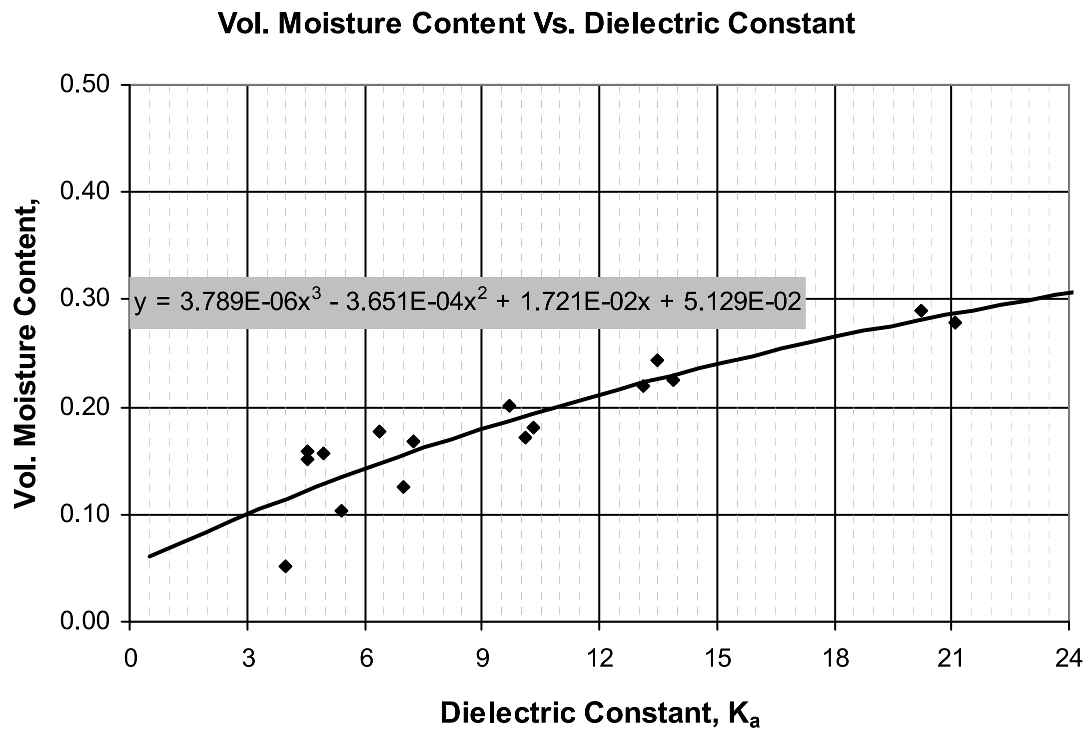


Figure 4.11 – Moisture Equation for Clay Subgrade

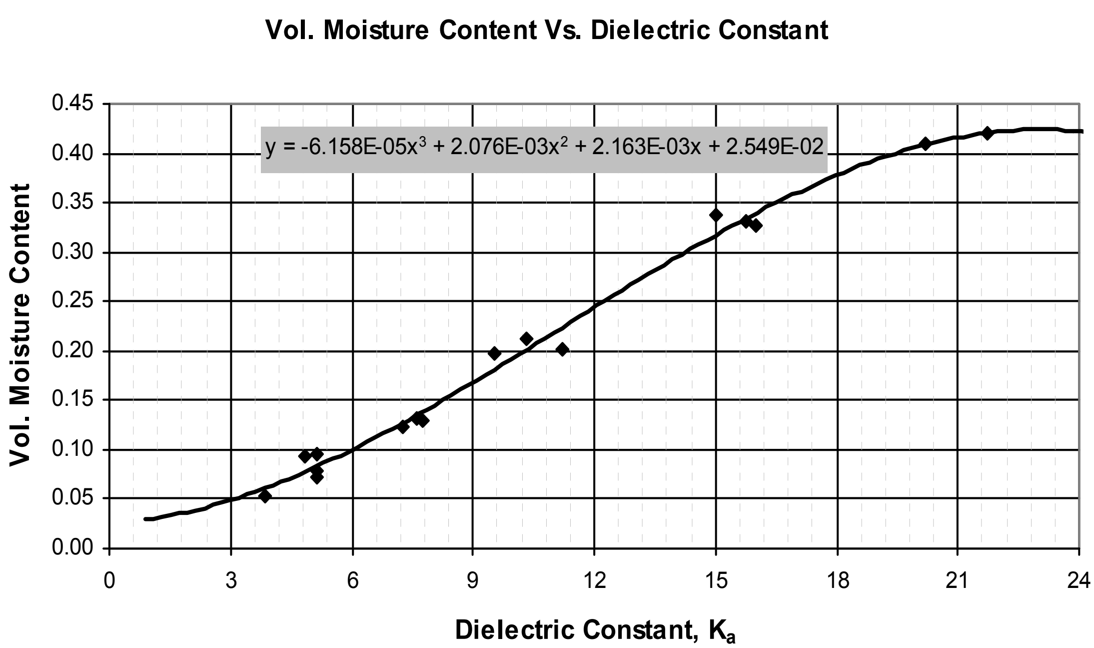


Figure 4.12 – Moisture Equation for Sandy Subgrade

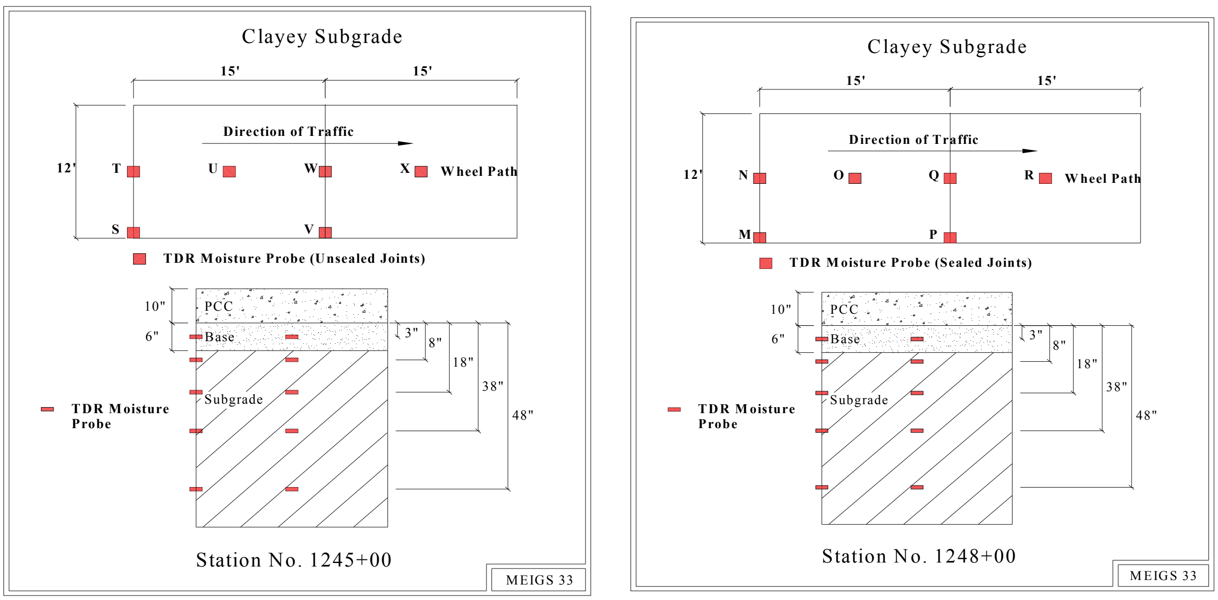
Table 4.3

Gravimetric Moisture Content for Sandy Subgrade (1 kg = 2.20 lb)

Volume of Soil			0.0191	m^3	Weight of Soil + Bucket		38.2	kg
					Weight of Bucket		4.6	kg
Bulk Density of Soil			1759.16	kg/m^3	Weight of Soil		33.6	kg
No.	**Vol. of Water (liters)**	**Weight of Can**	**Weight of Soil + Can (wet)**	**Wt. of Soil (wet)**	**Wt. of Soil + Can (dry)**	**Wt. of Soil (dry)**	**Gravimetric Water Content**	**Volumetric. Water Content**
1	0	12.2	19.0	6.8	18.8	6.6	0.0303	0.0533
2	1	10.9	22.5	11.6	22.0	11.1	0.0450	0.0792
3	1	12.2	23.9	11.7	23.3	11.1	0.0541	0.0951
4	1	10.8	22.6	11.8	22.0	11.2	0.0536	0.0942
5	1	10.9	23.7	12.8	23.2	12.3	0.0407	0.0715
6	2	12.2	27.5	15.3	26.5	14.3	0.0699	0.1230
7	2	10.9	22.6	11.7	21.8	10.9	0.0734	0.1291
8	2	10.8	25.1	14.3	24.1	13.3	0.0752	0.1323
9	3	10.9	28.8	17.9	27.0	16.1	0.1118	0.1967
10	3	12.2	28.9	16.7	27.1	14.9	0.1208	0.2125
11	3	10.8	31.3	20.5	29.2	18.4	0.1141	0.2008
12	4	10.9	28.3	17.4	25.5	14.6	0.1918	0.3374
13	4	12.2	22.3	10.1	20.7	8.5	0.1882	0.3311
14	4	10.9	26.2	15.3	23.8	12.9	0.1860	0.3273
15	5	10.8	27.2	16.4	24.1	13.3	0.2331	0.4100
16	5	10.9	24.9	14.0	22.2	11.3	0.2389	0.4203

TDR cables were installed under four sections of the Meigs County pavement. Each installation consisted of 6 cables placed under different positions in two adjoining slabs. Sections 1 and 2 had a clay subgrade and Sections 3 and 4 had a sandy subgrade. Sections 1 and 3 had unsealed joints Sections 2 and 4 had sealed joints. The configuration of the TDR cables is given in Figure 4.13 for Sections 1 and 2 and in figure 4.14 for Sections 3 and 4. Figure 4.15 shows the moisture readings from Sections 1 and 2 in July 2008, calculated using the equation in Figure 4.11. Figure 4.16 shows the moisture readings from Sections 3 and 4 in July 2008, calculated using the equation in Figure 4.12. Many readings from Sections 1 and 2 had to be omitted due to malfunctioning or saturated sensors.

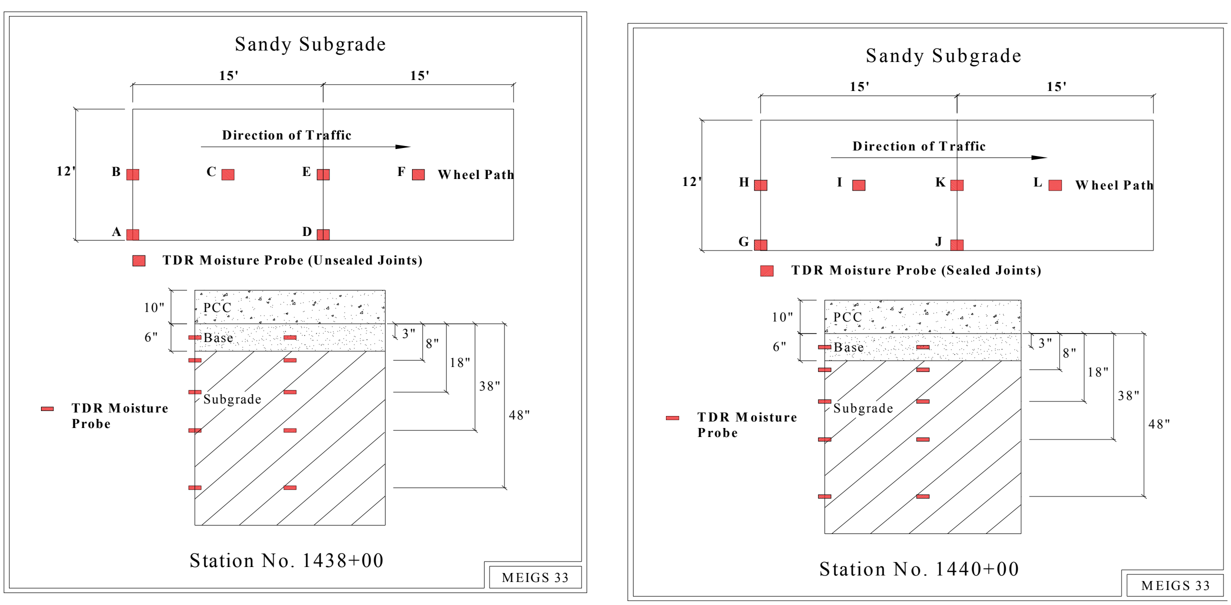
Distress survey results for MEG-33 are given in Appendix C. The notes mention some loss of joint seals, one longitudinal crack, and some minor surface defects. The loss of joint seals may explain the lack of significant differences seen between sealed and unsealed joints in Figure 4.14



Section 1

Section 2

Figure 4.13 – TDR Positions in Clay Subgrade on MEG-33



Section 3

Section 4

Figure 4.14 TDR Positions in Sandy Subgrade on MEG-33

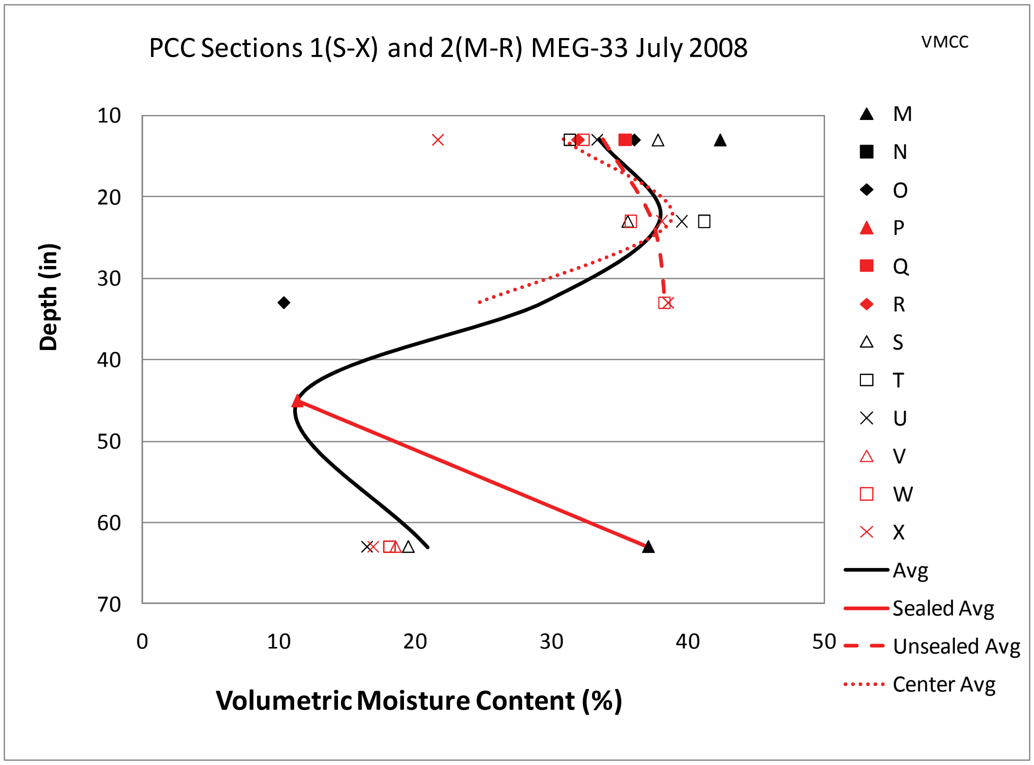


Figure 4.15 – Soil volumetric moisture content measured by TDR as a function of depth under MEG-33 Sections 1 and 2 (clay subgrade) July 2008 (1 in = .0254 m).

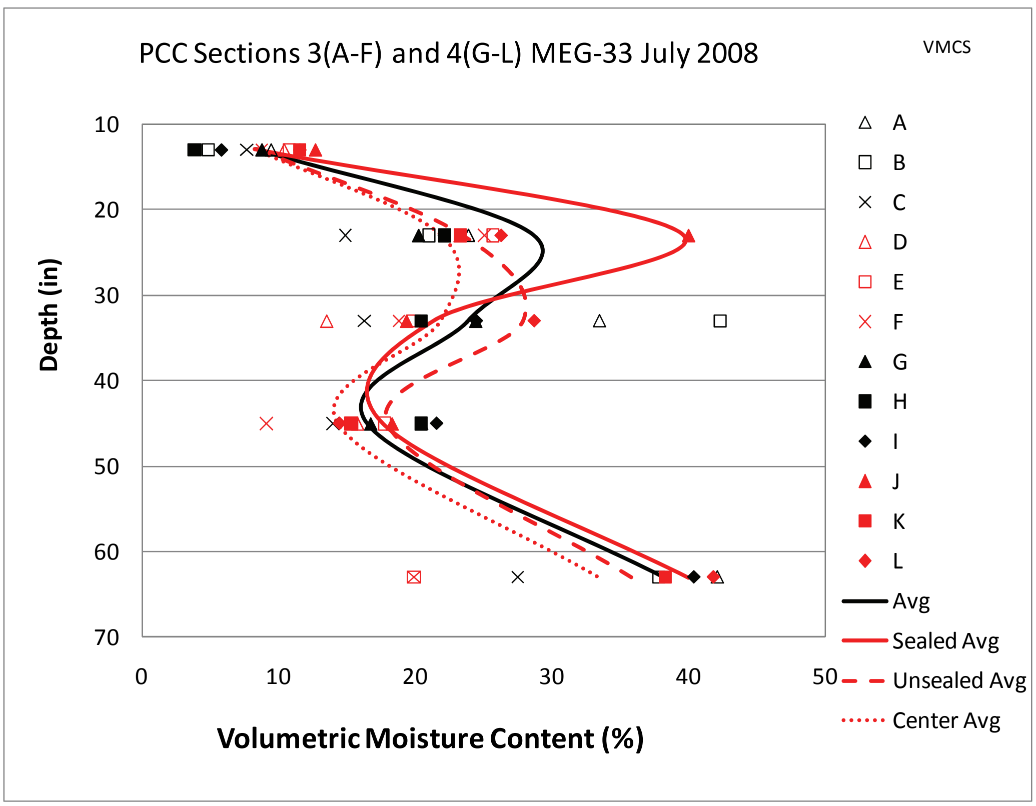


Figure 4.16 – Soil volumetric moisture content measured by TDR as a function of depth under MEG-33 Sections 3 and 4 (sandy subgrade) July 2008 (1 in = .0254 m).

4.5 STA 77

The first perpetual AC pavement in Ohio was constructed on I-77 in the City of Canton. The build-up was as follows:

1.5 in. (3.8 cm) ODOT 856 stone mastic wearing course with PG 76-22M polymer modified binder
1.75 in. (4.5 cm) ODOT 442 Superpave, Type A leveling course, with PG 76-22M polymer modified binder
9 in. (22.9 cm) ODOT 302 large stone ATB with PG 64 -22 asphalt binder
4 in. (10.2 cm) Modified ODOT 302 fatigue resistant ATB with 3 % air voids and 94 - 97% density
6 in. (15.2 cm) ODOT 304 crushed granular base with underdrains

The following instrumentation was installed in the NB right-hand driving lane near Station 234+00:

6 Dynatest strain gauges 1 inch (2.5 cm) from the bottom of the 302 mix

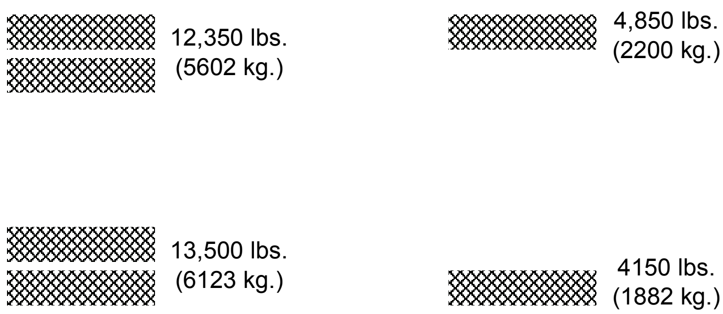
2 Pressure cells at the top of the subgrade

2 Thermocouples near and at the same depth as the strain gauges

Controlled vehicle tests were conducted on the late evening of December 15, 2003. This time was selected because of the large volume of traffic at the site, and the difficulty of setting up an effective traffic control zone which allowed trucks to approach the sensors at the prescribed speeds and still protected those at the site. Figure 4.13 shows various parameters associated with the tests. The data obtained from these tests are on a CD attached to this report.

No further monitoring has been done at this site because of the high volume of traffic.

STA-77 Controlled Vehicle Tests - 12/15/03



Single-Axle Dump Truck Wheel Weights

Time	Pavement Temperatures		
	Thermo. I	Thermo. II	Surface
10:30 PM	36° F (2° C)	36° F (2° C)	32° F (0° C)
11:30 PM	36° F (2° C)	36° F (2° C)	33° F (1° C)
12:29 AM	36° F (2° C)	36° F (2° C)	31° F (-1° C)

Truck Run Data					
Run No.	Nominal Speed mph (kph)	Offset inches (cm)	Run No.	Nominal Speed mph (kph)	Offset inches (cm)
1	Creep		9	Aborted	
2	Creep		10	Creep	12 (30.5)
3	30 (48)		11	Creep	-12 (-30.5)
4	30 (48)		12	Creep	0
5	30 (48)		13	50 (80)	
6	40 (64)	Perfect	14	50 (80)	
7	40 (64)		15	50 (80)	
8	40 (64)				

Figure 4.17 – STA-77 Controlled Vehicle Test Data

Chapter 5
Analysis of WAY-30 AC and PCC Sections using the Mechanistic-Empirical Pavement Design Guide Software and Site-Specific Data

A new analysis of the WAY30 AC and PCC pavements was performed using the Mechanistic/Empirical Pavement Design Guide Software (MEPDG v. 1.100). The analyzed sections correspond to the Station 876+60 eastbound with PCC pavement and Station 876+60 westbound with AC pavement. In an earlier analysis of the same sections [Sargand, Figueroa and Romanello, 2008] with version 0.992 of the MEPDG software, default material properties were used. For this updated analysis, actual site-specific measurements of material properties of the subgrade soil, subbase material, base, Portland concrete and asphalt concrete obtained in the laboratory and field were input into the MEPDG software for each pavement section. Much of these data were collected as part of a separate research project [Sargand, Masada, Hernandez, Kim, 2010]. Recommended values from the AASHTO *Mechanistic-Empirical Pavement Design Guide: A Manual of Practice* [AASHTO, 2008] were used when actual data were not available. Below the source and value of each datum used is reported. The default values previously used were general averages for the entire United States, and not specific to conditions in this part of Ohio. Note that all the values in the simulation were entered and retrieved in English units, and metric equivalents are reported for convenience. Also, traffic inputs were updated using data gathered from the weigh-in-motion (WIM) station on WAY-30.

It should also be noted that the software was calibrated using national pavement data only, rather than data specific to the Wayne County region of Ohio. As a result, these findings should still be considered preliminary and utilized and interpreted with caution.

5.1 Input Values

5.1.1 Performance Criteria

The values of terminal International Roughness Index (IRI), maximum percentage of slabs cracked, and maximum mean faulting were taken for a primary road from the Mechanistic-Empirical Pavement Design Guide: A Manual of Practice [p.74 AASHTO 2008]. Note that these values needed to be assumed since they represent values that might occur in the future rather than actual observations. These values are summarized in Table 5.1 and Table 5.2 for the PCC and AC section respectively. The simulation was extended out to 20 years. For all relevant parameters, the reliability was specified at 50%, so the predictive curves indicate mean values. In some graphs horizontal lines indicate design limits.

Table 5.1. PCC performance parameters

Initial IRI	63 in/mi	0.000994 m/m
Terminal IRI	172 in/mi	0.00271 m/m
Amount of Slabs Cracked	15%	15%
Mean joint faulting	0.12 in	0.30 cm

Table 5.2. AC performance parameters

Initial IRI	63 in/mi	0.000994 m/m
Terminal IRI	172 in/mi	0.00271 m/m
AC surface down cracking - longitudinal cracking	2000 ft/mi	0.379 m/m
AC bottom up cracking – alligator cracking	20%	20 %
AC thermal fracture – transverse cracking	700 ft/mi	0.133 m/m
AC permanent deformation – rutting	0.25 in	0.64 cm
Total permanent pavement deformation	0.5 in	1.27 cm

5.1.2 Traffic Data

Vehicle data from ODOT for WAY30 are summarized in Table 5.3. The data included are based on an analysis of a complete year (2009) of WIM data from ATR#779, located in the test road. The traffic counts reflect the number of large vehicles (e.g. trucks) per day, and do not include an additional 12,852 passenger vehicles (e.g. cars, Classes 1-3) per day that are assumed to cause no significant damage to the pavement. Though the WIM annual average daily truck traffic (AADTT) value was lower that ODOT Technical Services estimates from 2006 and 2009, it was assumed to be more accurate for purposes of applying the MEPDG software. Traffic was assumed to grow at a rate of 4% per year, for a total of 15,294,000 trucks estimated to pass over the PCC driving lane of WAY-30 road during the 20 year simulation, and 16,110,000 trucks estimated to pass over the AC driving lane. Full results from the analysis of the WAY30 WIM data appear in Appendix D.

