Evaluation of Composite Pavement Unbonded Overlays: Phases I and II

CENTER FOR
PORTLAND CEMENT CONCRETE
PAVEMENT TECHNOLOGY

Department of Civil, Construction, and Environmental Engineering

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16. Abstract

In recent years, thin whitetopping has evolved as a viable rehabilitation technique for deteriorated asphalt cement concrete (ACC) pavements. Numerous projects have been constructed and tested; these projects allow researchers to identify the important elements contributing to the projects' successes. These elements include surface preparation, overlay thickness, synthetic fiber reinforcement usage, joint spacing, and joint sealing. Although the main factors affecting thin whitetopping performance have been identified by previous research, questions still existed as to the optimum design incorporating these variables. The objective of this research is to investigate the interaction between these variables over time.

Laboratory testing and field-testing were planned in order to accomplish the research objective. Laboratory testing involved shear testing of the bond between the portland cement concrete (PCC) overlay and the ACC surface. Field-testing involved falling weight deflectometer deflection responses, measurement of joint faulting and joint opening, and visual distress surveys on the 9.6-mile project. The project was located on Iowa Highway 13 extending north from the city of Manchester, Iowa, to Iowa Highway 3 in Delaware County. Variables investigated included ACC surface preparation, PCC thickness, synthetic fiber reinforcement usage, and joint spacing.

This report documents the planning, equipment selection, construction, field changes, and construction concerns of the project built in 2002. The data from this research could be combined with historical data to develop a design specification for the construction of thin, unbonded overlays.

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EVALUATION OF COMPOSITE PAVEMENT UNBONDED OVERLAYS: PHASES I AND II

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Iowa DOT Project HR-1093, TR-478
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INTRODUCTION

Background

Iowa is one of several states known for its large amounts of portland cement concrete (PCC) pavements. The original design life of the initial pavement systems was established as 20 years. This meant that by the 1970s much of the system had reached or was exceeding the design life. The decision was made to widen and resurface these pavements with asphalt cement concrete (ACC). This philosophy was used to extend the life for 10–15 years or until funding could be found to replace the pavements.

Rather than continue to overlay these composite pavements with asphalt, concrete alternatives that provide longer life at a lower life-cycle cost were needed. Thin, unbonded concrete overlays are a relatively new idea in the paving industry. Unbonded PCC overlays have been used to extend the pavement life of Iowa Highway 21 near Belle Plaine, Iowa. From this research, several valuable things were learned about slab thickness, bond strength, and the use of fiber reinforcement in the concrete. However, there is a definite need for further research in order to present a cost-effective concrete alternative to asphalt overlays.

Research Objectives

The goal of this research project was to measure the stability and durability of unbonded, thin PCC overlays over time. In conducting the research, the following factors were considered:

- bonding between the PCC and ACC layers
- joint spacing
- PCC thickness
- use of concrete fibers in the concrete
- surface preparation
- joint/crack preparation in the existing pavement

The objectives of this research will be accomplished by conducting both laboratory and field tests, collecting data, and analyzing the data appropriately. Following these steps, a final report containing information regarding the various research components will be produced. The report will document practices and results, as well as information concerning the achievements of the research.

REVIEW OF CONCRETE OVERLAY PROJECTS

Ultrathin Whitetopping Experiences

In 1991, the first modern ultrathin whitetopping (UTW) project was constructed on an entrance road to a waste management facility near Louisville, Kentucky. The project focused on assessing the viability of UTW. Table 1 shows the UTW properties for the project.

Table 1. UTW Properties for the Louisville, Kentucky, Project

Section Number	Dimensions (feet x feet)	PCC Thickness (inches)	Surface Preparation	Synthetic Fiber Usage (lb./c.y.)	Joint Spacing (feet x feet)
1	275 x 24	3.5	Milled	3.0	6 x 6
2	50 x 24	3.5–2.0	Milled	3.0	6 x 6
3	275 x 24	2.0	Milled	3.0	6 x 6, 2 x 2

The first urban arterial UTW project was developed in 1995. The city of Leawood, Kansas, constructed it, in conjunction with the Kansas Department of Transportation. The roadway selected was 119th Street between Roe Avenue and Mission Road. The project focused on evaluating synthetic fiber reinforcement usage, joint spacing, joint sealing, and the suitability of UTW in an urban application. Table 2 shows the UTW properties for the project.