The speed limit at the site is now 65 mph (105 km/h), and had been a split limit 65 mph (105 km/h) for cars and 55 mph (88.5 km/h) for trucks. The operational speed for Analyses C and D are based on an analysis of WIM speed data for 3230 trucks (ODOT Vehicle Class 4 and higher) on June 15, 2009. The percent trucks in design lane for Analyses C and D are based on an analysis of four-lane classifier data at the WIM site for June 1-28, 2009. Otherwise, the WIM-based counts and classification data used in Analyses C and D come from an analysis of twelve week-long samples of WIM data, one from each month of 2009. It should also be noted that for Analyses C and D, the actual values used in the software for AADTT is the total count for both lanes and the prevent of trucks in design direction and percent of trucks in design lane for east bound (EB) or west bound(WB) as noted in Table 5.3.

Table 5.3. Truck traffic data for WAY30 from Tech Services and from ATR #779

	EB - PCC	WB - AC	Both
2006 AADTT from Tech Services website	-	-	3800
2009 AADTT from Tech Services website	-	-	3690
2009 WIM data	1307	1390	2697
Number of lanes in design direction:	1	1	2
Percent of trucks in design direction (%):	48.6%	51.4%	-
Percent of trucks in design lane (%):	93.3%	92.9%	95
Operational speed (mph):			56.8 mph
Operational speed (km/h):			91.4 km/h
Traffic compound growth rate (assumed)			4 %

Table 5.4 shows a distribution by vehicle class, taken from an analysis of WIM data on WAY-30 by ORITE Research Engineer William Edwards. Table 5.5 shows the hourly truck distribution, also determined from the WAY-30 WIM data.

Table 5.4. AADTT distribution by vehicle class based on 2009 WIM data from ATR #779. Includes corrected estimate of Class 4 and 5 vehicles for January 2009.

Class	EB - PCC	WB - AC	Both
Class 4	1.10%	1.10%	1.10%
Class 5	15.70%	13.20%	14.40%
Class 6	6.76%	7.01%	6.89%
Class 7	4.18%	2.32%	3.22%
Class 8	7.84%	7.86%	7.85%
Class 9	61.34%	65.73%	63.60%
Class 10	2.45%	2.19%	2.32%
Class 11	0.28%	0.25%	0.26%
Class 12	0.27%	0.28%	0.27%
Class 13	0.06%	0.06%	0.06%

Table 5.5. ME-PDG hourly truck distribution based on 2009 WIM data from ATR #779.

Hourly truck traffic distribution by hour beginning:							
Hour	EB – PCC	WB – AC	Both	Hour	EB – PCC	WB – AC	Both
Midnight	1.6%	1.6%	1.6%	Noon	7.2%	7.3%	7.3%
1:00 am	1.6%	1.6%	1.5%	1:00 pm	6.9%	7.1%	7.0%
2:00 am	1.4%	1.4%	1.5%	2:00 pm	6.3%	6.9%	6.6%
3:00 am	1.6%	1.6%	1.8%	3:00 pm	5.9%	6.7%	6.3%
4:00 am	2.1%	2.1%	2.1%	4:00 pm	5.0%	5.6%	5.3%
5:00 am	3.0%	3.0%	2.8%	5:00 pm	4.3%	4.6%	4.4%
6:00 am	4.7%	4.7%	4.2%	6:00 pm	3.5%	3.5%	3.5%
7:00 am	5.6%	5.6%	5.1%	7:00 pm	2.8%	3.0%	2.9%
8:00 am	6.1%	6.1%	6.1%	8:00 pm	2.6%	2.4%	2.5%
9:00 am	6.6%	6.6%	6.6%	9:00 pm	2.4%	2.1%	2.3%
10:00 am	7.2%	7.2%	7.1%	10:00 pm	2.3%	2.0%	2.1%
11:00 am	7.3%	7.3%	7.2%	11:00 pm	1.9%	1.7%	1.8%

5.1.3 Climatic Data

The climatic data correspond to 110 months (July 1997 – May 2005) of weather station data from the Wayne County Airport in Wooster, Ohio, which the program selected based on the latitude, longitude, elevation, and water table depth input for the pavement site, as shown in Table 5.6.

Table 5.6. Location and water table depth of climatic station at Wooster, Ohio.

Latitude (degrees.minutes)	40.52	
Longitude (degrees.minutes)	-81.53	
Elevation	1130 ft	344 m
Depth of water table	100 ft	30.5 m

5.1.4 Pavement Layer Build-Up

The properties of the asphalt mix used in both sections are summarized below for each of the section. It is indicated in the presented tables whether the data corresponds to a property measured in the laboratory or if it is a value recommended by AASHTO (2008). Both AC and PCC sections were analyzed using the ME-PDG software, and the parameters used to simulate each pavement are described below.

The build-up of the AC pavement, as entered into the software, is shown in Table 5.7, while that for the PCC section is shown in Table 5.8. Each simulation was extended out to 20 years. For all relevant parameters, the reliability was specified at 50%, so the predictive curves indicate mean values. In some graphs horizontal lines indicate design limits set by the program.

Table 5.7. Asphalt Concrete section build-up

Layer	Temperature		depth	
	High	Low	(in)	(cm)
Stone Matrix Asphalt (SMA)	76°C (169°F)	-22°C (-7.6°F)	1.5	3.8
AC Superpave layer	76°C (169°F)	-22°C (-7.6°F)	1.75	4.45
ATB/AB	64°C (147°F)	-22°C (-7.6°F)	9.0	22.9
FRL/AB	58°C (136°F)	-22°C (-7.6°F)	4.0	10.2
DGAB			6.0	15.2
Subgrade A-4				

Table 5.8. Portland Cement Concrete section build-up

layer	depth	
	(in)	(cm)
PCC Surface	10	25.4
ATB/AB (Temperatures: High 64°C (147°F), Low -22°C (-7.6°F))	3.0	7.6
DGAB	4.0	10.2
Subgrade A-4	-	-

5.1.5 Subgrade and Subbase Materials

The properties of the subgrade and subbase material obtained in the field and lab tests were used for the analysis of each section. The subgrade soil type A-4 was selected for the subgrade and its properties are summarized in Table 5.9. The properties listed correspond to those that were changed from the default values in ME-PDG software. Similarly, the properties of the subbase material which was classified as an A-1a soil are summarized in Table 5.10.

The range of the measured subgrade modulus generally fell between 3 ksi (20.7 MPa) and 3.75 ksi (25.9 MPa), but could go as high as 5.45 ksi (37.6 MPa), for the PCC section (eastbound), as can be seen in Figure 5.1. For the AC section (westbound), values generally fell between 5.5 ksi (37.9 MPa) and 7.0 ksi (48.2 MPa), but could be as high as 9.91 ksi (68.3 MPa), as can be seen in Figure 5.2. For the subbase material, modulus values of up to 25 ksi (172 MPa) were obtained, as shown in Figure 5.3. The average (mean) modulus values were used instead, as these values are expected to represent typical performance on WAY30. These values are also listed.

Table 5.9. Subgrade (A-4 soil) additional material properties. Specimen STA 876+60

Property	Value	Source
Resilient Modulus (PCC section)	3707 psi (25.56 MPa)	Average value from field test
Resilient Modulus (AC section)	6846 psi (47.20 MPa)	Average value from field test
Plastic index (PCC section)	9.43%	Value from lab test
Plastic index (AC section)	8.23%	Value from lab test
Liquid limit (PCC section)	26.7%	From lab test
Liquid limit (AC section)	25.9%	From lab test
Material passing sieve #200 (PCC section)	38.2%	From lab test
Material passing sieve #200 (AC section)	39.3%	From lab test
Poisson's ratio	0.35	Assumed value
DGAB K_0	0.5	Derived by software

Table 5.10. Subbase (A-1a soil) additional material properties.

Property	Value	Source
Resilient Modulus	14813 psi (102.13 MPa)	Average value from field test
Poisson's ratio	0.35	Assumed value
DGAB K_0	0.5	Derived by software

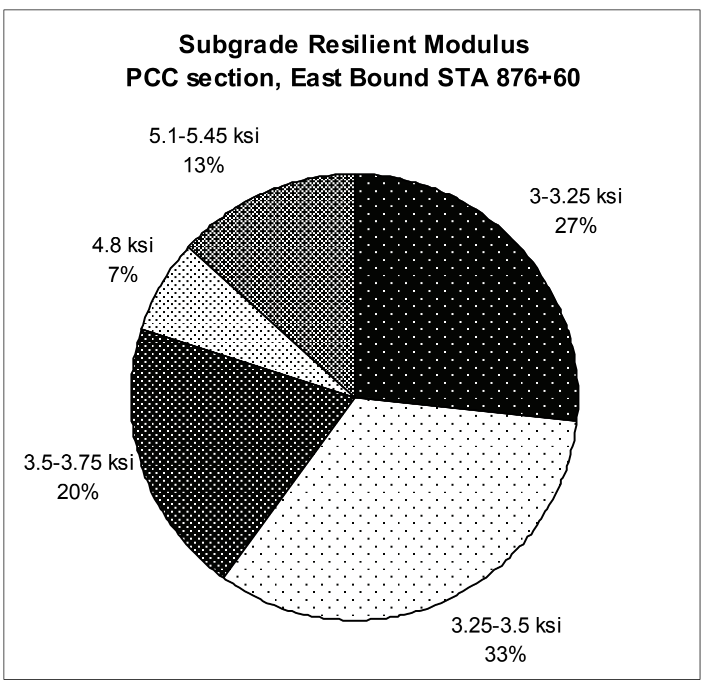


Figure 5.1. Subgrade Resilient Modulus values PCC Section.

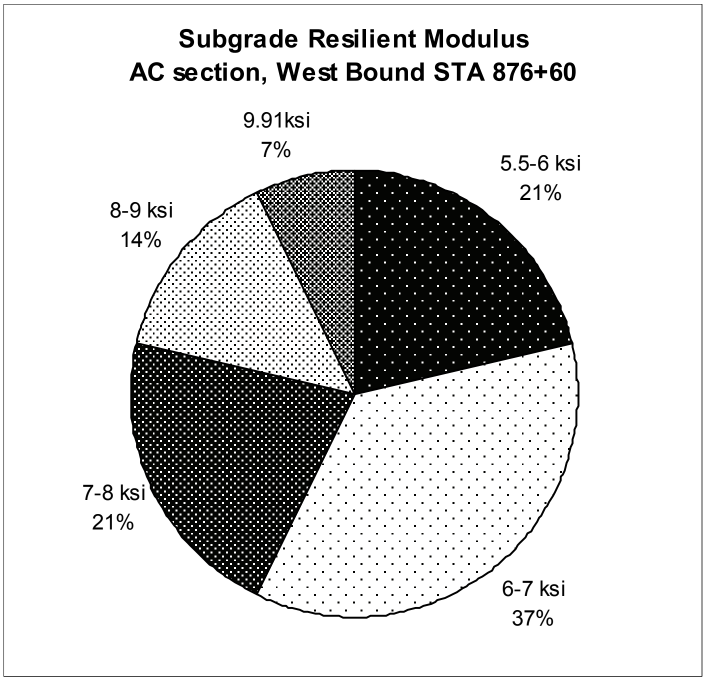


Figure 5.2. Subgrade Resilient Modulus AC Section.

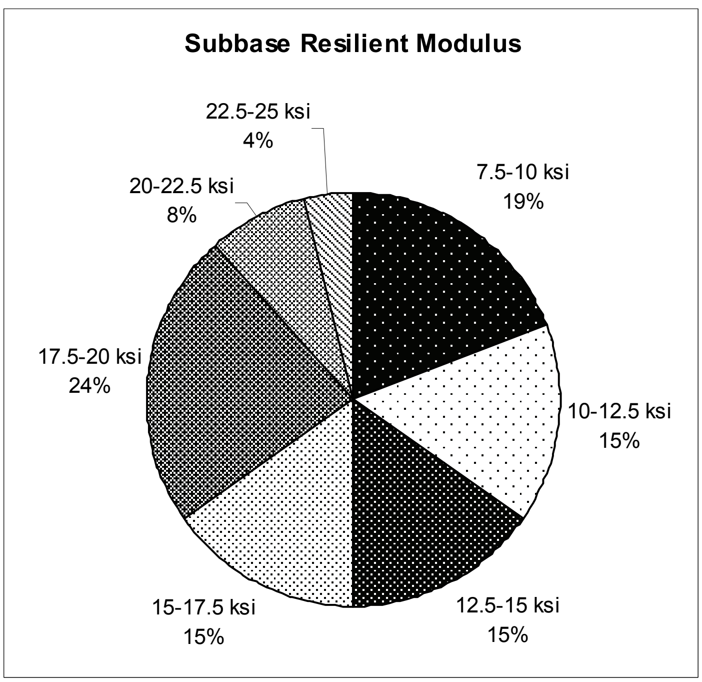


Figure 5.3. Subbase Resilient Modulus PCC and AC sections.

The grain size distribution for the subbase material listed in the report *Determination of Mechanical Properties used in Way-30 Test Pavements* [Sargand, Masada, Hernandez, and Kim, 2010] is repeated in Table 5.11.

Table 5.11. Subbase mechanical sieve analysis [Sargand et al. 2010].

Sieve	Mass Retained (slug)	Mass Retained (g)	% Passing	Sieve	Mass Retained (slug)	Mass Retained (g)	% Passing
1” (25 mm)	0.0036	52	98.96	#30 (0.600 mm)	0.0111	161.5	17.27
1/2” (12.5 mm)	0.1401	2044	58.08	#50 (0.300 mm)	0.0155	225.5	12.76
3/8” (9.5 mm)	0.0354	516	47.76	#100 (0.150 mm)	0.0190	277	7.22
#4 (4.75 mm)	0.0522	762.5	32.51	#200 (0.075 mm)	0.0128	186.5	3.49
#8 (2.36 mm)	0.0264	385.5	24.8	Pan	0.0119	174	0
#16 1.18 mm)	0.0147	215	20.5	TOTAL	0.3426	4999.5	-

5.1.6 PCC Properties

For the PCC section, full friction during the analysis period between the concrete slab and the asphalt permeable base was assumed, but the effect of the tied shoulder was not considered. The permanent curl/warp effective temperature for the slab determined by the software was 10ºF (-12°C).

The values for properties of the concrete mix are summarized in Table 5.12 and Table 5.13. The input level 1 for strength of the concrete was used. The value of the elastic modulus and modulus of rupture of concrete obtained in the lab was input for different ages of the concrete. These values as well as the Poisson ratio used correspond to those obtained for the GGBFS mix.

Properties used on modeling the asphalt treated base under the concrete slabs are summarized in Table 5.14 and Table 5.15. These properties correspond to values obtained in the laboratory for ODOT Item 301 as well as values recommended by Ohio Department of Transportation (ODOT) and AASHTO [2008].

Table 5.12. Concrete Mix Properties

Property	Value	Source
Cement type:	Type I	
Cementitious material content:	600 lb/yd^3 (0.356 g/cm^3)	Default
Water/cement ratio:	0.43	Average from maturity test
Unit weight	145 pcf (2.32 g/cm^3)	Maximum value from lab test
Poisson ratio	0.22	From lab test
Aggregate type:	Limestone	Default value
PCC zero-stress temperature	103°F (39°C)	Derived by program
Ultimate shrinkage at 40% R.H.	694 με	Derived by program
Reversible shrinkage (% of ultimate shrinkage)	50%	Default value
Time to develop 50% of ultimate shrinkage	35 days	Default value
Coefficient of thermal expansion	5.9×10^{-6}/ºF (10.6×10^{-6}/ºC)	Maturity test
Curing method:	Curing compound	Default value

Table 5.13. Concrete Strength

Time (days)	E (ksi)	R (psi)	E (GPa)	R (MPa)
7	3850	538.3	26.54	3.711
14	4010	491.4	27.65	3.388
28	4030	543.3	27.79	3.746
90	4070	608.7	28.06	4.197

Table 5.14. Asphalt Treated Base (ATB) mix properties

Cumulative % retained 3/4 inch (19 mm) sieve	26%
Cumulative % retained 3/8 inch (9.5 mm) sieve	52%
Cumulative % retained #4 (4.75 mm) sieve	72%
% Passing #200 (0.075 mm) sieve	1.2%

Table 5.15. ATB additional material properties

Property	Value	Source
Reference temperature	70°F (21°C)	Default value
Effective binder content	8.0%	ODOT maximum recommended value
Air voids	7.26%	From lab test
Unit weight	148 pcf (2.37 g/cm^3)	Default value
Poisson's ratio	0.35	Assumed value
DGAB K_0	0.5	Derived by software

5.1.7 AC Properties

The properties for the fatigue resistant layer (FRL) were taken using the specifications for ODOT Item 302 and the values obtained from the tests. The median values of the grain size distribution given in ODOT Item 302 specifications were taken. Other properties not listed here were assigned the default values given by the ME-PDG software. These properties are summarized in Table 5.16 and Table 5.17.

Table 5.16. Fatigue resistant layer (FRL) mix properties (ODOT Item 302 Specifications)

Cumulative % retained 3/4 inch (19 mm) sieve	32%
Cumulative % retained 3/8 inch (9.5 mm) sieve	51.5%
Cumulative % retained #4 (4.75 mm) sieve	66.5%
% Passing #200 (0.075 mm) sieve	4.5%

Table 5.17. Fatigue resistant layer (FRL) additional material properties

Property	Value	Source
Reference temperature	70°F (21°C)	Default value
Effective binder content	6.0%	ODOT maximum recommended value
Air voids	6.92%	From lab test
Unit weight	148 pcf (2.37 g/cm^3)	Default value
Poisson's ratio	0.35	Assumed value
DGAB K_0	0.5	Derived by software

As was done with the fatigue layer, the properties used to model the asphalt treated base (ATB) were taken from the specifications for ODOT Item 302 and the values obtained in the laboratory. The grain size distribution is the same as given in Table 5.16. The other properties were held the same as those for the fatigue layer with the exception of the percentage of air voids which was taken equal to 7.14% as reported by Sargand et al. [2010].

The bottom sub-layer of the sacrificial layer was modeled using the properties listed in Table 5.18 and Table 5.19. These properties were taken following the specifications for ODOT Item 442. The input grain size distribution corresponds to the median values of the size distribution given by the specification for a Type A mix (Table 442.02-2). The properties not listed here were assigned the default values given by the ME-PDG software.

Table 5.18. Superpave sacrificial layer mix properties (ODOT Item 442 Specifications)

Cumulative % retained 3/4 inch (19 mm) sieve	7.5%
Cumulative % retained 3/8 inch (9.5 mm) sieve	22.5%
Cumulative % retained #4 (4.75 mm) sieve	52.5%
% Passing #200 (0.075 mm) sieve	4%

Table 5.19. Superpave sacrificial layer additional material properties

Property	Value	Source
Reference temperature	70°F (21°C)	Default value
Effective binder content	5.7%	ODOT minimum recommended value
Air voids	7.24%	From lab test
Unit weight	148 pcf (2.37 g/cm^3)	Default value
Poisson's ratio	0.35	Assumed value

The wearing course material properties used were those corresponding to a stone matrix asphalt concrete described in ODOT Item 443 and obtained from the laboratory tests. Similarly to the superpave mix, the grain size distribution used for modeling corresponds to the median values of the range given by the ODOT specifications (Table 443.03-1). These values are summarized in Table 5.20 and Table 5.21.

Table 5.20. Wearing course layer mix properties (ODOT Item 443 Specifications)

Cumulative % retained 3/4 inch (19 mm) sieve	0%
Cumulative % retained 3/8 inch (9.5 mm) sieve	37.5%
Cumulative % retained #4 (4.75 mm) sieve	76%
% Passing #200 (0.075 mm) sieve	5%

Table 5.21. Wearing course layer additional material properties

Property	Value	Source
Reference temperature	70°F (21°C)	Default value
Effective binder content	7.5%	ODOT maximum recommended value
Air voids	7.0%	From lab test
Unit weight	148 pcf (2.37 g/cm^3)	Default value
Poisson's ratio	0.35	Assumed value

The thermal cracking properties used for the asphalt mix correspond to those of the top layer and are summarized in Table 5.22. These properties are taken following the recommendations and default values given by the AASHTO *Mechanistic-Empirical Pavement Design Guide: A Manual of Practice* [AASHTO, 2008]. The creep compliance values are deduced from the plots reported for the SMA mix by Sargand et al. [2010] and are reproduced in Table 5.23.

Table 5.22. Wearing course thermal cracking properties

Property	Value	Source
Average tensile strength at 14°F (-10°C)	755.1 psi (5.206 MPa)	From lab test
Aggregate coefficient of thermal contraction (in/in)	7.5%	ODOT maximum recommended value
Mix coefficient of thermal contraction	7.0%	From lab test

Table 5.23. Wearing course creep compliance

Load time (sec)	Creep compliance (10^{-4}/psi)			Creep compliance (10^{-8}/Pa)		
	-4ºF	14ºF	32ºF	-20ºC	-10ºC	0ºC
1	2.031	2.862	4.039	1.400	1.973	2.785
2	2.136	3.013	4.37	1.473	2.077	3.013
5	2.274	3.297	4.989	1.568	2.273	3.440
10	2.427	3.63	5.754	1.673	2.503	3.967
20	2.582	3.989	6.426	1.780	2.750	4.431
50	2.851	4.542	8.021	1.966	3.132	5.530
100	3.025	5.071	9.553	2.086	3.496	6.587

5.2 Results of AC Pavement Analysis

Figure 5.4 to Figure 5.14 show the obtained results from the analysis of the AC section. Table 5.24 presents the final values of the various parameters in the analysis. Only one of the design limits for this pavement is exceeded over the 20 year term of the simulation. The total rutting depth in Figure 13 meets the design limit of 0.5 in (1.27 cm) after 17.75 years, and this is primarily because of the weakness of the subgrade, as the AC rutting remains well below half of the AC rutting design limit of 0.25 in (0.64 cm). Recall that the subgrade parameters used represented worst case rather than average values. Most other parameters, such as longitudinal cracking (Figure 5.6) or thermal cracking (Figure 5.11) remain at zero throughout the simulation period. Others increase only slightly over time, as in the case of alligator cracking, as shown in Figure 5.7, and in Figure 5.8 compared to the design limit.

Comparing the new simulation with the previous one using default values, reported by Sargand, Figueroa, and Romanello [2008], we see much lower predicted top-down cracking in the new simulation. Alligator cracking gets worse, with 20-year damage increasing from 0.022% to 0.85% and the cracking rate increasing from 0.018% to about 0.5%, however these values remain at least an order of magnitude below the design limits. Thermal cracking and IRI results are about the same. The rutting results are worse in the new simulation, and as mentioned before, this is a result of using the worst-case values for the subgrade parameters. It should be noted that in the original WAY-30 report [Sargand, Figueroa, and Romanello, 2008], this design limit was 0.75 in, which is well above the final value in the new simulation.

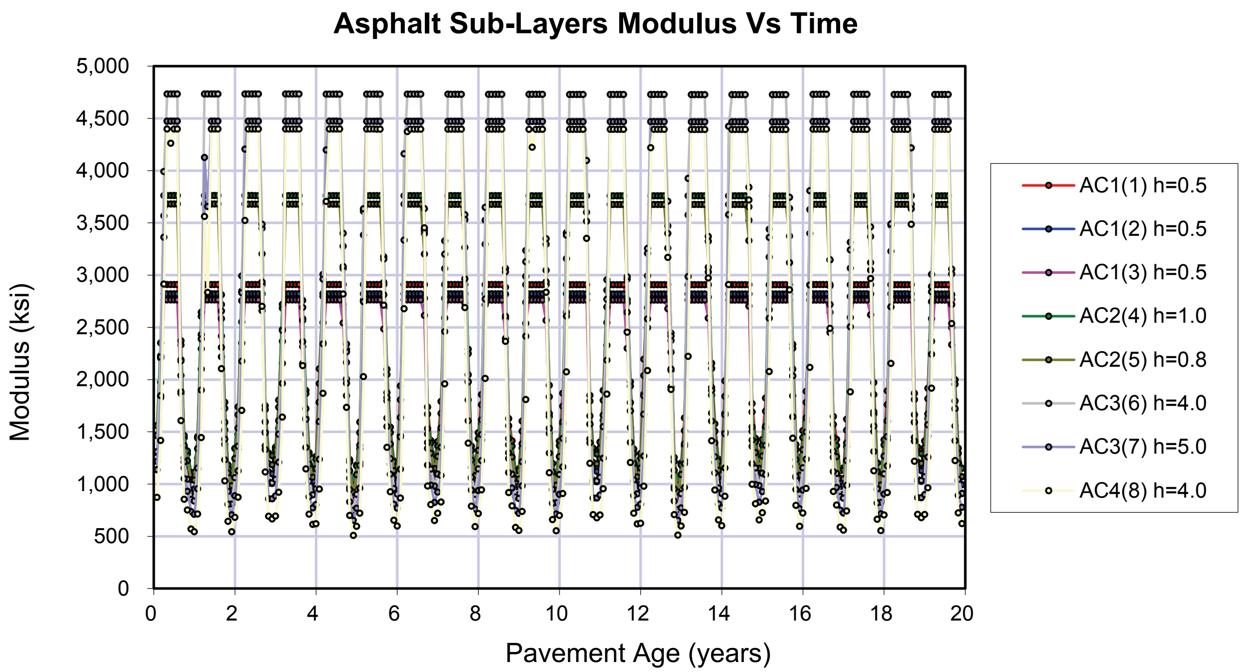


Figure 5.4. Predicted moduli of WAY-30 perpetual pavement layers as a function of age (1000 ksi = 6895 MPa). AC1, AC2, indicate layers of asphalt in the perpetual pavement structure, and *d* denotes the depth from the pavement surface (d=0).

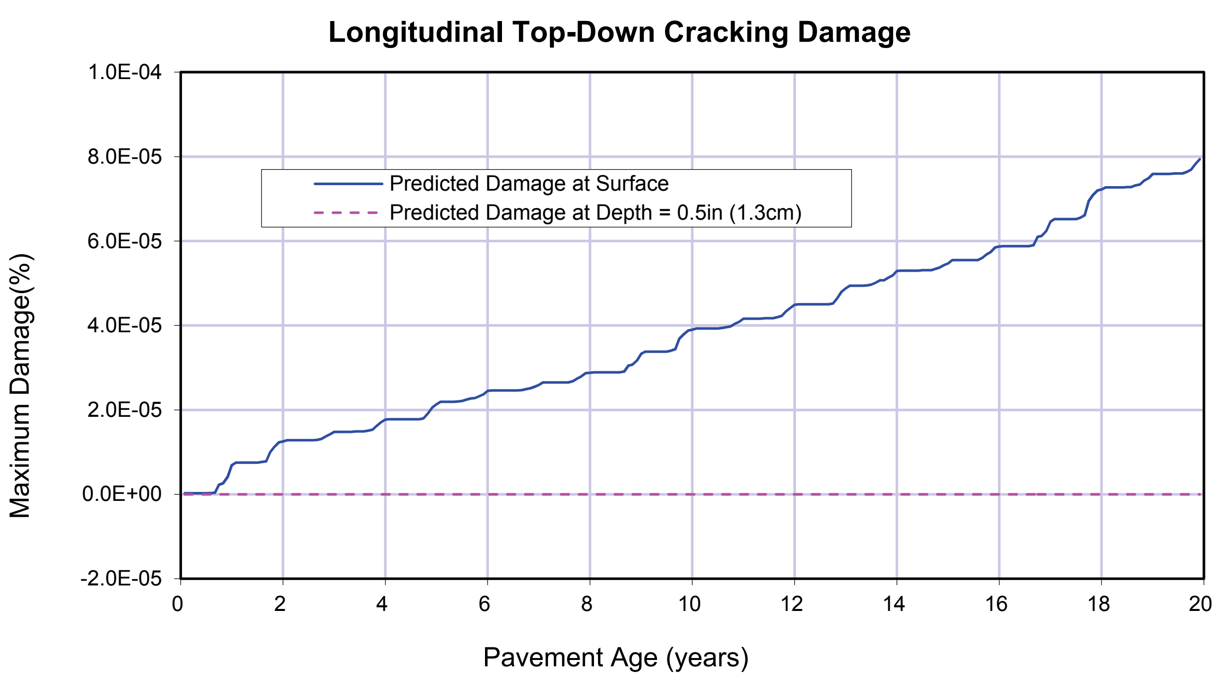


Figure 5.5. Pavement surface cracking of WAY-30 AC perpetual pavement as a function of age.

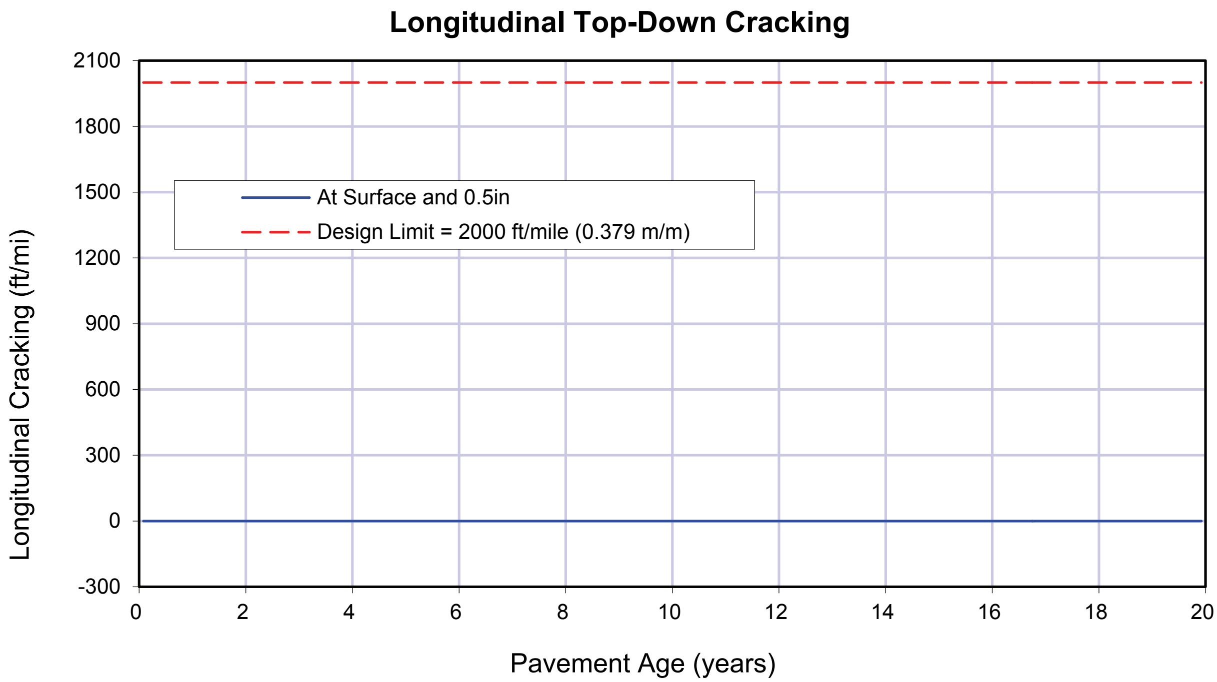


Figure 5.6. Predicted surface cracking in ft/mi of WAY-30 AC perpetual pavement as a function of age. (1 ft/mi = 0.000189 m/m)

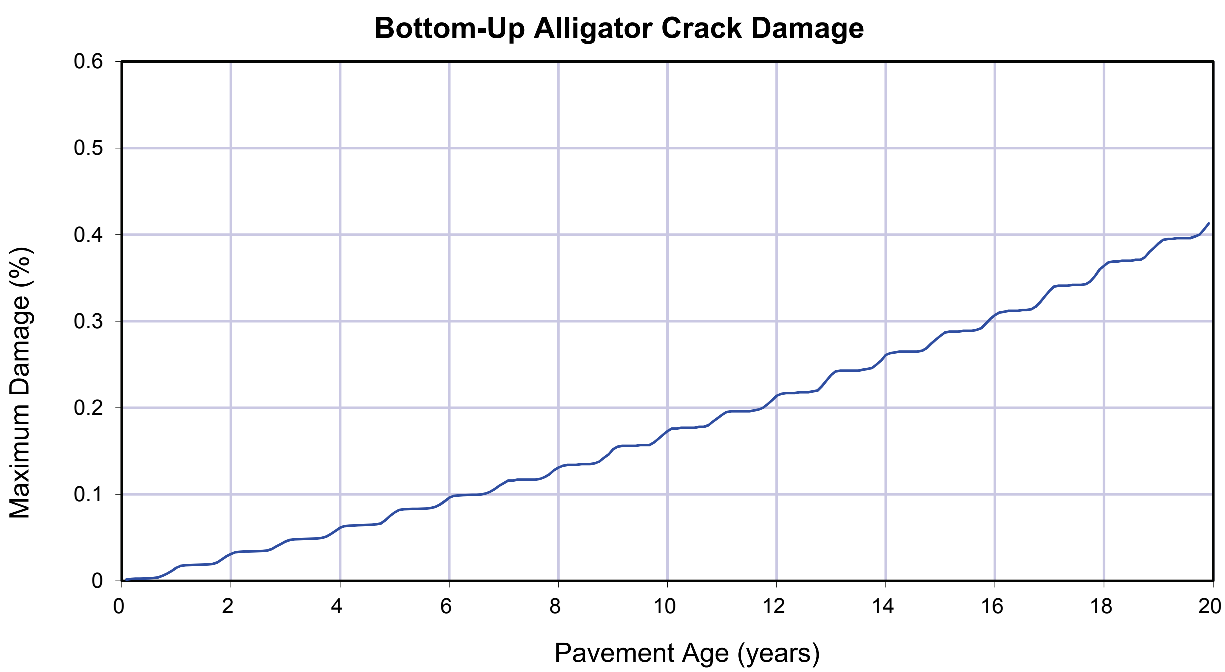


Figure 5.7. Percent of alligator cracking damage of WAY-30 AC perpetual pavement as a function of age.

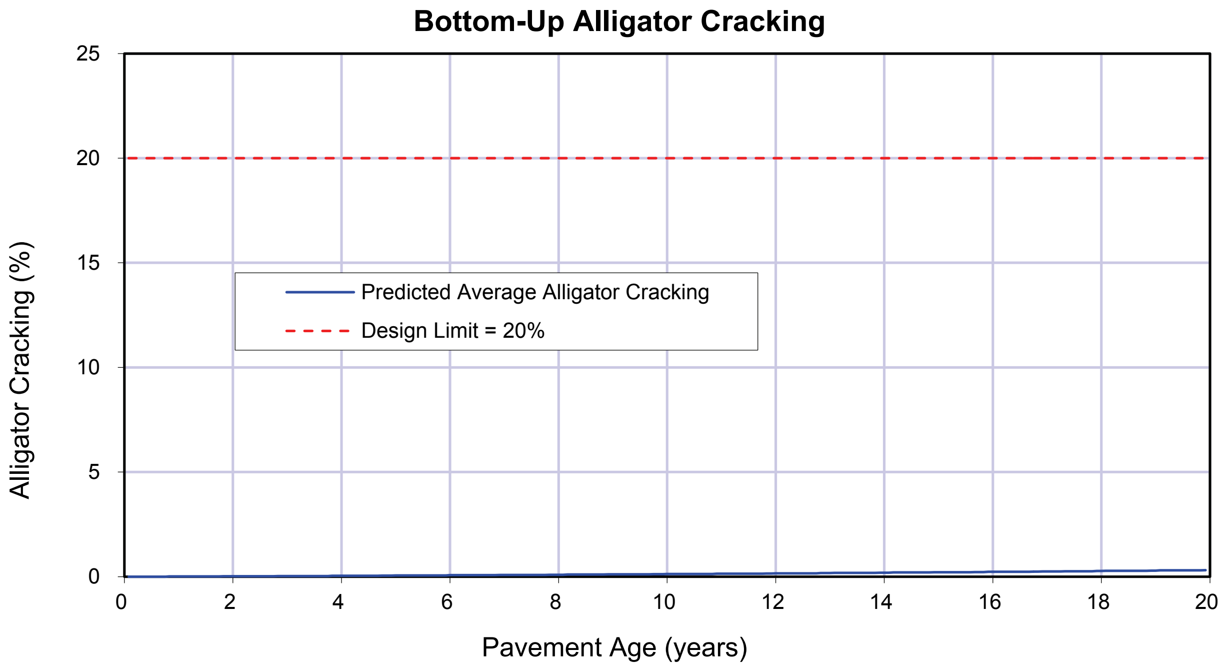


Figure 5.8. Predicted percentage of alligator cracking of WAY-30 AC perpetual pavement as a function of age.

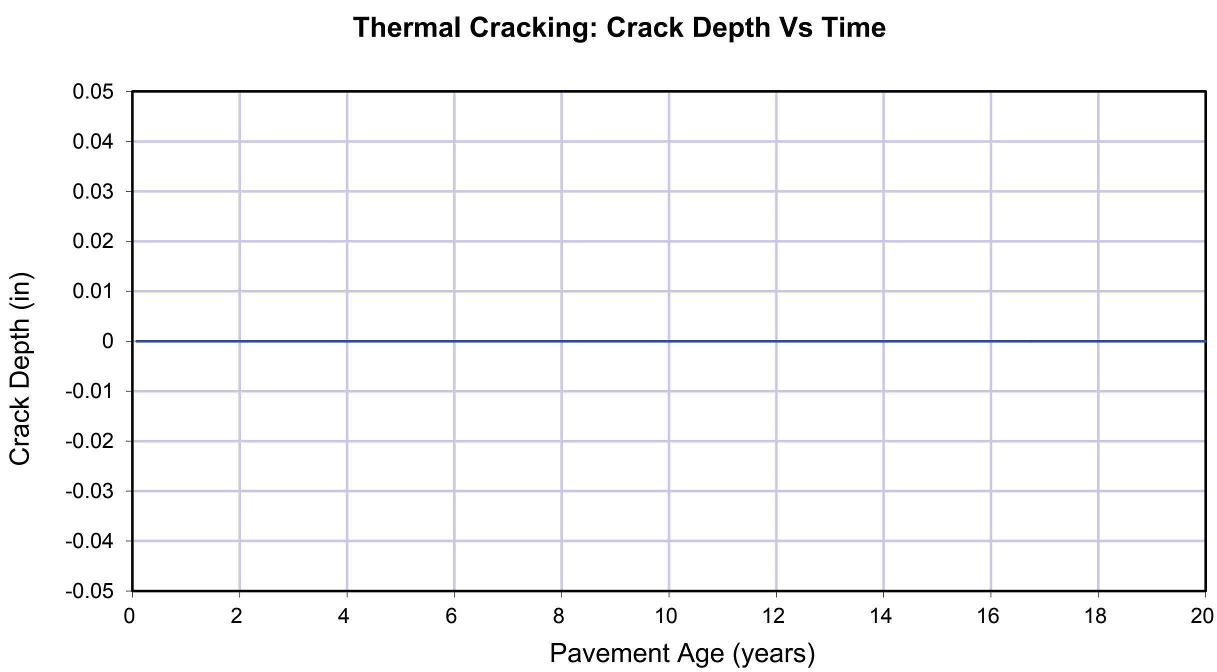


Figure 5.9. Average crack depth of WAY-30 AC perpetual pavement as a function of age.

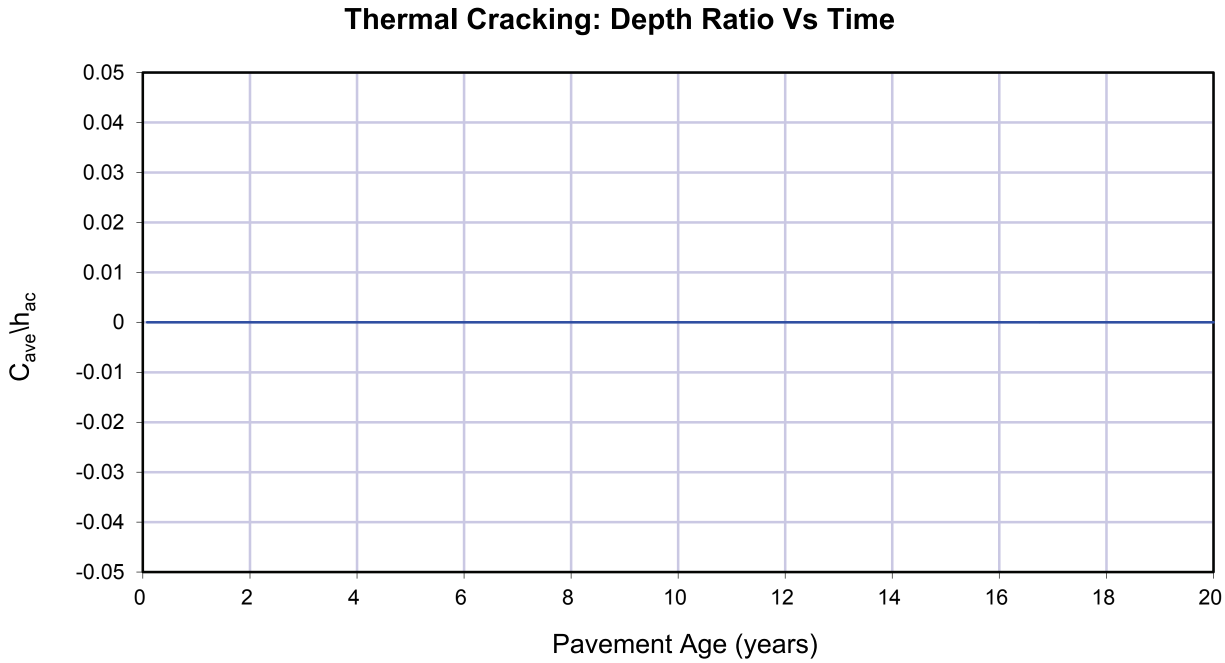


Figure 5.10. Thermal crack depth ratio (Average crack depth divided by height of asphalt surface layer (3.25in=8.26cm)) of WAY-30 perpetual pavement as a function of age.

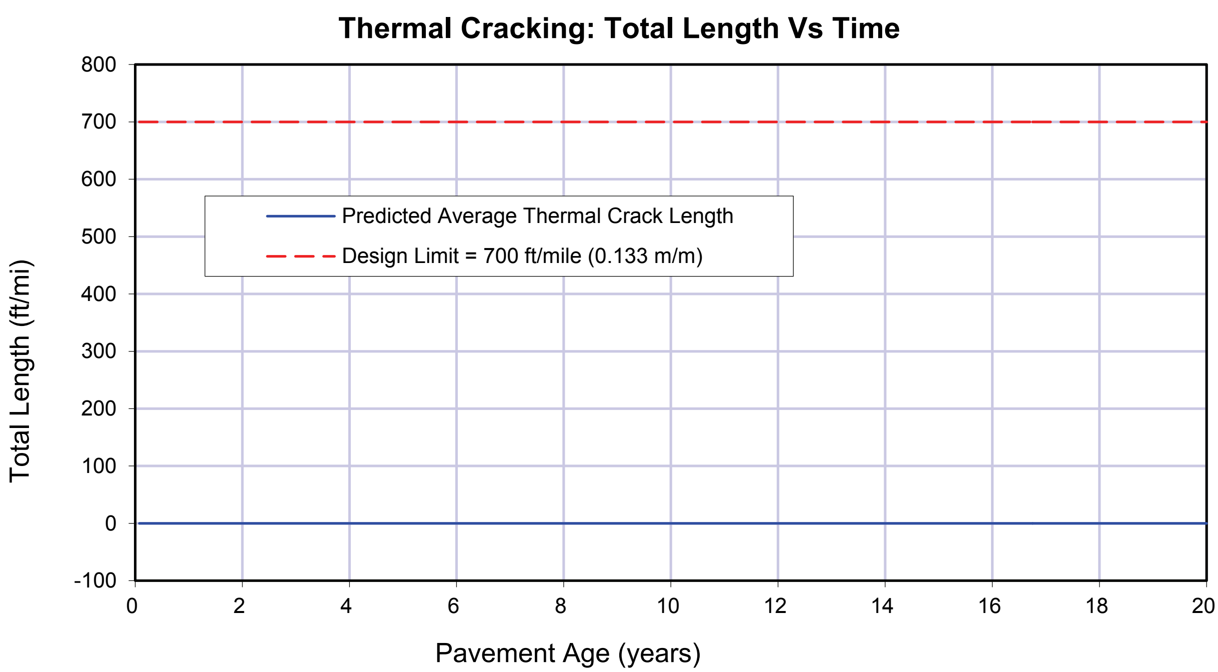


Figure 5.11. Thermal crack l ength of WAY-30 AC perpetual pavement as a function of age.

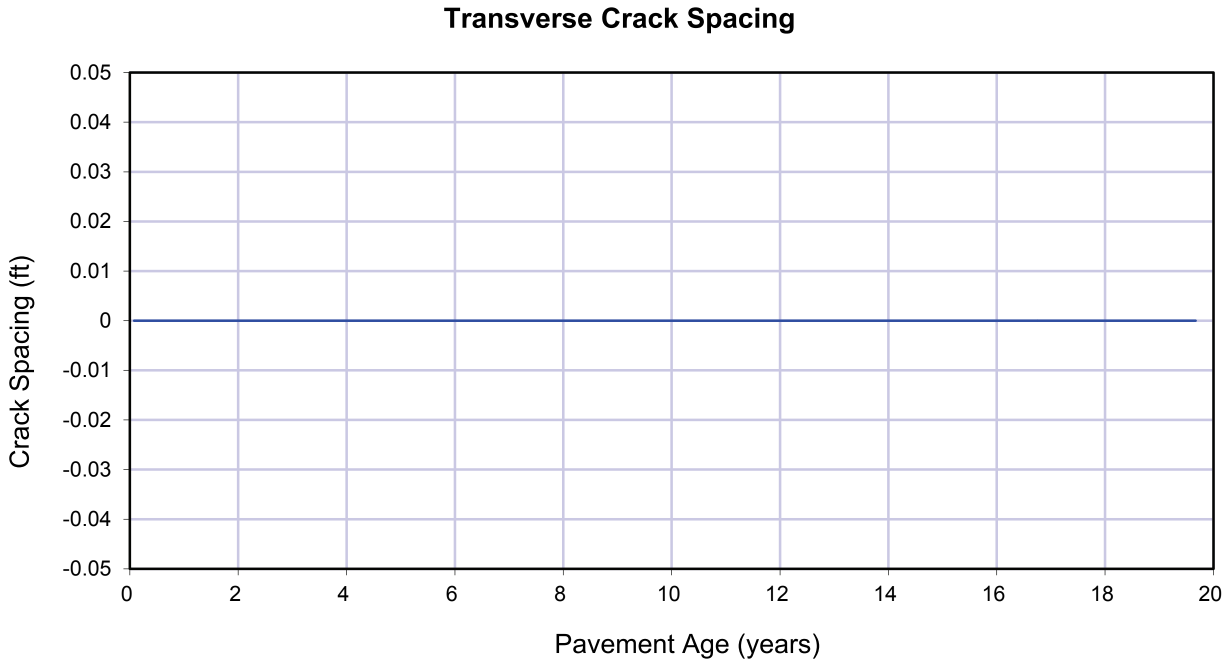


Figure 5.12. Transverse crack spacing of WAY-30 AC perpetual pavement as a function of age.