Table 2. UTW Properties for the Leawood, Kansas, Project

Section Number	Dimensions (feet x feet)	PCC Thickness (inches)	Surface Preparation	Synthetic Fiber Usage (lb./c.y.)	Joint Spacing (feet x feet)	Joint Sealant
1	800 x 24	2.0	Milled	3.0	3 x 3	—
2	800 x 24	2.0	Milled	—	3 x 3	—
3	800 x 24	2.0	Milled	3.0	3 x 3	Silicone
4	800 x 24	2.0	Milled	—	4 x 4	—
5	800 x 24	2.0	Milled	3.0	4 x 4	—
6	800 x 24	2.0	Milled	—	4 x 4	Silicone

In 1994, the Iowa Department of Transportation (Iowa DOT) constructed a 7.2-mile UTW project in Iowa County, near Belle Plaine, Iowa. The project was located on Iowa Highway 21 between Iowa Highway 212 and U.S. Highway 6. The objective of this research was to investigate the interface bonding condition between an ultrathin PCC overlay and an ACC base over time with consideration for the ACC surface preparation (milled, patch only, or cold in-place recycle), PCC thickness (2, 4, 6, or 8, inches), synthetic fiber reinforcement usage (fibrillated, monofilament, or no fibers), joint spacing (2 x 2, 4 x 4, 6 x 6, 12 x 12, and 15 x 12 foot panels), and joint sealing (widths of 1/8 or 1/4 of an inch, seal or no seal).

The conclusions from these projects and the results of the Iowa Highway 13 will be used to formulate a design specification for UTW projects.

Unbonded Overlay Experience on County Roads

Pottawattamie County has been interested in the unbonded overlay of a composite pavement since the early 1990s. The county has constructed nine separate projects involving the overlay of composite pavements consisting of an original PCC pavement with a surface layer of various depths of bituminous materials.

The earliest unbonded overlay was placed on 9.44 miles in 1992. The original section was 22 feet in width and made up of a 6-inch depth of PCC layer with a 3-inch asphaltic concrete overlay. A 6-inch PCC overlay was placed on the composite pavement. The visual survey in 2002 identified some 61 transverse joint patches, and some 268 longitudinal cracks primarily at the lane midpoint or centerline.

In the same year, the county tried to use a slurry coat as the bond breaker between an existing 22-foot wide, 6-inch-deep PCC pavement and a 6-inch PCC overlay of three projects for a total length of 7.9 miles. Testing indicated that the slurry effort was not successful as a bond breaker. The 2002 visual survey identified some 26 transverse joint patches and over 50 longitudinal cracks of random or midlane location.

In 1995, the county constructed 10.57 miles of unbonded overlay on a 22-foot-wide PCC pavement, 6 inches in depth, overlaid by 3 inches of ACC. A 2002 visual survey of the project noted approximately 100 feet of longitudinal random cracks, two transverse cracks, and one corner crack.

Approximately 3.07 miles of unbonded overlay were placed on a 22-foot-wide section of PCC in 1996, which was 6 inches in depth and had a previous 3-inch ACC overlay placed at various locations in 1963–1976. A 6-inch PCC overlay was placed on this pavement. This pavement currently exhibits only minor evidence of transverse joint cracking and one expansion joint problem.

In 2000, the county overlaid 5.00 miles of 22-foot-wide pavement with 6 inches of PCC. The underlying 6-inch PCC pavement that was overlaid with 2 inches of ACC in previous years. This project points out the need to consider expansion joints in the design, with some 18 expansion joints noting some distress and one corner broken slab in the project.

In 2001, the county constructed two unbonded overlay projects. The first was 1.01 miles in length, 22 feet in width, and consisted of a thickened edge (7 inches) and centerline (6 inches) depth. It was overlaid in previous years with 4 inches of ACC. No distress is noted at this time in the overlay.