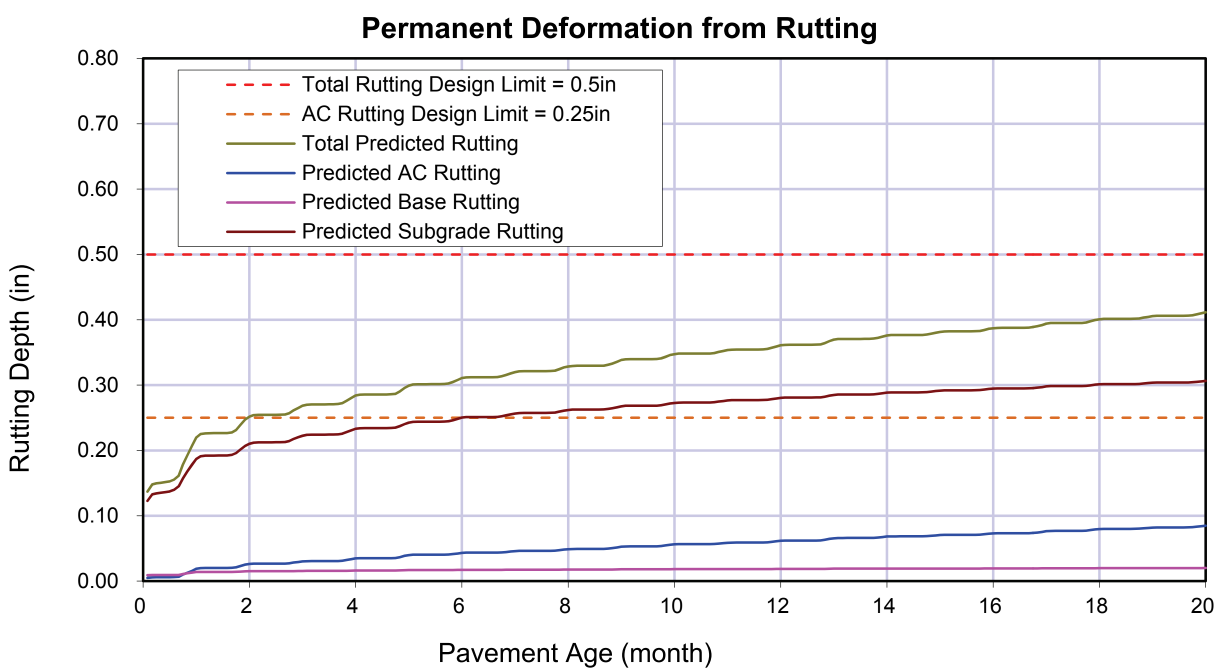


Figure 5.13. Rutting of WAY-30 AC perpetual pavement as a function of age (1 in = 2.54 cm).

Figure 5.14. IRI of WAY-30 AC perpetual pavement as a function of age (1 in/mi = 1.58x10^{-5} m/m; 172 in/mi =0.00271 m/m).

Table 5.24 Final MEPDG simulation values from analysis of AC Perpetual Pavement.

	English units			Metric units		
Parameter	Unit	Design limit	Final value	Unit	Design limit	Final value
Minimum last year AC modulus • SMA • AC Superpave Layer • ATB/AB • FRL/AB	ksi	-	 1018.4 1110.1 842.4 620.8	MPa	-	 7022 7654 5808 4280
Maximum last year AC modulus • SMA • AC Superpave Layer • ATB/AB • FRL/AB	ksi	-	 1018.4 3317.7 4599 4395.2	MPa	-	 7022 22875 31709 30304
Average top-down cracking damage at surface	%	-	8.03×10^{-5}	%	-	8.03×10^{-5}
Average top-down cracking damage at 0.5 in	%	-	$<10^{-8}$	%	-	$<10^{-8}$
Longitudinal top-down cracking at surface	ft/mi	2000	0	m/m	0.379	0
Longitudinal top-down cracking at 0.5 in	ft/mi	2000	0	m/m	0.379	0
Bottom-up alligator crack maximum damage	%	-	0.42	%	-	0.42
Bottom-up alligator cracking	%	20%[1]	0.32	%	20%[1]	0.32
Average crack depth	in	-	0	mm	-	0
Thermal crack depth ratio c_{ave}/h_{ac}	-	-	0	-	-	0
Thermal cracking length	ft/mi	700[2]	0	m/m	0.133[2]	0
Transverse crack spacing	ft	-	0	m	-	0
Total rut depth	in	0.5[3]	0.4115	mm	12.7[3]	10.452
Asphalt concrete rut depth	in	0.25	0.0849	mm	6.35	2.156
Base rut depth	in	-	0.0201	mm	-	0.511
Subgrade rut depth	in	-	0.3065	mm	-	7.785
IRI	in/mi	172[4]	111.9	m/m	0.00271[4]	0.00177

[1]Design limit = 25% in Sargand, Figueroa, and Romanello [2008]
[2]Design limit = 1000 ft/mi (0.189 m/m) in Sargand, Figueroa, and Romanello [2008]
[3]Design limit = 0.75 in (19 mm) in Sargand, Figueroa, and Romanello [2008]
[4]Initial value = 63 in/mi (0.000994 m/m)

5.3 Results of PCC Pavement Analysis

Figure 5.15 to Figure 5.19 show the obtained results from the analysis of the PCC section. Predicted faulting (Figure 5.15) and cracking (Figure 5.18) remain well below the design limits. The same is also true of the IRI, shown in Figure 5.19. Table 5.25 presents the final values of the various parameters in the analysis.

Comparing the new simulation to the previous one that used default values [Sargand, Figueroa, and Romanello, 2008], it can be seen that the new simulation predicts much better performance in most areas than before. For example faulting after 20 years decreased from 0.12 in (3.0 mm) to about 0.015 in (~0.38 mm), and the minimum load transfer efficiency at 20 years increased from 55% to about 93%. The maximum top-down crack damage decreased from 0.2 to 0.015. The final IRI decreased from about 140 in/mi (originally reported as 0.0022 m/m or mi/mi) to about 85 in/mi (0.00135 m/m or mi/mi), a decrease of nearly 40%. The only measure to get worse in the new simulation is the final (20 year) percentage of slabs cracked, which increases to 4% from nearly 0%. This result is probably again due to using the worst-case values for subgrade input parameters, and is still well below the design limit of 15%.

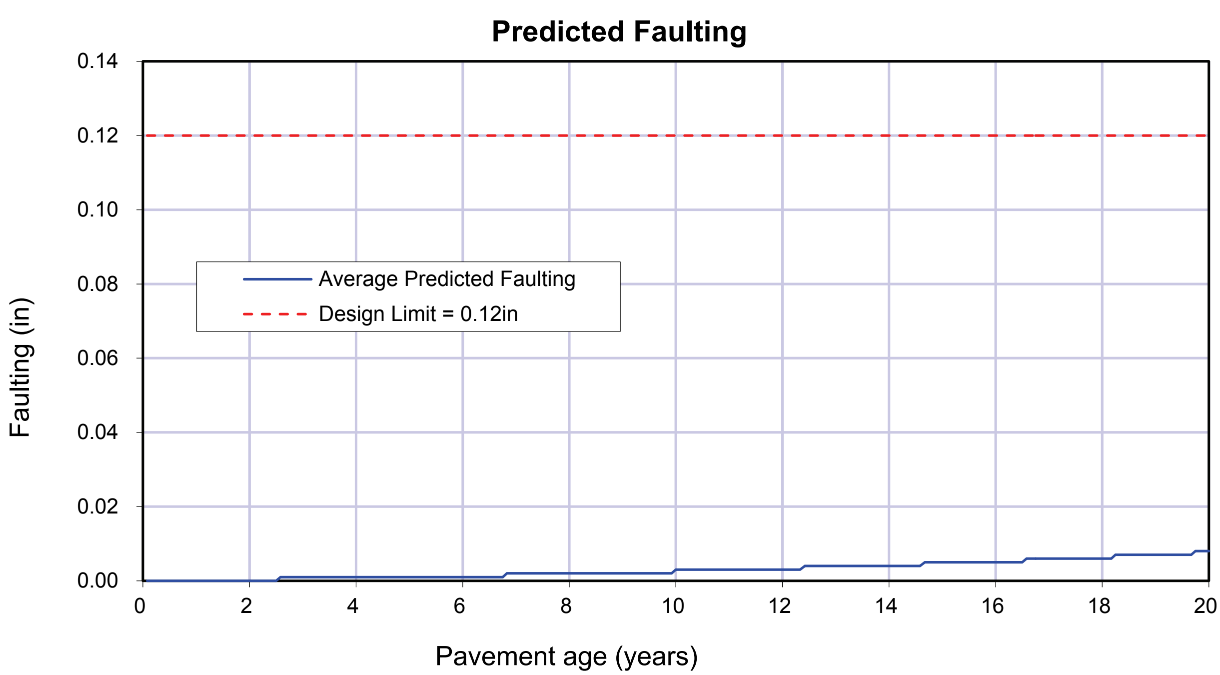


Figure 5.15. Predicted faulting of WAY-30 PCC Pavement as a function of age (1 in=2.54 cm).

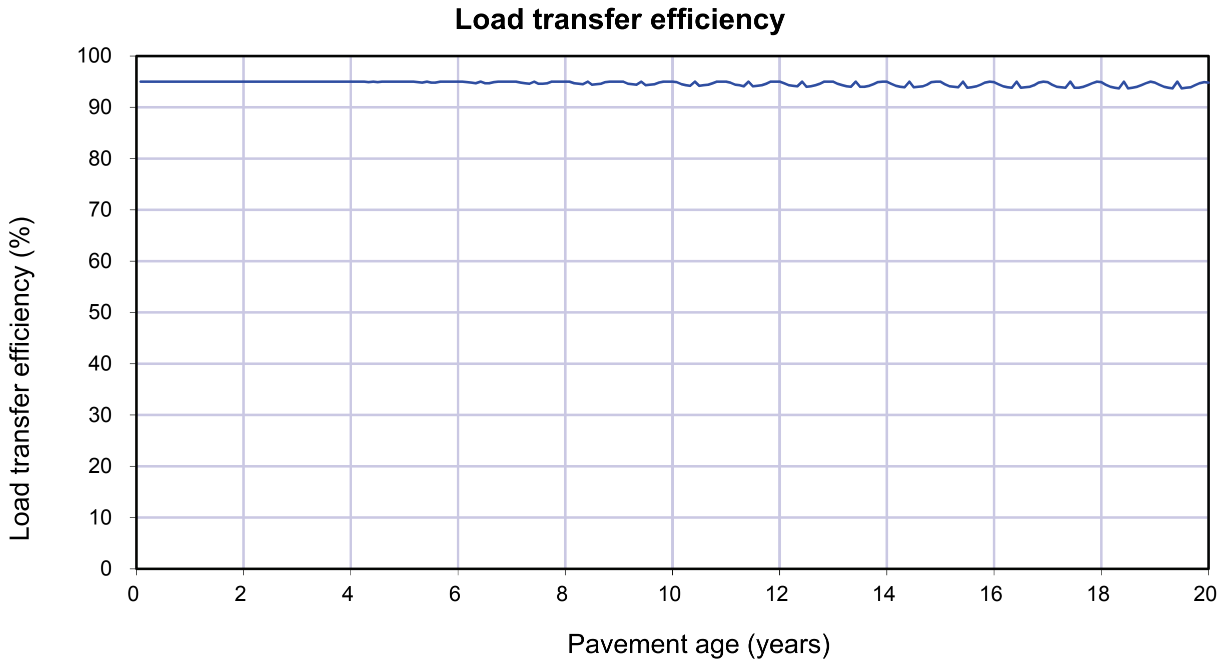


Figure 5.16. Load Transfer of WAY-30 PCC pavement as a function of age.

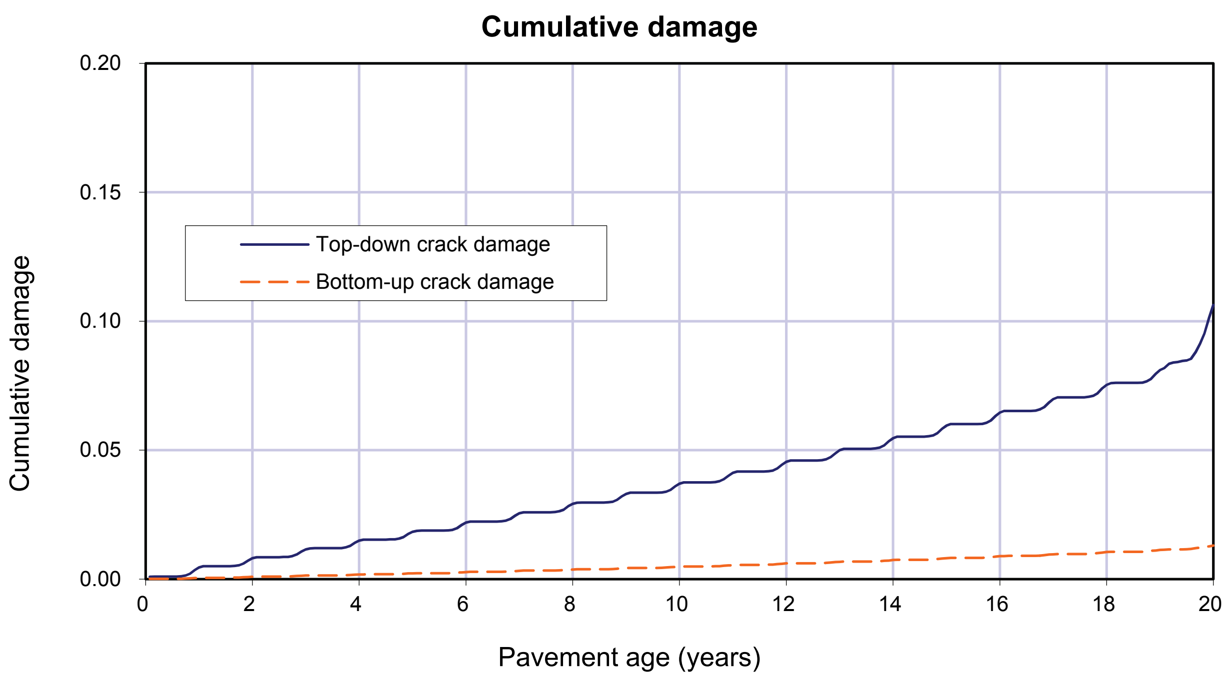


Figure 5.17. Cumulative damage of WAY-30 PCC pavement as a function of age.

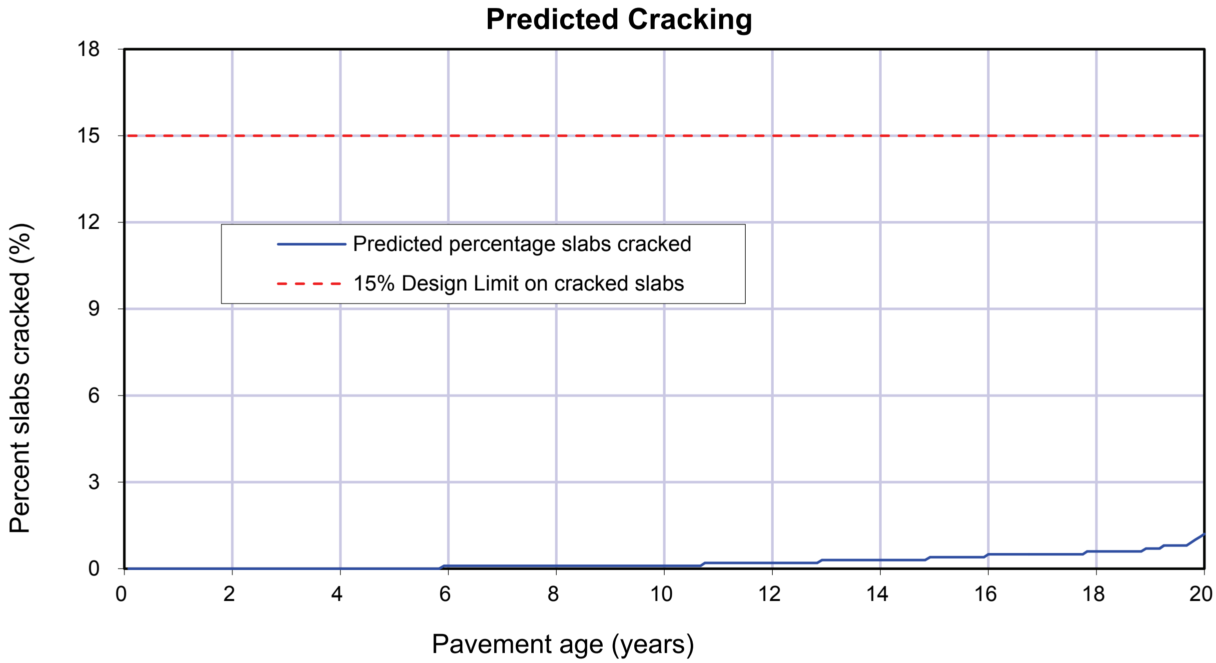


Figure 5.18. Percent of cracking of WAY-30 PCC pavement as a function of age.

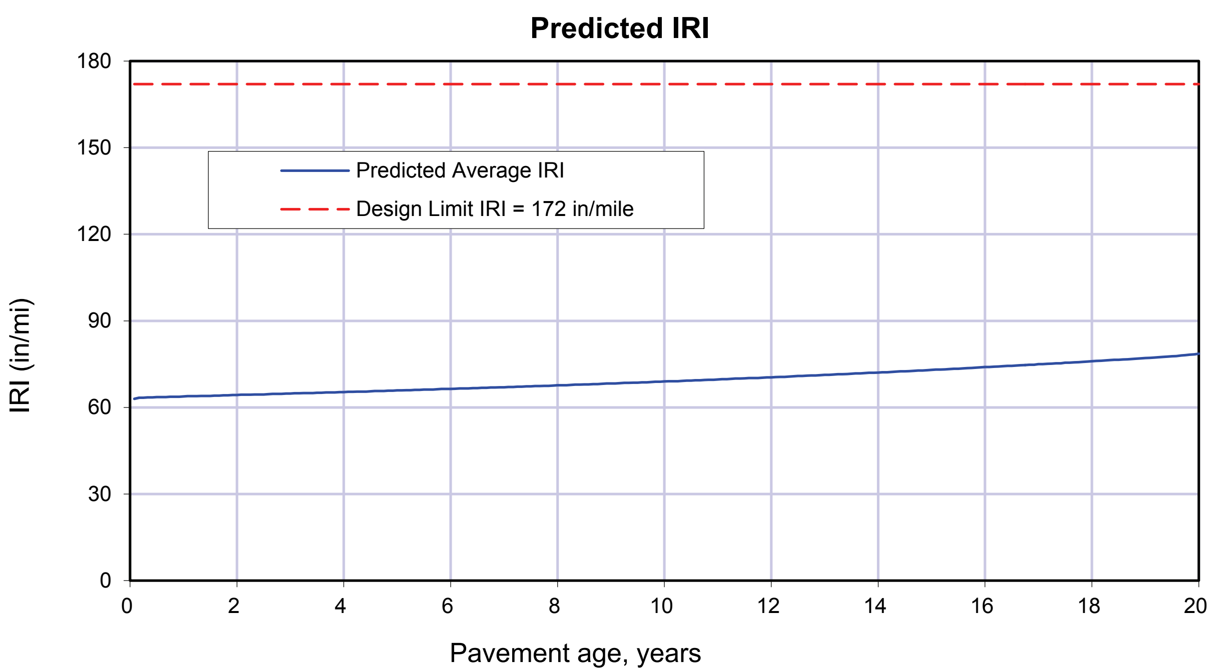


Figure 5.19. IRI of WAY-30 PCC perpetual pavement as a function of age (1 in/mi = 1.58x10^{-5} m/m).

Table 5.25 Final MEPDG simulation values from analysis of PCC pavement.

Parameter		Unit	Design limit	Final value
Faulting		in	0.12	0.0077
		mm	3.05	0.196
Minimum Load Transfer Efficiency (LTE)		%	-	93.7
Top-down cracking cumulative damage		-	-	0.1063
Bottom-up cracking cumulative damage		-	-	0.0130
Percentage of cracked slabs		%	15%	1.2
IRI		in/mi	172.0[1]	78.6
		m/m	0.00272[2]	0.00124

[1]Initial value = 63 in/mi
[2]Initial value = 0.000994 m/m

Chapter 6
Conclusions

WAY-30

1. No clear differences in performance are apparent on sections of PCC containing fly ash and ground granulated blast furnace slag. As the previous report on WAY-30 concluded [Sargand, Figueroa, and Romanello, 2008], this pavement cured at an ideal temperature and had no significant loss of support after curing. No distresses have appeared in these sections, other than one cracked slab that may be a result of an irregularity in the base.
2. The perpetual AC and long lasting PCC pavements are both performing well at this time.
3. The one joint with composite dowel bars shows high deflections and low load transfer. Deflections at joints between Stations 876 and 877 with standard epoxy coated dowel bars were highly variable, but load transfer remained good.
4. As shown from the TDR data collected, subgrade moisture fluctuates slightly with the seasons, but does not change significantly.
5. A new MEPDG software simulation of the two pavements generates results with various differences from those of the previous simulation [Sargand, Figueroa, and Romanello, 2008]. The simulated AC perpetual pavement stayed below the original design limits for all results. The final total and subgrade rutting values were higher in the new simulation because the input subgrade parameters were worst-case values from the project data. In the case of PCC, most of the simulated measures improved considerably, sometimes as much as an order of magnitude. The major exception was the percentage of slabs cracked, which at 4% after 20 years is still well below the design limit of 15% and is again probably a result of using worst-case numbers for subgrade input data.

DEL 23 SHRP Pavement

1. Seven PCC sections were replaced with more robust pavement sections containing different slab lengths, slab widths, and different sizes of coarse aggregate. The objective was to study the influences of joint spacing and of aggregate size in the mix on performance.
2. Unfortunately, we could not make clear comparisons of sections 268, 269, 270, 271, and 272 because these pavements have suffered premature distress in the form of longitudinal cracking after one year of service. Based on a preliminary forensic study, the root causes

of the failure appear to be inconsistent pavement thickness and improper cutting of the longitudinal joints.

3. Section 267 had an 8 inch (20.3 cm) base of 304 aggregate, while the other six sections had 4 inches (10.2 cm) of 301 ATB over 4 inches (10.2 cm) of 304 aggregate. Sections 266 and 267, with 12 foot (3.7 m) slab widths, had higher FWD deflections, but load transfers at the joints were good.
4. The heat of hydration dissipated 4 – 5 days after the concrete was placed.
5. Load response testing was conducted on these sections.

ATH 33

1. No differences in FWD response were noted in 2004 and high traffic volumes on this two-lane urban highway have prevented any further testing.
2. Some minor transverse cracking has been observed at driveway entrances where high early strength concrete was used. This mix differs from that use in the highway travel lanes and was used late in the project to shorten the delay in opening the finished road to traffic.
3. The large aggregate in the PCC pavement used in this project performed exceptionally well, as indicated by the performance of the pavement.

ATH 50

1. Load transfer in six joints with fiberglass dowel bars was consistently 15-20% lower than the stainless tubes and epoxy-coated steel bars over the first six years of service, then dropped dramatically to about 30% in 2005 and remained at that level in 2008.

LOG 33

1. Of the six sections of AC pavement with different bases, the sections with 4 inches (10.2 cm) of 306 CTFDB over 4 inches (10.2 cm) of 304 DGAB, 4 inches (10.2 cm) of 307 IA DGAB over 4 inches (10.2 cm) of 304 DGAB and a total thickness of 6 inches (15.2 cm) of 304 DGAB had the lowest FWD deflections.
2. The section with 4 inches (10.2 cm) of 307 NJ DGAB over 4 inches (10.2 cm) of 304 DGAB had the highest deflection.
3. The sections continue to perform well and no major unexpected distresses have been observed. There has been rehabilitation of the top layer, which was anticipated.

4. No reflected cracking has appeared on asphalt pavements due to base materials. This is true even for stiff bases. This is because the thick AC layer insulates the base from large temperature fluctuations.
5. LOG-33 meets the criteria for an AC perpetual pavement. Data from this project can be compared to other projects in Ohio.

<u>MEG 33</u>

1. FWD midslab and joint deflections, Df1/Df7 at midslab, and joint load transfers were higher on the sandy subgrade than on the clay subgrade.
2. Sealing material is working out of some joints.
3. As the previous study on this pavement indicated, the moisture under both types of subgrade has stabilized and remains unchanged, other than limited seasonal fluctuations.

<u>STA 77</u>

1. High traffic volumes prevented any further monitoring of this project.

<u>General remarks</u>

1. On all sections where they have been installed, composite dowel bars have performed well.
2. Subgrade moisture fluctuates slightly with the seasons, but does not change significantly, staying within a well-defined range regardless of the type of base or pavement.
3. Rigid pavement performance is sensitive to the construction method.
4. PCC pavements installed on stiff base layers do not perform as well as those installed on flexible base layers.
5. The earlier findings regarding the selection of base materials have been confirmed in this study [Sargand, Wu, and Figueroa, 2006]. Namely, the performance of PCC and AC pavements is influenced greatly by the stiffness of the base. A softer base works better with PCC pavements, while AC pavements perform better on stiffer bases. With AC pavements on cement-treated bases, there is always some concern that there will be reflection cracking; however, a sufficient thickness of AC pavement will reduce temperature fluctuations in a stiff base and thus reduce or eliminate reflection cracking.
6. PCC pavement with large aggregate performed exceptionally well.

7. In the majority of instances, PCC pavement slab distress occurred in the form of mid-panel cracking initiated from the top. These are manifestations of curling and warping.
8. The DEL23 and WAY30 projects have provided a wealth of data for calibration of the MEPDG software for Ohio.

Many pavements in this study are relatively new and it may be some time before useful results emerge. The more prominent projects are WAY-30 where the performance of perpetual AC and long lasting PCC pavements are being compared directly, and the seven PCC replacement sections in the northbound driving lane of DEL 23 where the effects of different slab lengths, slab widths, and coarse aggregate sizes are being evaluated for performance. The dowel bars on ATH-50 and the AC pavement bases on LOG-33 are still useful for the evaluation of long-term performance.

Chapter 7
Implementation

1. Monitor FWD Df1/Df7 ratios on in-service pavements to confirm the preliminary ranges established here for good, fair, and poor performance on AC pavements.
2. 306 Cement Treated Free Draining Base and 307 IA Dense Graded Aggregate provide the best support for AC pavements. The 307 NJ base should be avoided for PCC pavement.
3. The detailed data collected on the WAY-30 project, including data from the weather station data and on material properties make the pavement a good candidate for inclusion in the MEPDG calibration effort for Ohio.
4. Similarly, MEG-33 and ATH-33 have provided data that can be used in the MEPDG calibration.
5. The data collected from these projects could be used for the validation of the load response computations of the MEPDG software for Ohio. This is in addition to calibration of the software's performance computations.
6. ODOT should specify the use of large aggregate in PCC pavement mixes.
7. Based on the results of this study, ODOT should review its construction procedures with an emphasis on when, how, and to what depth to cut PCC joints.
8. Every effort should be made to incorporate environmental factors in the design of PCC pavements.

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3. Sargand, Shad and staff, “Evaluation of Pavement Performance on DEL 23,” Ohio University, Athens Ohio, Ohio DOT Report FHWA/OH-2007/05, March 2007.

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7. Sargand, Shad, Figueroa, J. Ludwig, Edwards, William, and Al-Rawashdeh, Abdalla, “Performance Assessment of Warm Mix Asphalt (WMA) Pavements,” Ohio University, Athens, Ohio, Ohio DOT Report FHWA/OH-2009/08, September 2009.

APPENDIX A

DEL 23 Series 10 Controlled Vehicle Test Lateral Offsets

Table A.1

DEL 23 Series 10 Vehicle Offsets – File 269A

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 9/25/07 **Truck Load –** Heavy **File –** 269A									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
1	1	SA	7	8	7.5	5			3:30
	2	TA	8	19	13.5				
2	3	SA	7	8	7.5				
	4	TA	6	7	6.5				
3	5	SA	8	8	8				
	6	TA	14	13.5	13.75				
4	7	SA	15	15	15	25			
	8	TA	14	13	13.5				
5	9	SA	12	12	12				4:16
	10	TA	11.5	12	11.75				
6	11	SA	17	18	17.5				
	12	TA	12	12	12				
7	13	SA	14	14	14	55			
	14	TA	10.5	11	10.75				
8	15	SA	13	14	13.5				5:30
	16	TA	7	7	7				
9	17	SA	10	11	10.5				
	18	TA	18	19.5	18.75				

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.2

DEL 23 Series 10 Vehicle Offsets – File 270A

<table>
<tr><th colspan="10">DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections</th></tr>
<tr><th colspan="10">Date – 9/25/07 Truck Load – Heavy File – 270A</th></tr>
<tr><th rowspan="2">Run No.</th><th rowspan="2">Data Set</th><th rowspan="2">Truck Type*</th><th colspan="3">Wheel Offset (in.)</th><th rowspan="2">Nominal Speed (mph)</th><th rowspan="2" colspan="2">Pavement Temp. °C</th><th rowspan="2">Time</th></tr>
<tr><th>Approach</th><th>Leave</th><th>Average</th></tr>
<tr><td rowspan="2">1</td><td>1</td><td>SA</td><td>13</td><td>13.25</td><td>13.125</td><td rowspan="6">5</td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>TA</td><td>24</td><td>24</td><td>24</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">2</td><td>3</td><td>SA</td><td>8.75</td><td>8.5</td><td>8.625</td><td></td><td></td><td></td></tr>
<tr><td>4</td><td>TA</td><td>10.5</td><td>10.224</td><td>10.362</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">3</td><td>5</td><td>SA</td><td>10</td><td>9.75</td><td>9.875</td><td></td><td></td><td></td></tr>
<tr><td>6</td><td>TA</td><td>12.5</td><td>11.5</td><td>12</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">4</td><td>7</td><td>SA</td><td>12</td><td>10.25</td><td>11.125</td><td rowspan="6">25</td><td>WP1</td><td>33.5</td><td rowspan="4">4:50PM</td></tr>
<tr><td>8</td><td>TA</td><td>10.5</td><td>11</td><td>10.75</td><td>WP2</td><td>31.0</td></tr>
<tr><td rowspan="2">5</td><td>9</td><td>SA</td><td>14.75</td><td>15</td><td>14.875</td><td>WP3</td><td>29.0</td></tr>
<tr><td>10</td><td>TA</td><td>12.5</td><td>13</td><td>12.75</td><td>WP4</td><td>27.5</td></tr>
<tr><td rowspan="2">6</td><td>11</td><td>SA</td><td>20.5</td><td>20.5</td><td>20.5</td><td></td><td></td><td></td></tr>
<tr><td>12</td><td>TA</td><td>11</td><td>11</td><td>11</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">7</td><td>13</td><td>SA</td><td>14</td><td>14.25</td><td>14.125</td><td rowspan="6">55</td><td></td><td></td><td></td></tr>
<tr><td>14</td><td>TA</td><td>10.75</td><td>10.25</td><td>10.5</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">8</td><td>15</td><td>SA</td><td>17.75</td><td>18</td><td>17.875</td><td></td><td></td><td>5:30P</td></tr>
<tr><td>16</td><td>TA</td><td>12</td><td>12.5</td><td>12.25</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">9</td><td>17</td><td>SA</td><td>19.75</td><td>20.5</td><td>20.125</td><td></td><td></td><td></td></tr>
<tr><td>18</td><td>TA</td><td>18</td><td>19.5</td><td>18.75</td><td></td><td></td><td></td></tr>
</table>

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.3

DEL 23 Series 10 Vehicle Offsets – File 271A

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 9/25/07 **Truck Load –** Heavy **File –** 271A									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
1	1	SA	15.5	15.75	15.625	5			3:30PM
	2	TA	18.5	19	18.75				3:30PM
2	3	SA	17.25	16.5	16.875				3:40PM
	4	TA	18.25	7.75	13				3:40PM
3	5	SA	16	16	16				3:45PM
	6	TA	12	12	12				3:45PM
4	7	SA	18.75	17.5	18.125				3:50PM
	8	TA	16	10	13				3:50PM
5	9	SA	4	3.75	3.875	25			4:45PM
	10	TA	10.5	11	10.75				4:50PM
6	11	SA	9.5	10	9.75				4:52PM
	12	TA	8.5	8	8.25				4:53PM
7	13	SA	17.25	17	17.125	55			4:58PM
	14	TA	7.5	17.5	12.5				5:04PM
8	15	SA	17	16.25	16.625				5:08PM
	16	TA	8.5	8.5	8.5				5:15PM
9	17	SA	13.5	12.75	13.125				5:17PM
	18	TA	16.75	16.5	16.625				5:27PM
10	19	SA	1.5	1.5	1.5				5:32PM
	20	TA	17.5	17.25	17.375				5:43PM

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.4

DEL 23 Series 10 Vehicle Offsets – File 272A

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 9/25/07 **Truck Load –** Heavy **File –** 272A									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
1	1	SA	12	10.75	11.375	5			3:30PM
	2	TA	19.75	19.5	19.625				3:30PM
2	3	SA	14.25	12.5	13.375				3:40PM
	4	TA	7.25	4.25	5.75				3:40PM
3	5	SA	13	11.5	12.25				3:45PM
	6	TA	15.75	15	15.375				3:45PM
4	7	SA	17.5	16.25	16.875				3:50PM
	8	TA	18.5	17.25	17.875				3:50PM
5	9	SA	10.5	10.5	10.5	25			4:45PM
	10	TA	8.5	8.75	8.625				4:50PM
6	11	SA	14.5	8.75	11.625				4:52PM
	12	TA	12.75	14.5	13.625				4:53PM
7	13	SA	16.25	14.5	15.375	55			4:58PM
	14	TA	14	17	15.5				5:04PM
8	15	SA	16	15.25	15.625				5:08PM
	16	TA	9	9.5	9.25				5:15PM
9	17	SA	13.25	13.25	13.25				5:17PM
	18	TA	17.75	18.75	18.25				5:27PM
10	19	SA	4.5	5	4.75				5:32PM
	20	TA	20.5	22	21.25				5:43PM

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.5

DEL 23 Series 10 Vehicle Offsets – File 268B

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 9/26/07 **Truck Load –** Heavy **File –** 268B									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
1	1	SA	13	15	14	5	Morning Test		
	2	TA	10.5	9	9.75				
2	3	SA	13	13	13				
	4	TA	9	8	8.5		WP1	22.4	9:15AM
3	5	SA	11	11	11		WP2	23.0	
	6	TA	10.5	10	10.25		WP3	23.6	
4	7	SA	9	9	9	25	WP4	24.2	
	8	TA	12.75	12	12.375				
5	9	SA	15	15	15				
	10	TA	13	12.5	12.75				
6	11	SA	15	15	15				
	12	TA	16	15	15.5				
7	13	SA	13	14	13.5	55	WP1	23.8	10:00AM
	14	TA	11.5	12.5	12		WP2	24.0	
8	15	SA	10.5	11	10.75		WP3	24.8	
	16	TA	12.5	13	12.75		WP4	25.3	
9	17	SA	14.25	15	14.625				
	18	TA	12	13	12.5				
10	19	SA	9	11	10	5			10:37
	20	TA	13	13	13				
11	21	SA	12	11.5	11.75				
	22	TA	11	10	10.5				
12	23	SA	12	13	12.5		WP1	25.0	11:15AM
	24	TA	10.5	10	10.25		WP2	24.6	
13	25	SA	15	15	15	25	WP3	24.8	
	26	TA	13	12	12.5		WP4	25.2	
14	27	SA	16	17	16.5				
	28	TA	10	10	10				
15	29	SA	14	13	13.5		WP1	26.2	11:48AM
	30	TA	14	14	14		WP2	25.8	
16	31	SA	14	15.5	14.75	55	WP3	25.8	
	32	TA	14.25	15	14.625		WP4	26.1	

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.5 Continued

DEL 23 Series 10 Vehicle Offsets – File 268B

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 9/26/07 **Truck Load –** Heavy **File –** 268B									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
17	33	SA	12.25	12.25	12.25	55			
	34	TA	18	17.5	17.75				
18	35	SA	16	16	16				
	36	TA	15	13.5	14.25				
19	37	SA	12	13	12.5	5	Afternoon Test		
	38	TA	11.5	10.5	11		WP1	27.1	3:10PM
20	39	SA	12	12	12		WP2	26.8	
	40	TA	14	13.5	13.75		WP3	26.0	
21	41	SA	12	11	11.5		WP4	25.8	
	42	TA	14	14	14				
22	43	SA	10	13	11.5	25			
	44	TA	12	10	11				
23	45	SA	14	14	14				
	46	TA	13	14	13.5				
24	47	SA	15	14.5	14.75		WP1	26.5	4:05PM
	48	TA	14	13.5	13.75		WP2	25.9	
25	49	SA	9.25	9.75	9.5	55	WP3	25.7	
	50	TA	16	15.5	15.75		WP4	25.7	
26	51	SA	8.5	8.75	8.625				
	52	TA	15.5	14.5	15				
27	53	SA	12.5	13	12.75				
	54	TA	17	16.5	16.75			End	4:18PM

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.6

DEL 23 Series 10 Vehicle Offsets – File 269B

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 9/26/07 **Truck Load –** Heavy **File –** 269B									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph))**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
1	1	SA	12.25	12.25	12.25	5	Morning Test		
	2	TA	12	12.25	12.125				9.10AM
2	3	SA	10.75	11	10.875				
	4	TA	12	11.75	11.875				
3	5	SA	12	12	12				
	6	TA	9.75	8.5	9.125				
4	7	SA	13	13	13	25			
	8	TA	15.75	16.25	16				
5	9	SA	14.5	14.5	14.5				
	10	TA	11	11.25	11.125				
6	11	SA	13.5	14.5	14				
	12	TA	9.25	8.75	9				
7	13	SA	5.5	6.25	5.875	55			
	14	TA	10.25	11	10.625				
8	15	SA	9.75	11.25	10.5				
	16	TA	9.5	9.5	9.5				
9	17	SA	12.25	11.5	11.875				
	18	TA	11.5	12.5	12				
10	19	SA	11.5	11.5	11.5	5			10.30A
	20	TA	11.75	11.75	11.75				
11	21	SA	11.25	11.75	11.5				
	22	TA	9.25	9.75	9.5				
12	23	SA	9.5	9	9.25				
	24	TA	7.5	6.75	7.125				
13	25	SA	11.75	11.75	11.75	25			
	26	TA	15.25	15.5	15.375				
14	27	SA	15.5	14.25	14.875				
	28	TA	12.75	12.75	12.75				
15	29	SA	10.5	10.5	10.5				
	30	TA	13.5	14.25	13.875				
16	31	SA	11.5	11.5	11.5	55			
	32	TA	10.25	11.75	11				

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.6 Continued

DEL 23 Series 10 Vehicle Offsets – File 269B

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 9/26/07 **Truck Load –** Heavy **File –** 269B									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
17	33	SA	12	11.5	11.75	55			11:30AM
	34	TA	11	11.25	11.125				
18	35	SA	9	8.75	8.875				
	36	TA	12.5	12.25	12.375				
19	37	SA	14.25	13	13.625	5	Afternoon Test		
	38	TA	13	12.5	12.75				3:10PM
20	39	SA	12.5	12	12.25				
	40	TA	12	12.5	12.25				
21	41	SA	10.25	11.25	10.75				
	42	TA	12	12.25	12.125				
22	43	SA	15.75	17	16.375	25			
	44	TA	13.5	13	13.25				
23	45	SA	17.75	17	17.375				
	46	TA	11.5	11.25	11.375				
24	47	SA	13	13.5	13.25				
	48	TA	10.75	10.75	10.75				
25	49	SA	12.5	13.25	12.875	55			
	50	TA	8.75	8.5	8.625				
26	51	SA	10.75	11.75	11.25				
	52	TA	13.25	12.75	13				
27	53	SA	15.5	16	15.75				
	54	TA	14.5	13.5	14				

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.7

DEL 23 Series 10 Vehicle Offsets – File 270B

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 9/26/07 **Truck Load –** Heavy **File –** 270B									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph))**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
1	1	SA	15	16.25	15.625	5	Morning Test		
	2	TA	13.5	13.75	13.625				9.10AM
2	3	SA	9.75	10.75	10.25				
	4	TA	9	8.75	8.875				
3	5	SA	11	12	11.5				
	6	TA	12.25	12	12.125				
4	7	SA	15.25	15.5	15.375	25			
	8	TA	13.25	13.25	13.25				
5	9	SA	13.75	13.5	13.625				
	10	TA	12.5	11.75	12.125				
6	11	SA	14.5	12.25	13.375				
	12	TA	9.5	10.75	10.125				
7	13	SA	6.5	6.5	6.5	55			
	14	TA	14.25	14	14.125				
8	15	SA	16	16.25	16.125				
	16	TA	10.5	11.5	11				
9	17	SA	10	9.5	9.75				
	18	TA	9.25	9.5	9.375				
10	19	SA	10	10.5	10.25	5			10.30AM
	20	TA	11.25	11.5	11.375				
11	21	SA	10.5	10.25	10.375				
	22	TA	10	10.25	10.125				
12	23	SA	8.75	8.75	8.75				
	24	TA	7	8.5	7.75				
13	25	SA	13.25	13.5	13.375	25			
	26	TA	10.5	10.5	10.5				
14	27	SA	11	10.75	10.875				
	28	TA	11	10.25	10.625				
15	29	SA	18.5	18	18.25				
	30	TA	12.5	12	12.25				
16	31	SA	6.5	7	6.75	55			
	32	TA	17	16.75	16.875				

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.7 Continued

DEL 23 Series 10 Vehicle Offsets – File 270B

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 9/26/07 **Truck Load –** Heavy **File –** 270B									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
17	33	SA	7	5.75	6.375	55			11:30A
	34	TA	11.5	11.25	11.375				
18	35	SA	8.75	8.5	8.625				
	36	TA	8	6.75	7.375				
19	37	SA	8.25	8.75	8.5	5	Afternoon Test		
	38	TA	11.5	12.5	12				3:10PM
20	39	SA	10	10.5	10.25				
	40	TA	11.25	10.25	10.75				
21	41	SA	12.25	12.75	12.5				
	42	TA	13.75	14	13.875				
22	43	SA	15.25	14.5	14.875	25			
	44	TA	10.5	10.5	10.5				
23	45	SA	16.75	17.5	17.125				
	46	TA	11.5	12	11.75				
24	47	SA	13.5	13.5	13.5				
	48	TA	13	13.75	13.375				
25	49	SA	19.25	19.25	19.25	55			
	50	TA	12.5	12.5	12.5				
26	51	SA	15.5	15.5	15.5				
	52	TA	14.25	14.25	14.25				
27	53	SA	18.25	19	18.625				
	54	TA	9	6	7.5				

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.8

DEL 23 Series 10 Vehicle Offsets – File 271B

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 9/26/07 **Truck Load –** Heavy **File –** 271B									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph))**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
1	1	SA	15	16.25	15.625	5	Morning Test		
	2	TA	14.25	13.75	14				9:10AM
2	3	SA	9.5	9.75	9.625				
	4	TA	12	12.25	12.125				
3	5	SA	14	12	13				
	6	TA	9.5	9.25	9.375				9:35AM
4	7	SA	9.25	9	9.125	25			
	8	TA	8.5	9	8.75				
5	9	SA	6.5	6.75	6.625				
	10	TA	14.5	13.75	14.125				
6	11	SA	6	6.75	6.375				
	12	TA	10	9.25	9.625				10:00A
7	13	SA	8	8.25	8.125	55			
	14	TA	12.25	12.5	12.375				
8	15	SA	11	10.25	10.625				
	16	TA	11.5	12	11.75				
9	17	SA	6.5	7	6.75				
	18	TA	19.5	19.25	19.375				10:20A
10	19	SA	11	11	11	5			10:40A
	20	TA	11.5	11	11.25				
11	21	SA	11.5	10.25	10.875				
	22	TA	10.5	10.5	10.5				
12	23	SA	11.5	11.5	11.5				
	24	TA	7.5	7	7.25				11:00A
13	25	SA	8.5	8	8.25	25			
	26	TA	11	10	10.5				
14	27	SA	8.5	7.5	8				
	28	TA	11.75	10.75	11.25				
15	29	SA	4.5	4	4.25				
	30	TA	13	13.75	13.375				11:30A

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.8 Continued

DEL 23 Series 10 Vehicle Offsets – File 271B

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 9/26/07 **Truck Load –** Heavy **File –** 271B									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
16	31	SA	6.75	7	6.875	55			11:35AM
	32	TA	15.5	15	15.25				
17	33	SA	10	8.5	9.25				
	34	TA	16	15	15.5				
18	35	SA	4.5	5	4.75				11:50AM
	36	TA	16.75	16.75	16.75				
	37	SA	False Alarm			Afternoon Test			
19	38	SA	10.5	10.5	10.5	5			3:20PM
	39	TA	9.25	9.75	9.5				
20	40	SA	10	9.5	9.75				
	41	TA	9	9	9				
21	42	SA	11	11	11				
	43	TA	10.25	10	10.125				3:40PM
22	44	SA	6	7	6.5	25			
	45	TA	13	13.25	13.125				
23	46	SA	9.5	9.5	9.5				
	47	TA	12.25	12.25	12.25				
24	48	SA	11	11	11				
	49	TA	14	14.5	14.25				4:00PM
25	50	SA	7.5	11	9.25	55			
	51	TA	18.5	17.75	18.125				
26	52	SA	14.5	11.5	13				
	53	TA	14	14	14				
27	54	SA	15	15	15				
	55	TA	19	19	19				

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.9

DEL 23 Series 10 Vehicle Offsets – File 272B

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 9/26/07 **Truck Load –** Heavy **File –** 272B									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
1	1	SA	14	12.5	13.25	5	Morning Test		
	2	TA	16.5	17	16.75				9:10AM
2	3	SA	15.5	11.5	13.5				
	4	TA	14.25	12.5	13.375				
3	5	SA	11.5	11	11.25				
	6	TA	12	11.5	11.75				9:35AM
4	7	SA	14	15	14.5	25			9:36AM
	8	TA	13.75	13.5	13.625				
5	9	SA	14	14.5	14.25				
	10	TA	13.75	13.5	13.625				
6	11	SA	14	14	14				
	12	TA	11.5	11.25	11.375				
7	13	SA	12	12.5	12.25	55			10:00AM
	14	TA	12.5	12.5	12.5				
8	15	SA	10	10.5	10.25				
	16	TA	15.5	15.25	15.375				
9	17	SA	11.25	11.75	11.5				
	18	TA	20.5	20.5	20.5				10:20AM
10	19	SA	12.5	10.75	11.625	5			10:40AM
	20	TA	13	12.25	12.625				
11	21	SA	9.25	8.25	8.75				
	22	TA	13.75	13.25	13.5				
12	23	SA	12	13	12.5				
	24	TA	8.5	7.5	8				11:00AM
13	25	SA	9.75	9.5	9.625	25			
	26	TA	11.75	12.5	12.125				
14	27	SA	11.5	11	11.25				
	28	TA	10.25	11	10.625				
15	29	SA	13	12	12.5				
	30	TA	15	14	14.5				11:30AM

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.9 Continued

DEL 23 Series 10 Vehicle Offsets – File 272B

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 9/26/07 **Truck Load –** Heavy **File –** 272B									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
16	31	SA	7.5	11.5	9.5	55			11:30AM
	32	TA	14	14.5	14.25				
17	33	SA	7	7	7				
	34	TA	13.25	11.5	12.375				
18	35	SA	10.75	11.25	11				11:50AM
	36	TA	14.5	14	14.25				
	37	SA	False Alarm			Afternoon Test			
19	38	SA	10.25	8.5	9.375	5			3:20PM
	39	TA	16	15.5	15.75				
20	40	SA	10.75	10.5	10.625				
	41	TA	13.25	13	13.125				
21	42	SA	13.5	13	13.25				
	43	TA	12.25	11.5	11.875				3:40PM
22	44	SA	15	14.25	14.625	25			
	45	TA	11.5	10.5	11				
23	46	SA	12	11	11.5				
	47	TA	13.25	13	13.125				
24	48	SA	14	13.75	13.875				
	49	TA	16	15.5	15.75				4:00PM
25	50	SA	11.5	11	11.25	55			
	51	TA	15.5	15	15.25				
26	52	SA	15.5	15.5	15.5				
	53	TA	14.5	14.5	14.5				
27	54	SA	15.25	14.5	14.875				
	55	TA	18	17					