The second unbonded overlay placed in 2001 was 6.00 miles in length, 22 feet in width, and placed on 2 inches of ACC over 6 inches of original PCC. There are no signs of visual distress showing on this project also.

The lessons learned from the Pottawattamie County experience include the following:

- Slurry bond breakers are not sufficient in depth to develop the bond breaker impact on the overlay performance.
- Attention must be given to existing expansion joints or the evidence of soil movement areas in the design of the joint locations in the overlay.
- Bridging or reinforcement over existing working cracks should be considered in the overlay design.
- Unbonded PCC overlays can be placed efficiently over composite pavements and provide good performance for extending the life of in-service pavements.

TEST SITE DESCRIPTION

Existing pavement condition was a major factor in the site decision. Care was also taken to select a project that could be constructed during the summer months of June through August. These dates were used to reduce the effects road closure would have on the through traffic as well as the school traffic. It was also desirable to take advantage of the warm, summer temperatures to increase the speed of concrete strength development.

The Iowa Highway 13 project is a 9.6-mile long stretch of roadway that extends from Manchester, Iowa, to Iowa Highway 3 in Delaware County. Figure 1 illustrates the project location. This portion of Iowa 13 is a two-lane rural roadway, 24 feet in width, with a narrow granular surfaced shoulder and rolling longitudinal grade with minimum ditch depths approximately 3 to 6 feet below the top of the pavement.

In 1931, the first improvements were made to Iowa 13 in the project area. The improvements included a thickened edge pavement with 10-inch depths at each edge and 7 inches at the centerline, 18 feet wide centered on the roadbed. The pavement cross section also included a 4-inch high lip curb on each edge to control pavement drainage. Longitudinal subdrains were placed at the low points of the roadway to facilitate water runoff. Table 6 shows the stationing and side of the road of the existing subdrains. The concrete slab was used as the driving surface until 1964, when 2 inches of Type B ACC was placed over it. This was done in order to both fill in the curbed section on the outer wheel path and rehabilitate the driving surface. In 1984, another 3-inch ACC widening surface was applied to the roadway. The first lift was 1.5 inches of Type B ACC binder and the surface layer was 1.5 inches of Type A ACC. This overlay extended the roadway from its original 18 feet to its present 24-foot width. Figure 2 shows the pavement layers and the dates of their construction.