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.10

DEL 23 Series 10 Vehicle Offsets – File 268C

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 10/1/07 **Truck Load –** Light **File –** 268C									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
1	1	SA	11	12	11.5	5	WP	20.2	10:40AM
	2	TA	13	14	13.5		WP	20.5	
2	3	SA	14	14	14		WP	21.6	
	4	TA	14	15	14.5		WP	22.2	
3	5	SA	15	15	15				
	6	TA	11	11	11		WP	21.9	
4	7	SA	13	13	13	25	WP	20.8	11:25AM
	8	TA	12	12	12		WP	20.9	
5	9	SA	13	13	13		WP	21.9	
	10	TA	12.5	13	12.75				
6	11	SA	13	13	13		WP	22.5	11:47PM
	12	TA	13	13.5	13.25		WP	21.8	
7	13	SA	13.5	13.5	13.5	55	WP	21.7	
	14	TA	15.5	15	15.25		WP	22.2	
8	15	SA	12	12	12		WP	23.5	12:26PM
	16	TA	16.5	16	16.25		WP	22.3	
9	17	SA	15	14	14.5		WP	22.4	
	18	TA	11.5	12	11.75		WP	22.8	
10	19	SA	29.5	29	29.25	5	White Line		
	20	TA	34.5	35	34.75				
11	21	SA	51	49.5	50.25		(EOP)		
	22	TA	49	46.5	47.75				

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.11

DEL 23 Series 10 Vehicle Offsets – File 269C

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 10/1/07 **Truck Load –** Light **File –** 269C									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
1	1	SA	15	14.75	14.875	5			10:45AM
	2	TA	13.75	13.5	13.625				
2	3	SA	16	15.75	15.875				
	4	TA	15.5	15	15.25				
3	5	SA	14	14.75	14.375				
	6	TA	11	10.34	10.67				
4	7	SA	14.25	14.5	14.375	25			
	8	TA	13	12	12.5				
5	9	SA	14.25	14.25	14.25				
	10	TA	11.75	13	12.375				
6	11	SA	12.5	13.5	13				
	12	TA	6.5	6	6.25				
7	13	SA	9.75	9.75	9.75	55			
	14	TA	11.75	11.5	11.625				
8	15	SA	8.5	9.25	8.875				
	16	TA	15	14.5	14.75				
9	17	SA	13	14	13.5				
	18	TA	12.5	12.5	12.5				
10	19	SA	45.25	45.25	45.25	5	White Line		
	20	TA	40	39.5	39.75				
11	21	SA	52	50.5	51.25		(EOP)		
	22	TA	51	50.25	50.625				

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.12

DEL 23 Series 10 Vehicle Offsets – File 270C

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 10/1/07 **Truck Load –** Light **File –** 270C									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
1	1	SA	14.75	14.25	14.5	5			10:45AM
	2	TA	13.5	13.75	13.625				
2	3	SA	14.5	13.5	14				
	4	TA	15.25	15	15.125				
3	5	SA	13	13	13				
	6	TA	10	10.25	10.125				
4	7	SA	14	13.25	13.625	25			
	8	TA	10.25	9.75	10				
5	9	SA	14.25	14.25	14.25				
	10	TA	15	14.75	14.875				
6	11	SA	14	14	14				
	12	TA	8.75	9.25	9				
7	13	SA	12	12	12	55			
	14	TA	11	10.5	10.75				
8	15	SA	13.25	14.5	13.875				
	16	TA	14	13.25	13.625				
9	17	SA	18.75	18.75	18.75				
	18	TA	13.5	13.75	13.625				
10	19	SA	43	41.25	42.125	5	White Line		
	20	TA	37.75	36.25	37				
11	21	SA	51.25	51	51.125		(EOP)		
	22	TA	51.5	52.5	52				

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.13

DEL 23 Series 10 Vehicle Offsets – File 271C

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 10/1/07 **Truck Load –** Light **File –** 271C									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
1	1	SA	14.25	15	14.625	5			10:45AM
	2	TA	13	13	13				
2	3	SA	9.5	9.75	9.625				
	4	TA	11.5	11.5	11.5				
3	5	SA	11.75	11.75	11.75				
	6	TA	9.75	9.5	9.625				11:10AM
4	7	SA	7.75	7	7.375	25			
	8	TA	10.75	10.5	10.625				
5	9	SA	8	8	8				
	10	TA	12.75	13.5	13.125				
6	11	SA	6	6	6				
	12	TA	10	9.75	9.875				11:35AM
7	13	SA	8	8	8	55			
	14	TA	12.25	12	12.125				
8	15	SA	10.25	11	10.625				
	16	TA	12	11.75	11.875				
9	17	SA	19.25	19.75	19.5				
	18	TA	17	16.5	16.75				12:06PM
10	19	SA	45.5	45	45.25	5	White Line		
	20	TA	38	38.25	38.125				12:23PM
11	21	SA	51.25	50.5	50.875		(EOP)		
	22	TA	54	52.25	53.125				12:34PM

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck
1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

Table A.14

DEL 23 Series 10 Vehicle Offsets – File 272C

DEL 23 Series 10 Controlled Vehicle Tests – PCC Replacement Sections									
Date – 10/1/07 **Truck Load –** Light **File –** 272C									
Run No.	**Data Set**	**Truck Type***	**Wheel Offset (in.)**			**Nominal Speed (mph)**	**Pavement Temp. °C**		**Time**
			Approach	**Leave**	**Average**				
1	1	SA	12	13.25	12.625	5			10:45AM
	2	TA	14.5	14.25	14.375				
2	3	SA	11	10.25	10.625				
	4	TA	12	11.25	11.625				
3	5	SA	11.75	11.75	11.75				
	6	TA	12.5	13	12.75				11:10AM
4	7	SA	9.5	9	9.25	25			
	8	TA	8.75	8	8.375				
5	9	SA	9.5	8.5	9				
	10	TA	17.5	17.5	17.5				
6	11	SA	10	10.25	10.125				
	12	TA	10.25	9.75	10				11:35AM
7	13	SA	11.25	11.5	11.375	55			
	14	TA	12.25	11.75	12				
8	15	SA	14.75	15.5	15.125				
	16	TA	10.5	10.25	10.375				
9	17	SA	18.5	17.25	17.875				
	18	TA	12.25	11.75	12				12:06PM
10	19	SA	45	43.5	44.25	5	White Line		
	20	TA	41.25	41.25	41.25				12:23PM
11	21	SA	53	50.75	51.875		(EOP)		
	22	TA	50	49.25	49.625				12:34PM

* SA: Single Axle ODOT Dump Truck. TA: Tandem Axle ODOT Dump Truck

1 inch = 2.54 cm, 5 mph = 8.0 kph, 25 mph = 40.2 kph, 55 mph = 88.5 mph, °F = 9/5(°C)+32

APPENDIX B

Use of the FWD Df1/Df7 Ratio on New SPS Pavements

Over the years, ODOT used two Dynaflect trailers to evaluate pavement stiffness and to design the thickness of AC overlays on distressed AC and PCC pavements. It was sometimes necessary to determine if asphalt concrete was covering a rigid layer of PC concrete in a pavement structure and to locate the beginning and ending limits of the concrete layer when historical data were not available. W1/W5 ratios greater than 3 indicated no PC concrete was present and W1/W5 ratios less than 3 indicated a rigid material like PC concrete or cement stabilized base was present in the pavement structure. This ratio was useful in the field to monitor changes in stiffness. As the FWD is being used more frequently to evaluate pavements, it was decided to explore the possibility of using a similar ratio with output from the first (Df1) and seventh (Df7) sensors on that device. To assemble a population of FWD data representing a broad spectrum of AC and PCC pavement stiffnesses, Df1 and Df7 were plotted in Figure 1 for centerline and right wheelpath readings from SPS-1 (AC), SPS-2 (PCC) and SPS-9 (AC) test sections on the Ohio SHRP Test Road before it was opened to traffic in August 1996. Additional data were used from SPS-8 (AC & PCC) sections, which were opened to traffic in 1994.

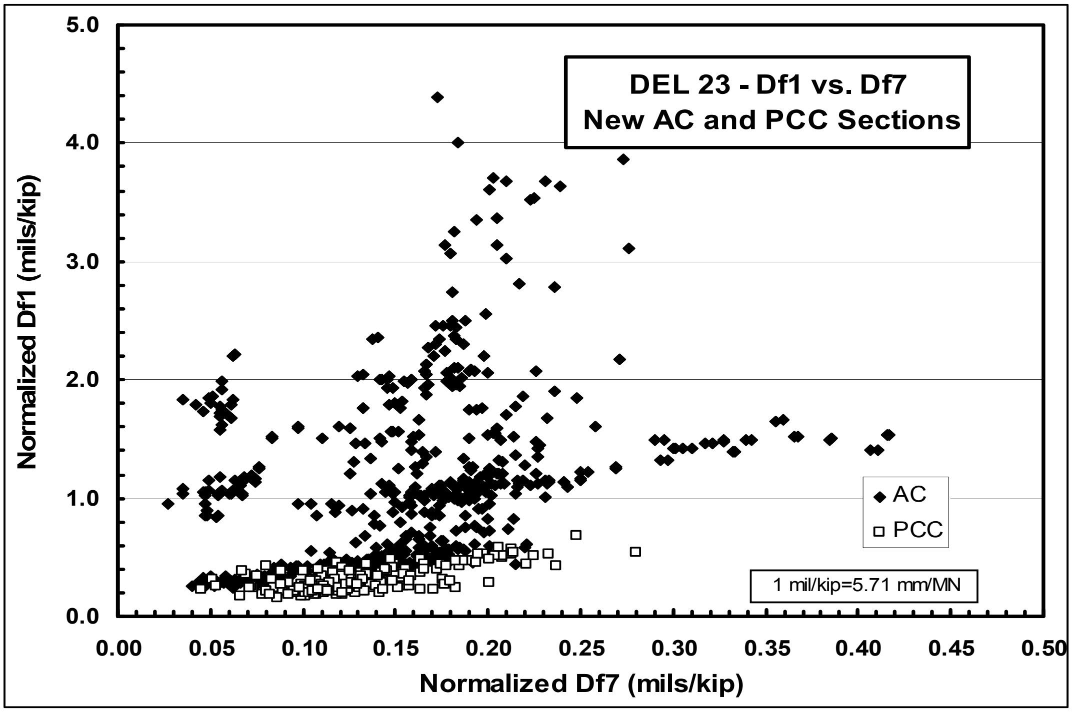


Figure B.1 – Df1 vs. Df7 on New SHRP SPS Sections

Sections in the SPS experiments were grouped into three levels of performance using years of service to replacement as the criterion. Four SPS-1 sections and two SPS-8AC sections showed early distress and were replaced by 1998. These AC sections were considered to have poor performance. Four other AC sections in the SPS-1 experiment were removed from service in 2002 and were considered to have fair performance. Sections in the SPS-1 experiment still in service, the more robust replacement sections in SPS-1, and the three SPS-9 sections were considered to have good performance. The two SPS-8AC replacement sections were of the same design as the original sections with the addition of a lime stabilized subgrade. Figures 2, 3 and 4 show DF1 vs. Df7 plots for the three AC performance levels with best-fit trendlines and Df1/Df7 slopes of 3, 5 and 7 approximating the limits of performance. Sections with Df1/Df7 ratios above 7 fell into the poor performance category. Section numbers from which the data were obtained are identified in the figure titles. Figure 5 shows data for the three groups in one graph.

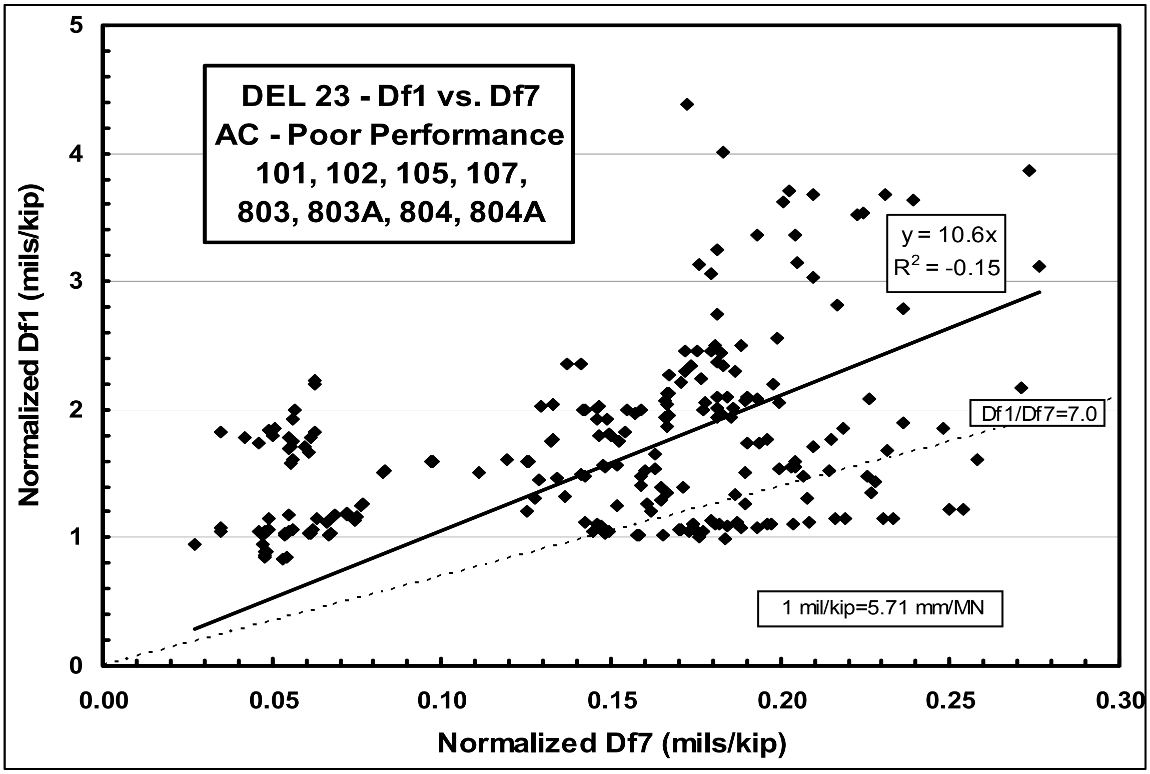


Figure B.2 – Df1 vs. Df7 for AC Sections with Poor Performance

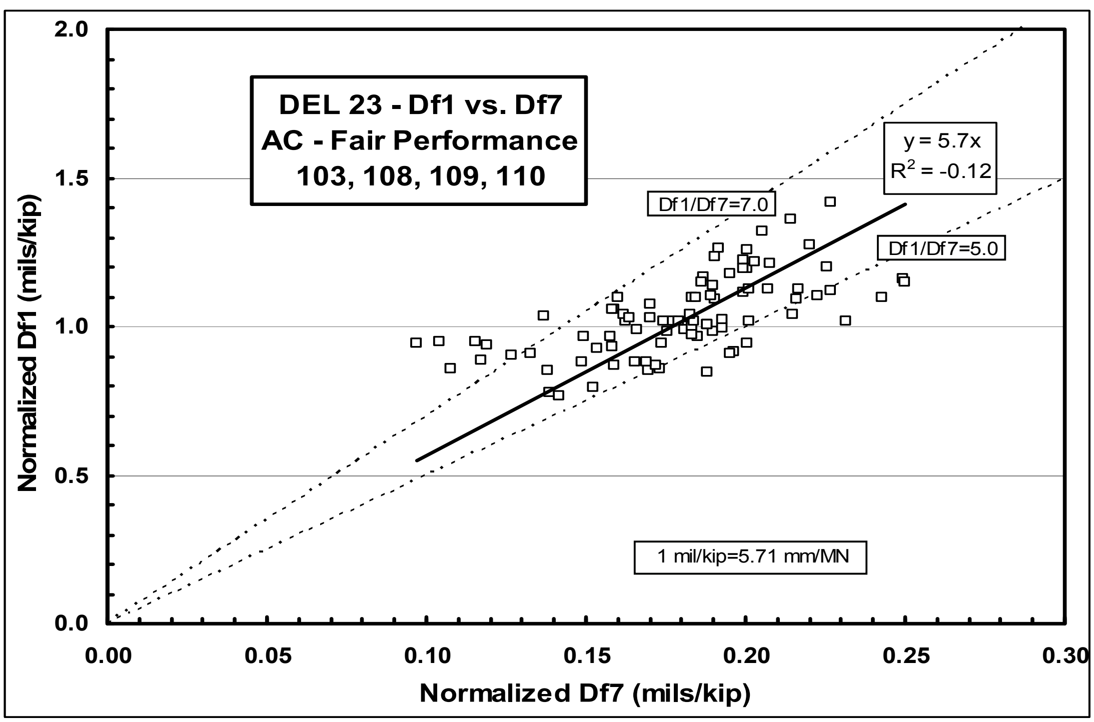


Figure B.3 – Df1 vs. Df7 for AC Sections with Fair Performance

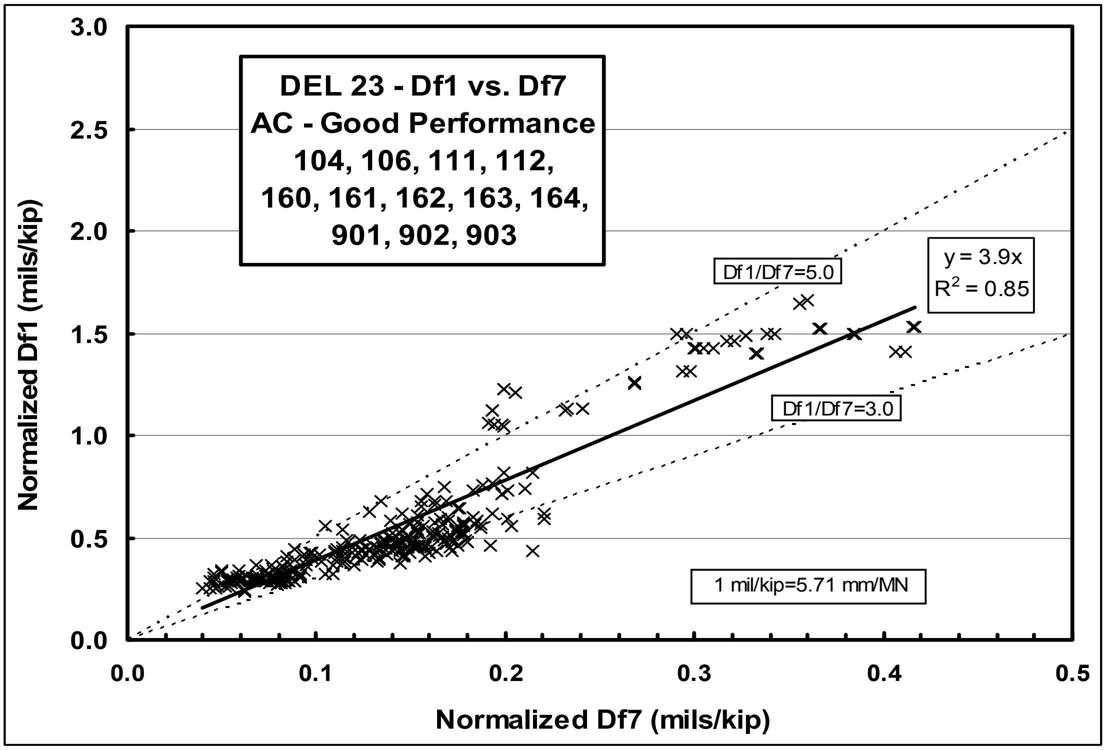
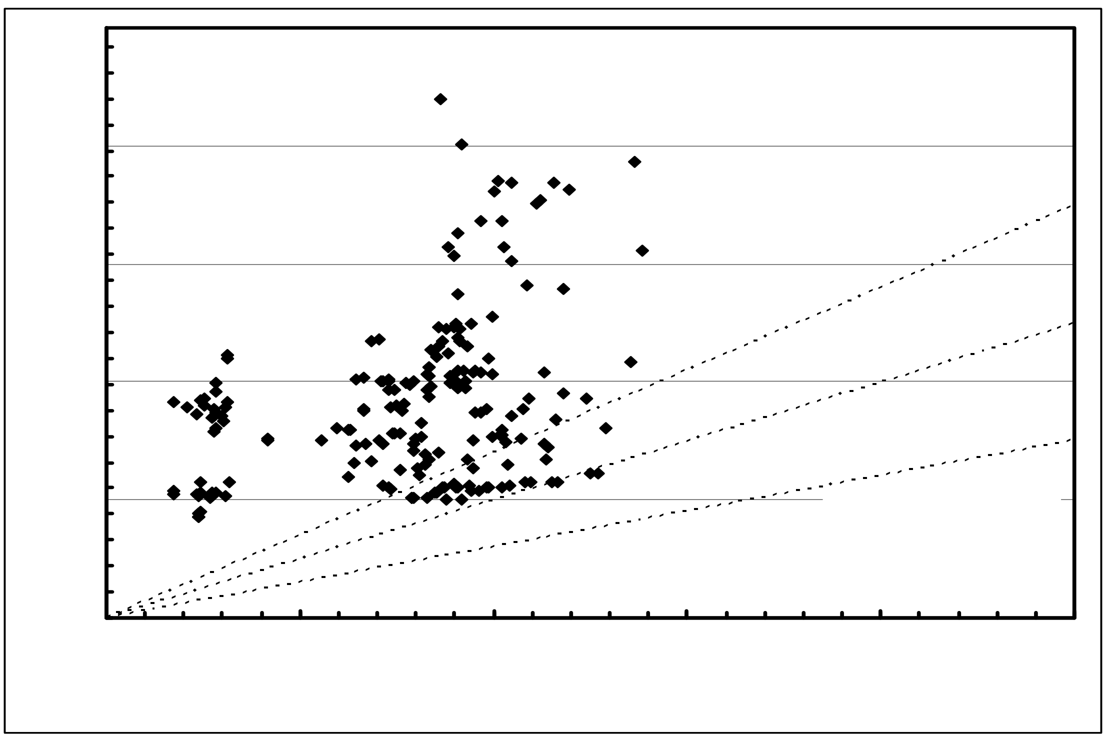


Figure B.4 – Df1 vs. Df7 for AC Sections with Good Performance



The plots in Figures 2-5 show clear differences in the ranges of Df1/Df7 ratios for the three levels of service on AC pavements. Ratios above 7 indicate poor service, ratios of 5 to 7 indicate fair service and ratios below 5 indicate good service. The large cluster of AC pavement sections having a Df1/Df7 ratio around 3 can be considered as providing excellent service.

On the SPS-2 pavement sections, fair performance was assigned to the first group of PCC sections closed for replacement in 2006, and good performance was assigned to PCC sections remaining in service to the present time. Figures 6 and 7 show plots of Df1/Df7 for these fair and good categories of PCC pavement performance, and Figure 8 shows the data combined. While the good sections have a slightly lower average Df1/Df7 ratio than the fair sections, the differences in FWD response are too small to reliably separate these levels of performance.

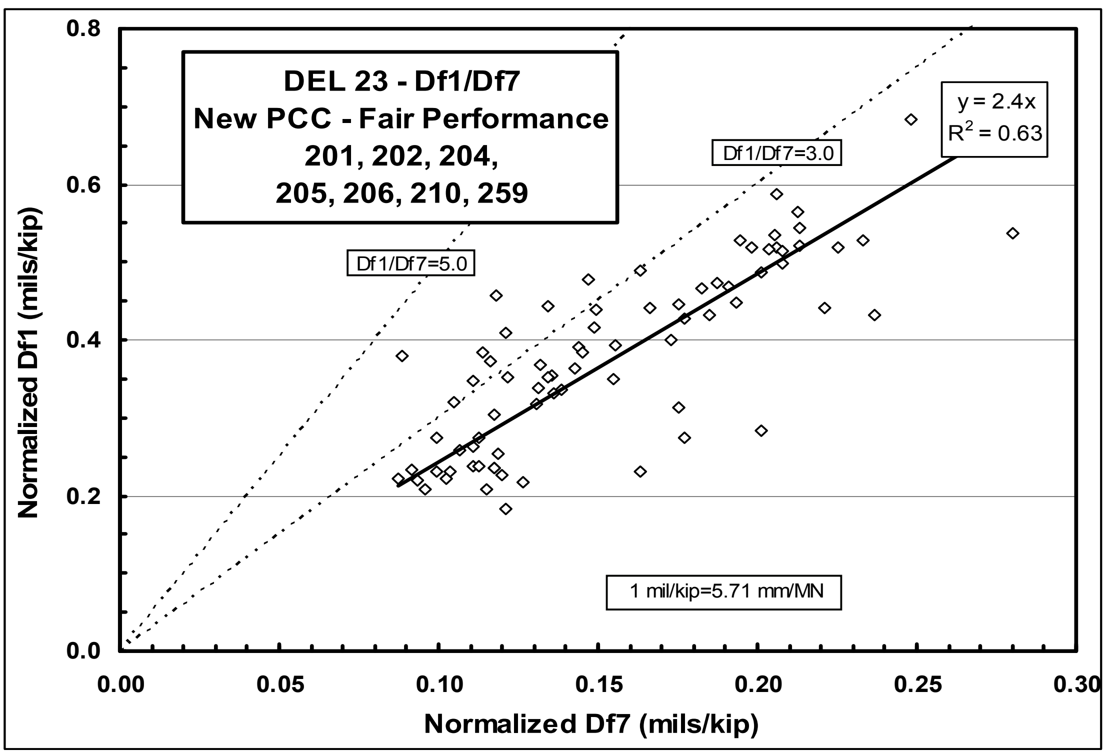


Figure B.6 - Df1 vs. Df7 for PCC Sections with Fair Performance

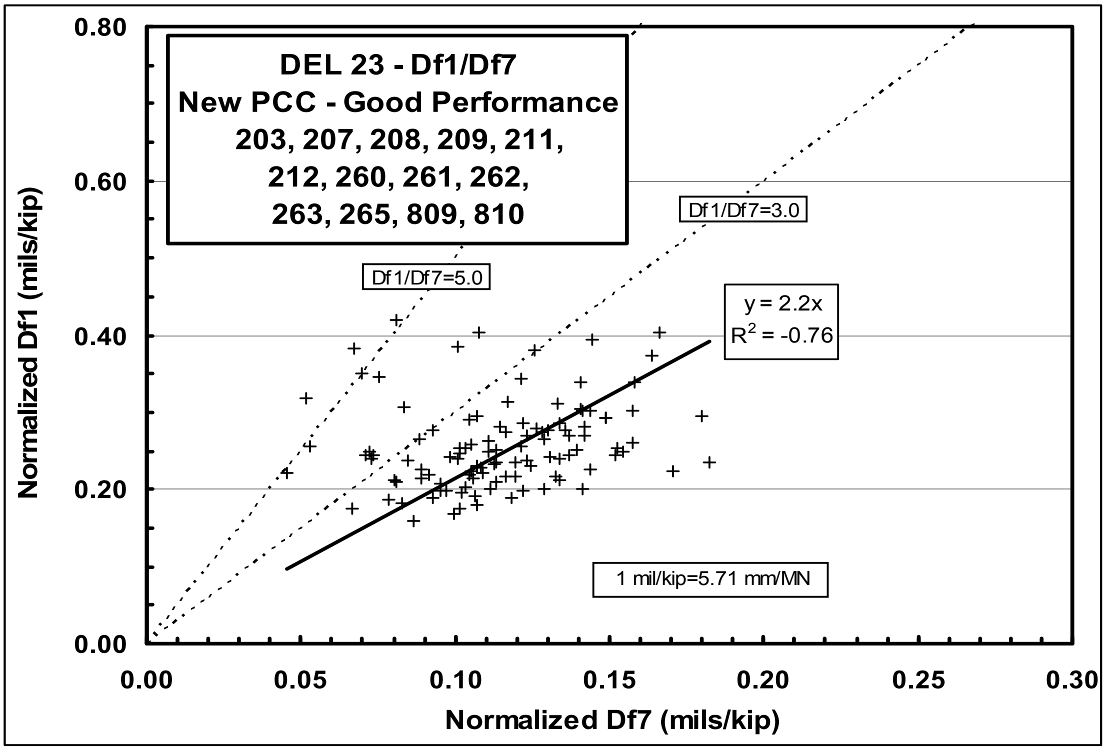


Figure B.7 - Df1 vs. Df7 for PCC Sections with Good Performance

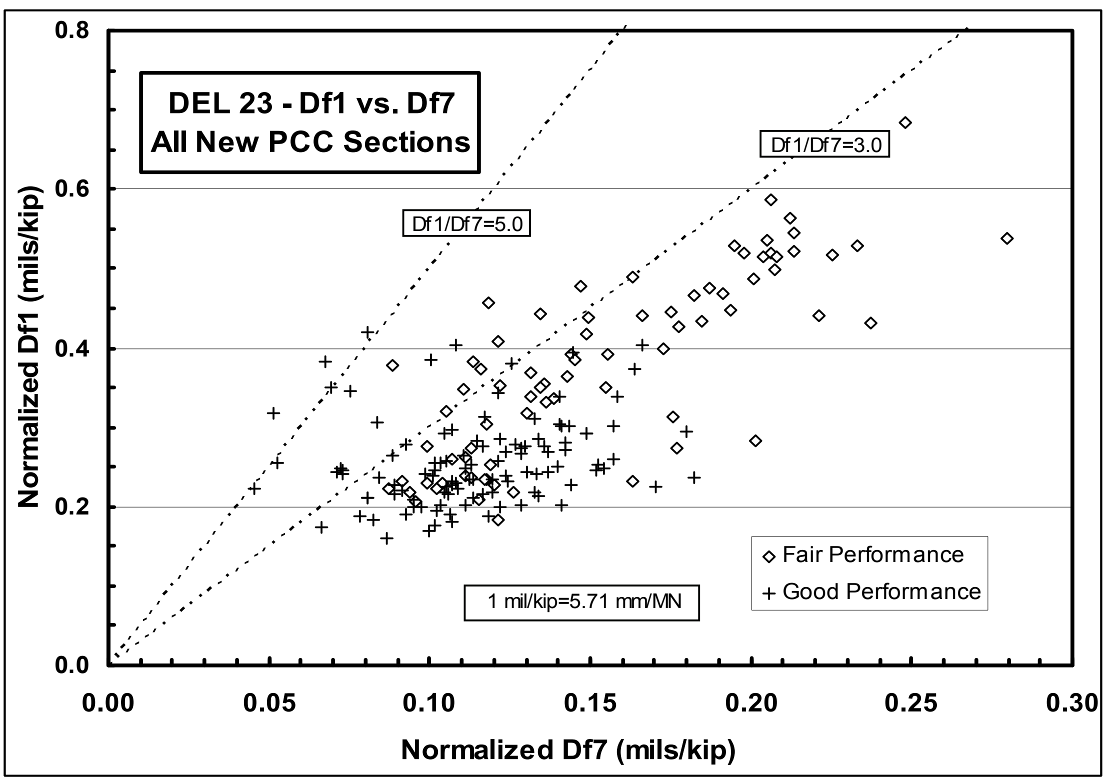


Figure B.8 - Df1 vs. Df7 for all PCC Sections

As was stated earlier, the Dynaflect W1/W5 ratio was useful in determining if a cementitious layer of material was located in the pavement structure. To apply this same principle to the FWD, an effort was made to use Df1/Df7 ratios to distinguish between AC and PCC pavements considered to have good performance. Weaker AC pavements would be easier to identify on the basis of a higher Df1/Df7 ratio. Figure 9 shows a plot of Df1/Df7 ratios for the good AC and good PCC pavements with the PCC pavements appearing to have slightly lower values of Df1/Df7. Figure 10 shows a blow-up of the congested data in Figure 9.

A best-fit line was calculated to separate the two types of pavement by having an equal percentage of AC pavements below the line as the percentage of PCC pavements above the line. This line was developed by calculating Df1/Df7 for all data in the plot, sorting the data from low to high on the AC sections and high to low on the PCC sections, calculating cumulative percentages above or below the starting points, and plotting the cumulative percentages, as in Figure 11, to identify the value of Df1/Df7 at which the lines cross. This crossing is where an equal percentage of AC and PCC points lie below and above that ratio, respectively. In Figure 11, the Df1/Df7 ratio separating AC and PCC pavements is 3.02 with an accuracy of about 86% of points for both pavements meeting that criterion. It is interesting that 12 of the 14 points for PCC sections in Figure 10 having a Df1/Df7 ratio greater than 3 were on Sections 209, 211 and 261, which were sections on either end of the weigh-in-motion scales. The high Df1/Df7 ratios on these sections probably reflect some common type of problem, such as a wet subgrade, which allows more curvature of the pavement under load. Another criterion for separating AC and PCC pavements in Figure 10 is that, when normalized Df7 is less than 0.10 mils/kip (0.57 mm/MN), AC pavements rarely have a maximum normalized deflection less than about 0.28 mils/kip (1.60 mm/MN), while PCC pavements rarely have a maximum normalized deflection more than 0.28 mils/kip (1.60 mm/MN).

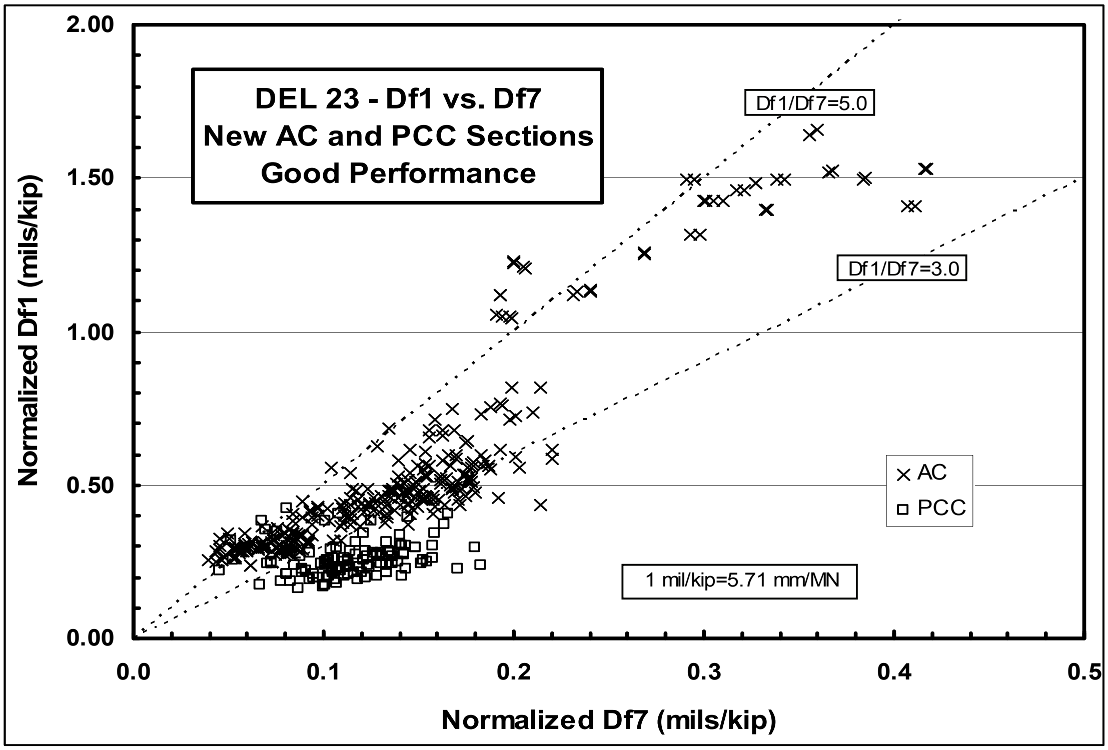


Figure B.9 – Df1 vs. Df7 for Good AC and Good PCC Pavements

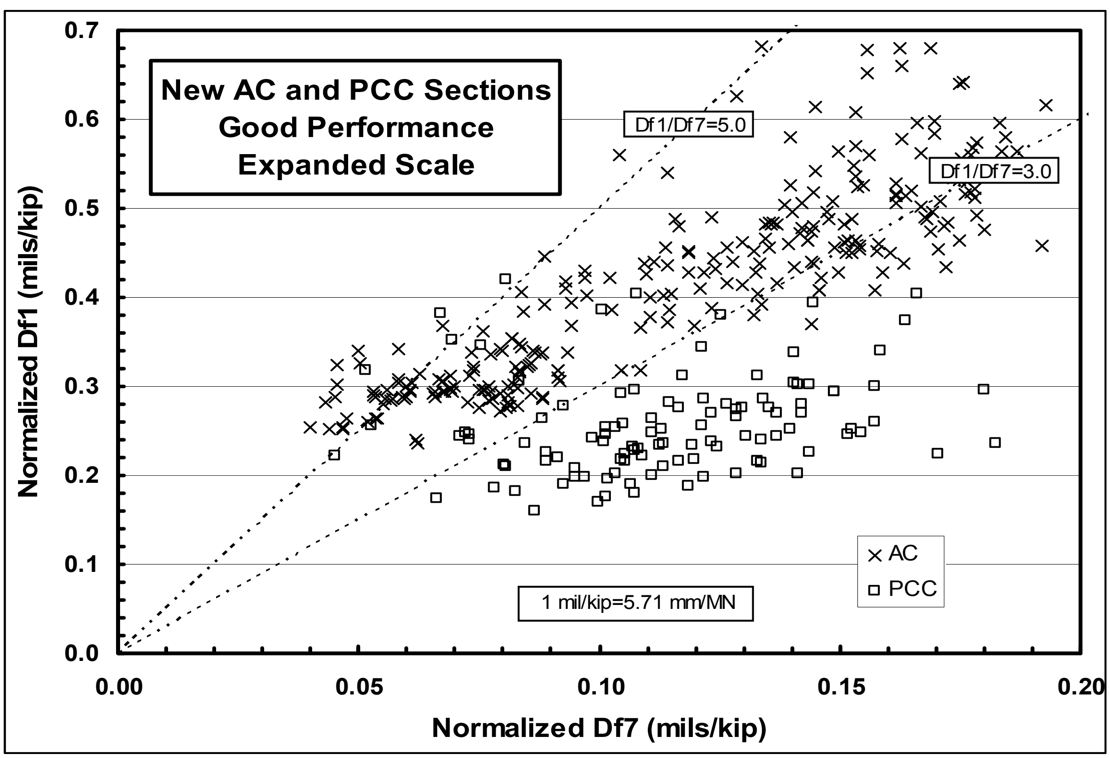


Figure B.10 – Expanded Scales for Df1/Df7 on Good Pavements

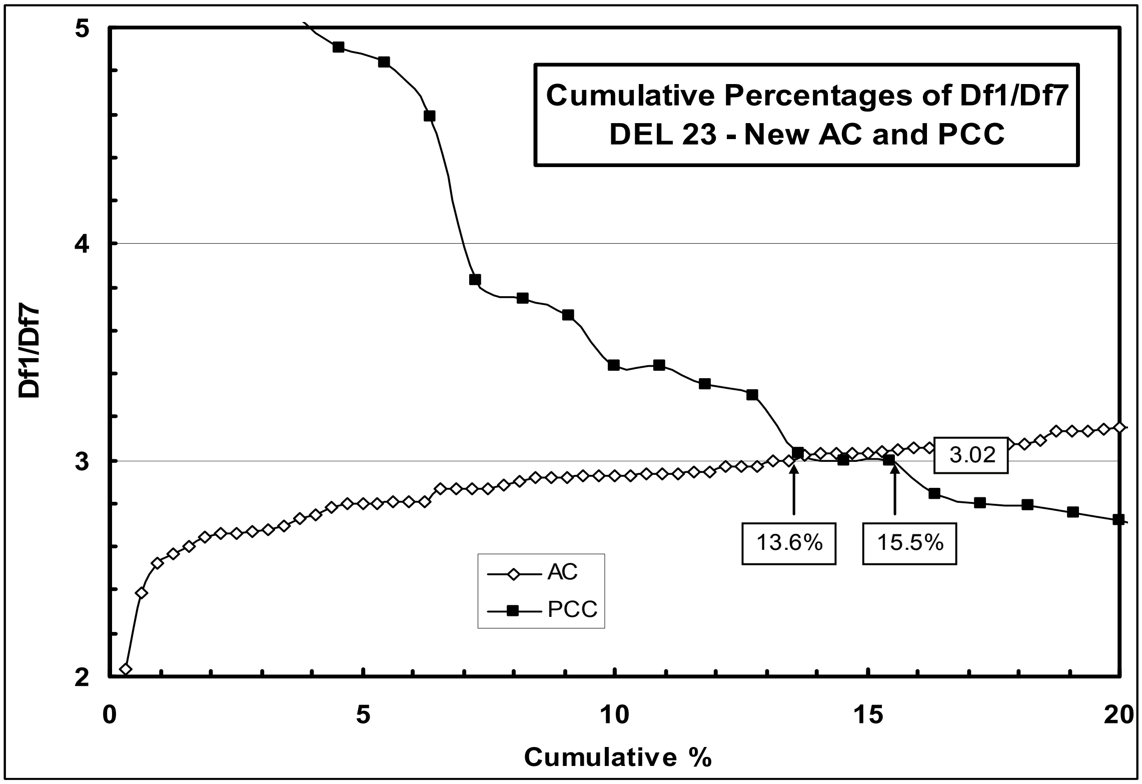


Figure B.11 – Cumulative Percentage Plots of Df1/Df7 for AC and PCC Pavements

Another parameter often used to evaluate pavement stiffness is Spreadability (SPR), which is the average of the five or seven deflections measured with the Dynaflect or FWD, divided by the first deflection, and expressed as a percent. A minimum Spreadability of 20% on the Dynaflect or 14% on the FWD indicates an extremely weak pavement structure with deflections only being recorded on the first geophone. A maximum Spreadability of 100% on both units indicates an infinitely rigid pavement where all geophones have the same reading. In general, AC pavements have Spreadabilities of 60-80% while PCC pavements have Spreadabilities of 75-85%. To check the relationship between Spreadability and Df1/Df7, a log-log plot is shown in Figure 12, where a power trendline shows an excellent relationship between the two parameters. Considering the ease with which Df1/Df7 can be calculated, there is little need to calculate Spreadability in the future. A table is inserted in the plot to show Spreadabilities correlating to the key Df1/Df7 ratios used in this analysis.

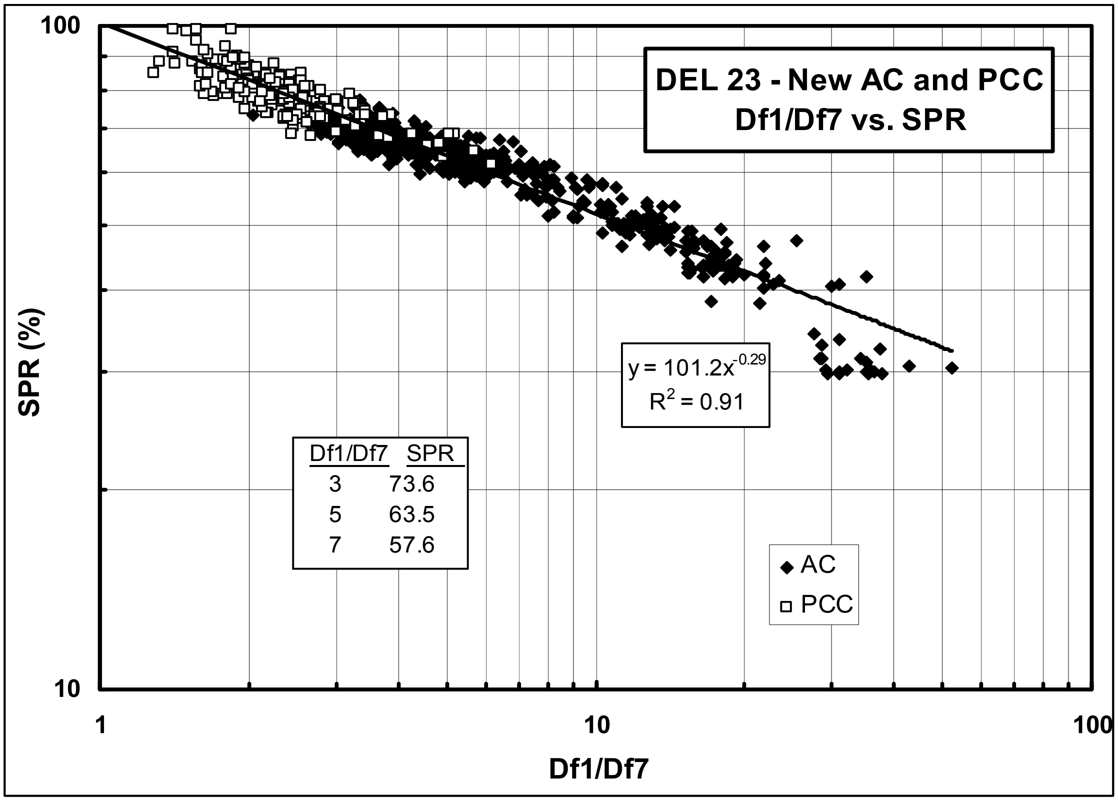


Figure B.12 – Df1/Df7 vs. Spreadability for AC and PCC Pavements

In summary, Df1/Df7 ratios from the FWD can be used as a rough indicator of AC pavement performance. A ratio of about 3 suggests excellent performance, a ratio of 3 to 5 indicates good performance, a ratio of 5 to 7 suggests fair performance, and a ratio of over 7 suggests poor performance. Perpetual AC pavements are expected to be in the 3 to 5 range. A Df1/Df7 ratio of 3 can be used to differentiate AC from PCC pavements with an accuracy of about 86%.

On PCC pavements, the Df1/Df7 ratio cannot reliably serve as an indicator of performance. If the ratio is much above 3 on rigid pavements, the subgrade may be wet or significant cracking may be present which allows the higher surface deformations. Also, if normalized Df7 is less than 0.10 mils/kip (0.57 mm/MN), normalized Df1 on AC pavements will typically be above 0.28 mils/kip (1.60 mm/MN), while normalized Df1 on PCC pavements will typically be less than 0.28 mils/kip (1.60 mm/MN).

Because an excellent correlation appears to exist between Df1/Df7 and SPR on AC and PCC pavements, there is little need to perform the extra calculations associated with SPR, especially in the field.

APPENDIX C

Distress Survey Notes

WAY30

March 22 2007

Section 283 (PCC section at Station 664)
Inspected 300 ft, no defects or cracks detected.

Section 284 (PCC section at Station 876)
2 longitudinal cracks @ station 874+85 (5'3", 3'43") approximately 8 inch long each at the joints
1 longitudinal crack @ 878+70 approximately mid lane
1 crack at mid lane, from mid panel to joint at station 879+30

Section 181 (AC at station 876)
No Distress
Section 182 (AC at station 664)
No Distress

October 10 2008

Sections revisited and inspected, same distress found, at 284 with no new instances.
Minor surface distress observed on both AC sections.

MEG 33

April 18 2008

Some joint seals are partially removed from the joints.
One longitudinal crack at 1246+90
Minor surface defects from station 1247+00 to 1242+00
No cracks observed from 1450+00 to 1425+00

DEL23

June 13 2007

Crack in concrete observed at 402+70 (between sections 208 and 207)

August 22 2007

Crack at station 325+00 observed.

APPENDIX D

Analysis of Traffic Data Recorded by the Weigh-in-Motion System on WAY-30

A Mettler-Toledo weigh-in-motion-system (WIM), identified as ATR #779, was installed in the eastbound and westbound driving lanes of WAY 30 just west of the CR 416 bridge at SLM 16.51. Classifiers were added to monitor traffic volumes and classifications in the passing lanes. A one week sample of complete WIM data selected to represent each month in 2009 was run through a program to obtain the distribution of daily truck volumes by lane, hour, and classification. These daily counts were summed for the week, the twelve weekly counts were totaled for the year, and these totals were adjusted to obtain an average AADTT of 2511 in the WAY 30 driving lanes for 2009. The same 84 daily WIM files were also run through a second program and combined as above to obtain a twelve week sample load spectra distribution by axle grouping (single, tandem, tridem, etc.), lane and weight bin. The sum of the twelve weekly distributions by lane, hour and classification is shown in Table D.1, and load spectra totals for the same twelve weeks are shown in Table D.2.

Based on classifier data from June 1-28, 2009, the passing lanes carry 6.72% of the total EB and 7.10% of the total WB truck traffic on WAY 30. The total calculated AADTT is 2697 for all four lanes. This figure provides an accurate estimate of daily truck traffic at the WAY 30 site in 2009 based on WIM data in the driving lanes, classifier data in the passing lanes, and lower truck traffic on weekends.

Truck volumes by driving lane direction and hour are summarized in Table D.3, truck volumes by driving lane direction and classification are provided in Table D.4. Data in Table D.3 and Table D.4 are totals from the twelve weekly samples. Average truck speeds by hour on are shown in Table D.5, based on a one-day sample of 3230 trucks on June 15, 2009. The average speed recorded is 56.8 mph (91.4 km/h), which is below the posted limit of 65 mph (105 km/h).