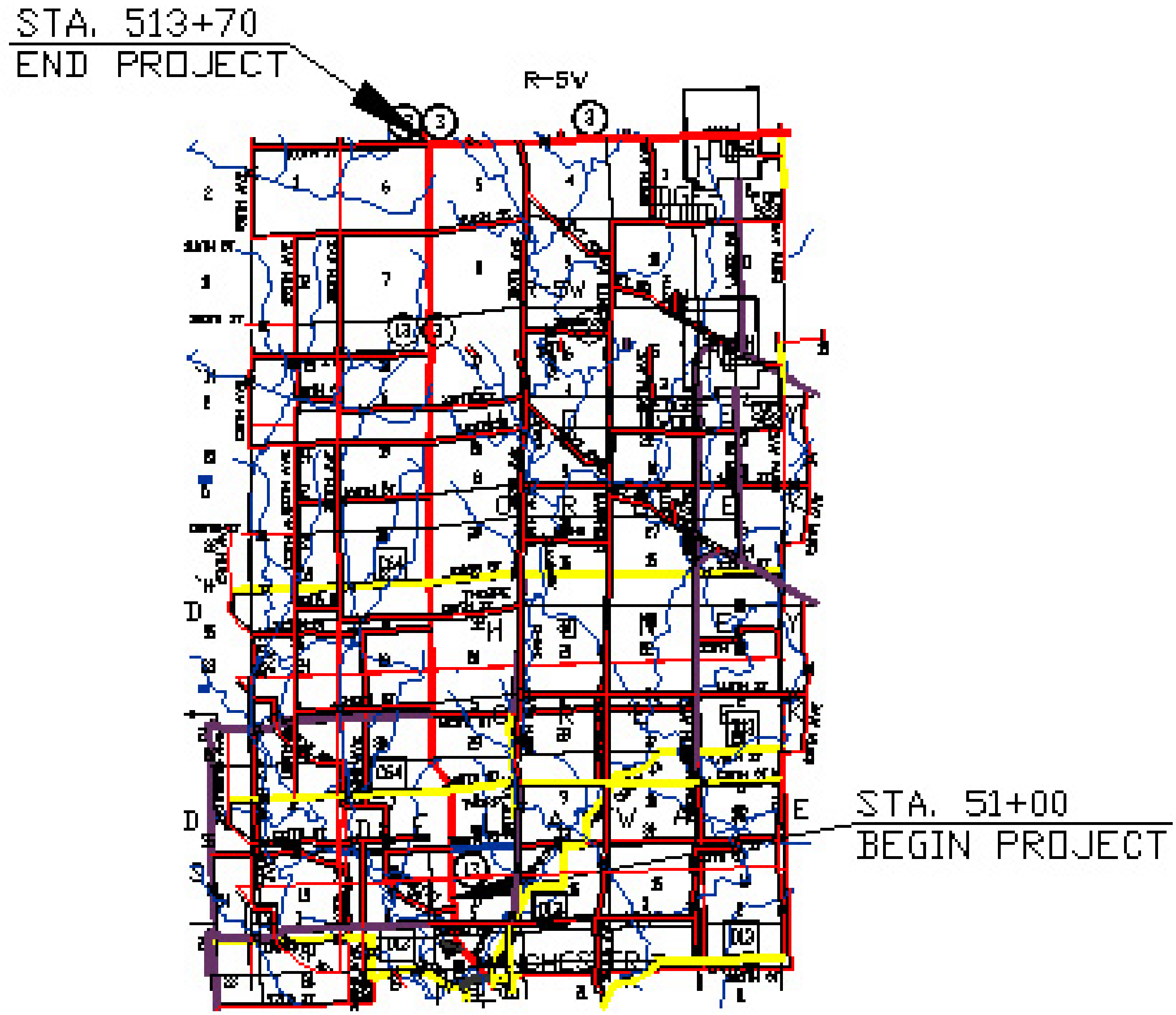

Figure 1. Project Location

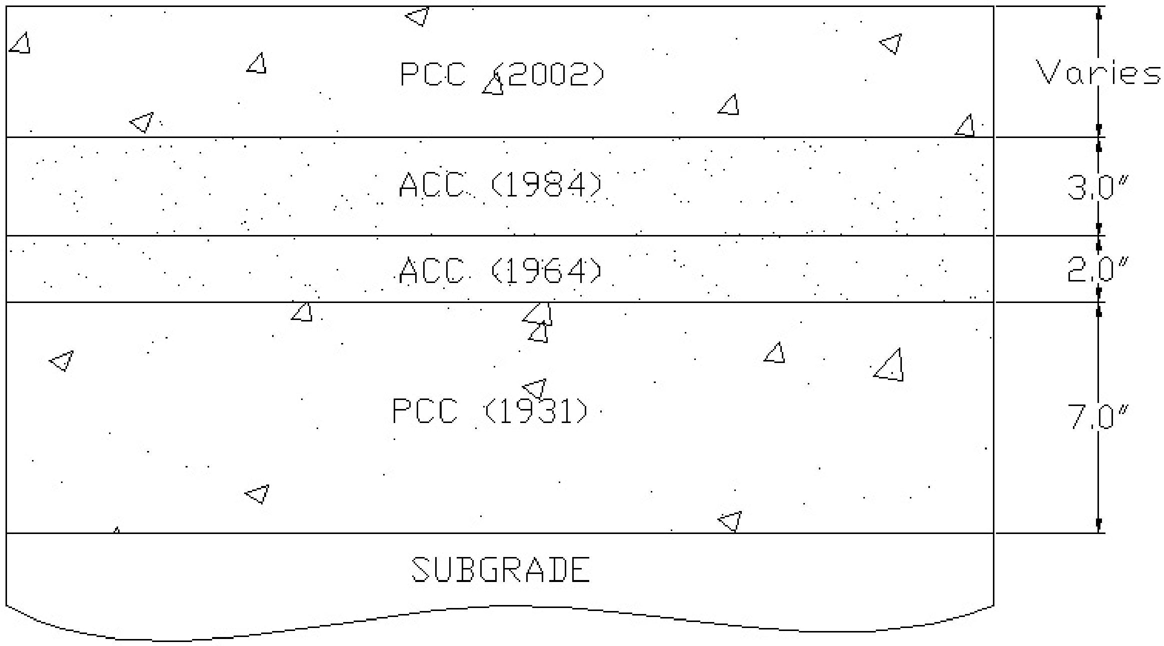

Figure 2. Pavement Layers and the Dates of Construction

The roadway, in 2002, was in good to fair condition with minimum cracking. One longitudinal crack extended through the entire 9.6 miles of roadway. It was located on both sides of the road where the concrete slab ends and the asphalt-widening unit extends. Figure 3 shows the longitudinal crack and the current condition of some of the roadway. Prior to the placement of the concrete overlay, the "floating" asphalt section was milled down to be replaced with a full 8-inch PCC slab.

Figure 3. Longitudinal Cracking and Current Condition of the Roadway

Soil Conditions

According to the Iowa County Soil Survey Report, Clyde - Floyd Complex and Kenyon Loam are the primary soil associations that occur along the project. The Clyde - Floyd Complex is deposited in the drainage ways of glacial uplands. This association is generally poorly drained, the permeability is moderate, the runoff is slow, and the soil has a high water capacity. This is a poor road fill soil because of its low strength and wetness. The Kenyon Loam is deposited along ridge tops and side slopes in the uplands. This association is generally moderately well drained, the permeability is moderate, the runoff is medium, and the soil has a high water capacity. This is a fair roadfill soil because of is low strength. Table 3 details the soil names and American Association of State Highway and Transportation Officials (AASHTO) classifications of the project soils.

Table 3. Soil Names and AASHTO Classifications of Project Soils

Station to Station		Soil Name and Class	AASHTO Classification
5100	6300	Waspie Loam	A-4
6300	6800	Saude Loam	A-6
6800	7200	Lawler Loam	A-6, A-7
7200	7500	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