Table D.1 – WAY 30 Truck Distributions in 2009

WAY 30 TRUCK DISTRIBUTION FOR 2009 - Totals for 7 days in each of 12 months																	
Card:	W39	Site	779	Date:	2009			Location:	WAY 30								
Hour	Number of Trucks by Lane				Total Number of Trucks by Classification in Driving Lanes											Total No. Trucks All Lanes	% Class 9 All Lanes
	31 EB-D	32 EB-P	72 WB-P	71 WB-D	4	5	6	7	8	9	10	11	12	13	14	15		
0	1671	-	-	1739	30	204	153	70	165	2668	39	24	67	4	0	0	3424	77.9
1	1610	-	-	1621	22	323	198	48	143	2334	55	28	84	2	0	0	3237	72.1
2	1442	-	-	1720	14	224	163	36	322	2187	75	44	98	4	0	0	3167	69.1
3	1629	-	-	2244	37	298	297	57	373	2639	99	30	51	1	0	0	3882	68.0
4	2175	-	-	2307	38	459	243	117	409	3056	115	22	22	1	0	0	4482	68.2
5	3029	-	-	2937	20	890	553	141	412	3726	139	40	41	3	0	0	5965	62.5
6	4771	-	-	4098	62	1480	853	273	679	5222	226	42	21	0	0	0	8858	59.0
7	5733	-	-	5129	148	1990	970	533	773	6080	324	11	16	5	0	0	10850	56.0
8	6269	-	-	6583	123	2311	959	570	841	7601	390	14	5	11	0	0	12825	59.3
9	6732	-	-	7272	138	2198	984	569	1027	8661	397	14	4	5	0	0	13997	61.9
10	7412	-	-	7605	156	2239	982	536	1189	9408	477	7	2	9	0	0	15005	62.7
11	7467	-	-	7792	143	2213	1041	574	1092	9780	396	6	6	8	0	0	15259	64.1
12	7382	-	-	7938	146	2267	1064	566	1227	9641	384	7	0	12	0	0	15314	63.0
13	7098	-	-	7734	153	2303	1148	548	1227	9004	429	6	2	6	0	0	14826	60.7
14	6467	-	-	7481	154	2169	1119	475	1110	8545	350	6	4	5	0	0	13937	61.3
15	6013	-	-	7228	169	2236	1149	412	1093	7817	301	14	2	8	0	0	13201	59.2
16	5108	-	-	6119	174	1859	819	309	952	6891	217	1	2	7	0	0	11231	61.4
17	4391	-	-	4953	197	1439	513	257	871	5911	135	10	7	5	0	0	9345	63.3
18	3631	-	-	3775	97	979	336	190	781	4930	90	7	5	2	0	0	7417	66.5
19	2912	-	-	3258	50	697	223	130	524	4479	72	10	0	3	0	0	6188	72.4
20	2655	-	-	2638	42	487	231	113	391	3955	57	11	16	7	0	0	5310	74.5
21	2506	-	-	2320	43	429	193	100	352	3569	48	70	37	4	0	0	4845	73.7
22	2348	-	-	2182	85	441	157	83	338	3268	44	76	43	7	0	0	4542	72.0
23	1989	-	-	1828	59	337	181	91	260	2782	29	49	44	2	0	0	3834	72.6
Total	102440	-	-	108501	2300	30472	14529	6798	16551	134154	4888	549	579	121	0	0	210941	63.6
AADTT	1220	-	-	1292	27	363	173	81	197	1597	58	7	7	1	0	0	2511	
% of Total	48.6	-	-	51.4	1.1	14.4	6.9	3.2	7.8	63.6	2.3	0.3	0.3	0.1	0.0	0.0		

Table D.2 - WAY 30 Load Spectra in 2009

WAY 30 LOAD SPECTRA FOR 2009 - Totals for 7 days in each of 12 months

Card: W39 | Site: 779 | Date: 2009 | Location: WAY 30

Single Axle Wt. Kips	Lane 31	Lane 32	Lane 72	Lane 71	Sum	Tandem Axles Wt. Kips	Lane 31	Lane 32	Lane 72	Lane 71	Sum
3	2566	-	-	2935	5501	6	824	-	-	899	1723
4	9051	-	-	6587	15638	8	1885	-	-	1960	3845
5	12056	-	-	9847	21903	10	6482	-	-	5857	12339
6	6961	-	-	6551	13512	12	10169	-	-	12685	22854
7	4663	-	-	4603	9266	14	15851	-	-	21389	37240
8	6845	-	-	7016	13861	16	10613	-	-	14142	24755
9	11216	-	-	12280	23496	18	7607	-	-	11031	18638
10	25866	-	-	27236	53102	20	6783	-	-	8767	15550
11	26127	-	-	31130	57257	22	5821	-	-	6268	12089
12	22382	-	-	24698	47080	24	5024	-	-	5105	10129
13	4409	-	-	4363	8772	26	4611	-	-	5012	9623
14	3856	-	-	3227	7083	28	5099	-	-	5847	10946
15	2897	-	-	2208	5105	30	7413	-	-	9626	17039
16	3419	-	-	2772	6191	32	9401	-	-	11957	21358
17	3892	-	-	3714	7606	34	14128	-	-	12926	27054
18	3400	-	-	4183	7583	36	10661	-	-	7823	18484
19	3415	-	-	5238	8653	38	3699	-	-	2683	6382
20	1307	-	-	2583	3890	40	1563	-	-	937	2500
21	701	-	-	1212	1913	42	755	-	-	334	1089
22	288	-	-	384	672	44	356	-	-	117	473
23	176	-	-	164	340	46	148	-	-	64	212
24	89	-	-	65	154	48	74	-	-	34	108
25	71	-	-	38	109	50	43	-	-	17	60
26	48	-	-	14	62	52	25	-	-	9	34
27	49	-	-	7	56	54	19	-	-	7	26
28	22	-	-	8	30	56	12	-	-	5	17
29	26	-	-	11	37	58	2	-	-	2	4
30	12	-	-	16	28	60	5	-	-	2	7
31	4	-	-	8	12	62	0	-	-	0	0
32	2	-	-	4	6	64	1	-	-	0	1
33	3	-	-	0	3	66	0	-	-	1	1
34	3	-	-	5	8	68	0	-	-	0	0
35	3	-	-	0	3	70	0	-	-	0	0
36	1	-	-	0	1	72	0	-	-	0	0
37	1	-	-	1	2	74	0	-	-	0	0
38	0	-	-	0	0	76	0	-	-	0	0
39	1	-	-	0	1	78	0	-	-	0	0
40	0	-	-	0	0	80	0	-	-	0	0
Sum	155828	-	-	163108	318936		129074	-	-	145506	274580

Tridem Axles Wt. Kips	Lane 31	Lane 32	Lane 72	Lane 71	Sum	Quad Axles Wt. Kips	Lane 31	Lane 32	Lane 72	Lane 71	Sum	Penta Axles Wt. Kips	Lane 31	Lane 32	Lane 72	Lane 71	Sum	Hex Axles Wt. Kips	Lane 31	Lane 32	Lane 72	Lane 71	Sum
12	5	-	-	13	18	12	0	-	-	0	0	12	0	-	-	0	0	12	0	-	-	0	0
15	72	-	-	32	104	15	2	-	-	0	2	15	0	-	-	0	0	15	0	-	-	0	0
18	129	-	-	134	263	18	40	-	-	10	50	18	0	-	-	0	0	18	0	-	-	0	0
21	114	-	-	271	385	21	136	-	-	39	175	21	0	-	-	1	1	21	0	-	-	0	0
24	72	-	-	202	274	24	77	-	-	26	103	24	1	-	-	1	2	24	0	-	-	0	0
27	74	-	-	111	185	27	71	-	-	27	98	27	3	-	-	4	7	27	0	-	-	0	0
30	171	-	-	69	240	30	72	-	-	20	92	30	1	-	-	1	2	30	1	-	-	1	2
33	118	-	-	57	175	33	54	-	-	13	67	33	4	-	-	1	5	33	0	-	-	2	2
36	221	-	-	95	316	36	54	-	-	10	64	36	4	-	-	0	4	36	1	-	-	2	3
39	365	-	-	205	570	39	69	-	-	20	89	39	3	-	-	2	5	39	0	-	-	0	0
42	601	-	-	435	1036	42	57	-	-	27	84	42	6	-	-	1	7	42	0	-	-	0	0
45	684	-	-	322	1006	45	93	-	-	27	120	45	9	-	-	4	13	45	0	-	-	1	1
48	263	-	-	93	356	48	106	-	-	64	170	48	8	-	-	4	12	48	1	-	-	0	1
51	157	-	-	65	222	51	139	-	-	111	250	51	32	-	-	6	38	51	0	-	-	2	2
54	76	-	-	28	104	54	166	-	-	76	242	54	64	-	-	20	84	54	4	-	-	3	7
57	68	-	-	17	85	57	122	-	-	54	176	57	36	-	-	23	59	57	14	-	-	4	18
60	41	-	-	14	55	60	82	-	-	61	143	60	16	-	-	81	97	60	30	-	-	9	39
63	25	-	-	14	39	63	38	-	-	38	76	63	7	-	-	72	79	63	31	-	-	8	39
66	6	-	-	5	11	66	12	-	-	15	27	66	1	-	-	25	26	66	27	-	-	21	48
69	1	-	-	3	4	69	1	-	-	7	8	69	0	-	-	10	10	69	21	-	-	43	64
72	2	-	-	1	3	72	1	-	-	6	7	72	0	-	-	11	11	72	45	-	-	87	132
75	1	-	-	0	1	75	1	-	-	4	5	75	0	-	-	12	12	75	40	-	-	64	104
78	0	-	-	0	0	78	0	-	-	1	1	78	0	-	-	5	5	78	1	-	-	14	15
81	0	-	-	0	0	81	0	-	-	0	0	81	0	-	-	4	4	81	0	-	-	0	0
84	0	-	-	0	0	84	0	-	-	0	0	84	0	-	-	0	0	84	0	-	-	0	0
87	0	-	-	0	0	87	0	-	-	0	0	87	0	-	-	0	0	87	0	-	-	0	0
90	0	-	-	0	0	90	0	-	-	0	0	90	0	-	-	0	0	90	0	-	-	0	0
93	0	-	-	0	0	93	0	-	-	0	0	93	0	-	-	0	0	93	0	-	-	0	0
96	0	-	-	0	0	96	0	-	-	0	0	96	0	-	-	0	0	96	0	-	-	0	0
99	0	-	-	0	0	99	0	-	-	0	0	99	0	-	-	0	0	99	0	-	-	0	0
102	0	-	-	0	0	102	0	-	-	0	0	102	0	-	-	0	0	102	0	-	-	0	0
Sum	3266	-	-	2186	5452		1393	-	-	656	2049		195	-	-	288	483		216	-	-	261	477

Table D.3 – WAY 30 Truck Distribution by Lane and Hour

2009 WAY 30 Hourly Summary - Total 7 days in each of 12 months						
Hour	**Total Trucks in Lane 31 (EB-D) by Hour**		**Total Trucks in Lane 71 (WB-D) by Hour**		**Total Trucks in Both Lanes by Hour**	
	Number	**%**	**Number**	**%**	**Number**	**%**
Midnight	1671	1.6	1739	1.6	3410	1.6
1:00 AM	1610	1.6	1621	1.5	3231	1.5
2:00 AM	1442	1.4	1720	1.6	3162	1.5
3:00 AM	1629	1.6	2244	2.1	3873	1.8
4:00 AM	2175	2.1	2307	2.1	4482	2.1
5:00 AM	3029	3.0	2937	2.7	5966	2.8
6:00 AM	4771	4.7	4098	3.8	8869	4.2
7:00 AM	5733	5.6	5129	4.7	10862	5.1
8:00 AM	6269	6.1	6583	6.1	12852	6.1
9:00 AM	6732	6.6	7272	6.7	14004	6.6
10:00 AM	7412	7.2	7605	7.0	15017	7.1
11:00 AM	7467	7.3	7792	7.2	15259	7.2
Noon	7382	7.2	7938	7.3	15320	7.3
1:00 PM	7098	6.9	7734	7.1	14832	7.0
2:00 PM	6467	6.3	7481	6.9	13948	6.6
3:00 PM	6013	5.9	7228	6.7	13241	6.3
4:00 PM	5108	5.0	6119	5.6	11227	5.3
5:00 PM	4391	4.3	4953	4.6	9344	4.4
6:00 PM	3631	3.5	3775	3.5	7406	3.5
7:00 PM	2912	2.8	3258	3.0	6170	2.9
8:00 PM	2655	2.6	2638	2.4	5293	2.5
9:00 PM	2506	2.4	2320	2.1	4826	2.3
10:00 PM	2348	2.3	2182	2.0	4530	2.1
11:00 PM	1989	1.9	1828	1.7	3817	1.8
Totals	102440	100.0	108501	100.0	210941	100.0
%	% EB	48.6	% WB	51.4		
AADTT	EB	1220	WB	1292	Total	2511

Table D.4 – WAY 30 Truck Driving Lane Distribution by Direction and Class

2009 WAY 30 WIM Class Distribution - Total 7 days in each of 12 months						
Class	Lane 31 EB-D		Lane 71 WB-D		Both Lanes	
	Number	%	Number	%	Number	%
4	1112	1.1	1188	1.1	2300	1.1
5	16130	15.7	14342	13.2	30472	14.4
6	6927	6.8	7602	7.0	14529	6.9
7	4280	4.2	2518	2.3	6798	3.2
8	8028	7.8	8523	7.9	16551	7.8
9	62835	61.3	71319	65.7	134154	63.6
10	2513	2.5	2375	2.2	4888	2.3
11	283	0.3	266	0.2	549	0.3
12	274	0.3	305	0.3	579	0.3
13	58	0.1	63	0.1	121	0.1
Totals	102440	100.0	108501	100.0	210941	100.0

Table D.5 – WAY 30 Truck Volumes and Speeds by Hour

WAY 30 Truck Speed by Hour - 6/15/09							
Hour	No. Trucks	Speed		Hour	No. Trucks	Speed	
		km/hr	mph			km/hr	mph
0	44	90.9	56.4	12	250	91.4	56.8
1	45	90.8	56.4	13	215	91.0	56.5
2	41	90.6	56.3	14	199	90.8	56.4
3	64	91.3	56.7	15	187	91.7	56.9
4	73	90.4	56.1	16	153	91.6	56.9
5	91	91.1	56.6	17	169	92.8	57.6
6	132	91.5	56.8	18	104	92.7	57.6
7	185	91.8	57.0	19	92	92.6	57.5
8	228	91.0	56.5	20	94	91.4	56.8
9	211	90.9	56.4	21	72	91.3	56.7
10	228	91.8	57.0	22	70	91.6	56.9
11	225	91.2	56.6	23	58	90.3	56.1
				Prorated Average Speed		91.4	56.8

APPENDIX E

Implementation Plan

OHIO DEPARTMENT OF TRANSPORTATION
OFFICE OF PAVEMENT ENGINEERING
RESEARCH IMPLEMENTATION PLAN

Title: **Monitoring and Modeling of Pavement Response and Performance**
State Job Number: 134287
PID Number:
Research Agency: Ohio University
Researcher(s): Shad Sargand and J. Ludwig Figueroa
Technical Liaison(s): Roger Green
Research Manager: Monique Evans
Sponsor(s): ODOT
Study Start Date: May 1, 2006
Study Completion Date: May 1, 2009
Study Duration: 36 Months
Study Cost: $785,129.03
Study Funding Type:

STATEMENT OF NEED:

Over the years, the Ohio Department of Transportation has constructed several pavements with a range of designs and materials to study and improve overall statewide performance. These pavements require constant monitoring to determine how they perform over time and what mechanisms are at work to cause distress. One major effort was the DEL-23 Test Road where 40 AC and PCC test sections in the SPS-1, SPS-2, SPS-8 and SPS-9 experiments were constructed for SHRP. While many sections have been replaced, many other sections remain in service. These remaining sections and seven PCC replacement sections need to be evaluated periodically. Other existing test roads around the state also need ongoing evaluation to assess performance, including in particular the perpetual AC pavement and long-life PCC pavement in Wayne County (WAY-30).

RESEARCH OBJECTIVES:

- Monitor the new perpetual AC and long-lasting PCC pavements constructed in Ohio and other existing instrumented pavements in the state.
- Verify ME design procedures for all pavements in the study by comparing theoretical calculations with measured response and performance
- Calibrate ME procedures presented in the NCHRP 1-37A AASHTO Pavement Guide for Ohio using data collected in this and other previous studies.
- Document all research findings in a final report.

RESEARCH TASKS:

- A1 Data Collection, Field Sampling and Pavement Surveys on US23 Delaware Co., US50 Athens Co., US33 Meigs Co., US33 Logan Co., US33 Athens Co., I77 Stark Co., and US30 Wayne Co.
- A2 Reconstruction of Strain Histories
- A3 Forensic Investigations (if needed)
- A4 Laboratory Testing for Forensic Investigations (if needed)
- A5 Data Summary and Environmental Analysis Reports
- A6 Data Summary and Environmental Analysis Relating to Distress
- A7 Climatic Modeling (execute MEPDG software with actual field data)
- A8 Instrumentation and monitoring of replacement SPS-2 test sections on US23 in Delaware Co.

RESEARCH DELIVERABLES:

Final Report, Executive Summary, Database DVD

RESEARCH RECOMMENDATIONS:

WAY-30

No clear differences in performance are apparent on sections of PCC containing fly ash and ground granulated blast furnace slag. As the previous report on WAY-30 concluded, this pavement cured at an ideal temperature and had no significant loss of support after curing. No distresses have appeared in these sections, other than one cracked slab that may be a result of an irregularity in the base.

The perpetual AC and long lasting PCC pavements are both performing well at this time.

The one joint with composite dowel bars shows high deflections and low load transfer. Deflections at joints between Stations 876 and 877 with standard epoxy coated dowel bars were highly variable, but load transfer remained good.

As shown from the TDR data collected, subgrade moisture fluctuates slightly with the seasons, but does not change significantly.

A new MEPDG software simulation of the two pavements generates results with various differences from those of the previous simulation [Sargand, Figueroa, and Romanello, 2008]. The simulated AC perpetual pavement stayed below the original design limits for all results. The final total and subgrade rutting values were higher in the new simulation because the input subgrade parameters were worst-case values from the project data. In the case of PCC, most of the simulated measures improved considerably, sometimes as much as an order of magnitude. The major exception was the percentage of slabs cracked, which at 4% after 20 years is still well below the design limit of 15% and is again probably a result of using worst-case numbers for subgrade input data.

DEL 23 SHRP Pavement

Seven PCC sections were replaced with more robust pavement sections containing different slab lengths, slab widths, and different sizes of coarse aggregate. The objective was to study the influences of joint spacing and of aggregate size in the mix on performance.

Unfortunately, we could not make clear comparisons of sections 268, 269, 270, 271, and 272 because these pavements have suffered premature distress in the form of longitudinal cracking after one year of service. Based on a preliminary forensic study, the root causes of the failure appear to be inconsistent pavement thickness and improper cutting of the longitudinal joints.

Section 267 had an 8 inch (20.3 cm) base of 304 aggregate, while the other six sections had 4 inches (10.2 cm) of 301 ATB over 4 inches (10.2 cm) of 304 aggregate. Sections 266 and 267, with 12 foot (3.7 m) slab widths, had higher FWD deflections, but load transfers at the joints were good.

The heat of hydration dissipated 4 – 5 days after the concrete was placed.

Load response testing was conducted on these sections.

ATH 33

No differences in FWD response were noted in 2004 and high traffic volumes on this two-lane urban highway have prevented any further testing.

Some minor transverse cracking has been observed at driveway entrances where high early strength concrete was used. This mix differs from that use in the highway travel lanes and was used late in the project to shorten the delay in opening the finished road to traffic.

The large aggregate in the PCC pavement used in this project performed exceptionally well, as indicated by the performance of the pavement.

ATH 50

Load transfer in six joints with fiberglass dowel bars was consistently 15-20% lower than the stainless tubes and epoxy-coated steel bars over the first six years of service, then dropped dramatically to about 30% in 2005 and remained at that level in 2008.

LOG 33

Of the six sections of AC pavement with different bases, the sections with 4 inches (10.2 cm) of 306 CTFDB over 4 inches (10.2 cm) of 304 DGAB, 4 inches (10.2 cm) of 307 IA DGAB over 4 inches (10.2 cm) of 304 DGAB and a total thickness of 6 inches (15.2 cm) of 304 DGAB had the lowest FWD deflections.

The section with 4 inches (10.2 cm) of 307 NJ DGAB over 4 inches (10.2 cm) of 304 DGAB had the highest deflection.

The sections continue to perform well and no major unexpected distresses have been observed. There has been rehabilitation of the top layer, which was anticipated.

No reflected cracking has appeared on asphalt pavements due to base materials. This is true even for stiff bases.

LOG-33 meets the criteria for an AC perpetual pavement. Data from this project can be compared to other projects in Ohio.

MEG 33

FWD midslab and joint deflections, Df1/Df7 at midslab, and joint load transfers were higher on the sandy subgrade than on the clay subgrade.

Sealing material is working out of some joints.

As the previous study on this pavement indicated, the moisture under both types of subgrade has stabilized and remains unchanged, other than limited seasonal fluctuations.

STA 77

High traffic volumes prevented any further monitoring of this project.

General remarks

On all sections where they have been installed, composite dowel bars have performed well.

Subgrade moisture fluctuates slightly with the seasons, but does not change significantly, staying within a well-defined range regardless of the type of base or pavement.

Rigid pavement performance is sensitive to the construction method.

PCC pavements installed on stiff base layers do not perform as well as those installed on flexible base layers.

The earlier findings regarding the selection of base materials have been confirmed in this study [Sargand, Wu, and Figueroa, 2006]. Namely, the performance of PCC and AC pavements is influenced greatly by the stiffness of the base. A softer base works better with PCC pavements, while AC pavements perform better on stiffer bases. With AC pavements on cement-treated bases, there is always some concern that there will be reflection cracking; however, a sufficient thickness of AC pavement will reduce temperature fluctuations in a stiff base and thus reduce or eliminate reflection cracking.

PCC pavement with large aggregate performed exceptionally well.

In the majority of instances, PCC pavement slab distress occurred in the form of mid-panel cracking initiated from the top. These are manifestations of curling and warping.

The DEL23 and WAY30 projects have provided a wealth of data for calibration of the MEPDG software for Ohio.

Many pavements in this study are relatively new and it may be some time before useful results emerge. The more prominent projects are WAY-30 where the performance of perpetual AC and long lasting PCC pavements are being compared directly, and the seven PCC replacement sections in the northbound driving lane of DEL 23 where the effects of different slab lengths, slab widths, and coarse aggregate sizes are being evaluated for performance. The dowel bars on ATH-50 and the AC pavement bases on LOG-33 are still useful for the evaluation of long-term performance.

<u>PROJECT PANEL COMMENTS</u>:

<u>IMPLEMENTATION STEPS and TIME FRAME</u>:

- Monitor FWD Df1/Df7 ratios on in-service pavements to confirm the preliminary ranges established here for good, fair, and poor performance on AC pavements.
- 306 Cement Treated Free Draining Base and 307 IA Dense Graded Aggregate provide the best support for AC pavements. The 307 NJ base should be avoided for PCC pavement.
- The detailed data collected on the WAY-30 project, including data from the weather station data and on material properties make the pavement a good candidate for inclusion in the MEPDG calibration effort for Ohio.
- Similarly, MEG-33 and ATH-33 have provided data that can be used in the MEPDG calibration.
- The data collected from these projects could be used for the validation of the load response computations of the MEPDG software for Ohio. This is in addition to calibration of the software's performance computations.
- ODOT should specify the use of large aggregate in PCC pavement mixes.
- Based on the results of this study, ODOT should review its construction procedures with an emphasis on when, how, and to what depth to cut PCC joints.
- Every effort should be made to incorporate environmental factors in the design of PCC pavements.

<u>EXPECTED BENEFITS</u>:

<u>EXPECTED RISKS, OBSTACLES, and STRATEGIES TO OVERCOME THEM</u>:

OTHER ODOT OFFICES AFFECTED BY THE CHANGE:

PROGRESS REPORTING and TIME FRAME:

TECHNOLOGY TRANSFER METHODS TO BE USED:

IMPLEMENTATION COST and SOURCE OF FUNDING:

Approved By: (attached additional sheets if necessary)

Office Administrator(s):

Signature: ______________________________ Office: ____________ Date: _______________

Signature: ______________________________ Office: ____________ Date: _______________

Division Deputy Director(s):

Signature: ______________________________ Division: ____________ Date: _______________

Signature: ______________________________ Division: ____________ Date: _______________

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