7500	8000	Olin Fine Sandy Loam	A-2, A-4
8000	8400	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
8400	9200	Kenyon Loam	A-6
9200	9500	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
9500	9800	Kenyon Loam	A-6
9800	10100	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
10100	11700	Kenyon Loam	A-6
11700	12100	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
12100	15300	Kenyon Loam	A-6
15300	16600	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
16600	17400	Kenyon Loam	A-6
17400	17600	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
17600	18500	Kenyon Loam	A-6
18500	19700	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
19700	19900	Kenyon Loam	A-6
19900	20700	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
20700	21200	Kenyon Loam	A-6
21200	21500	Dickinson Fine Sandy Loam	A-4, A-2
21500	22000	Olin Fine Sandy Loam	A-2, A-4
22000	22900	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
22900	23200	Rockton Loam	A-4
23200	26200	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
26200	26700	Kenyon Loam	A-6
26700	27100	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
27100	28000	Kenyon Loam	A-6
28000	28300	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
28300	28700	Kenyon Loam	A-6
28700	29900	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7

29900	30700	Kenyon Loam	A-6
30700	31000	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
31000	31300	Olin Fine Sandy Loam	A-2, A-4
31300	31400	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
31400	31600	Olin Fine Sandy Loam	A-2, A-4
31600	31900	Chelsea Loamy Fine Sand	A-2-4
31900	32200	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
32200	32500	Basset Loam	A-4, A-6
32500	32800	Colo-Ely Complex	Colo A-4, A-6, Ely A-7, A-6
32800	32900	Downs Silt Loam	A-4, A-6
32900	33200	Colo-Ely Complex	Colo A-4, A-6, Ely A-7, A-6
33200	34100	Downs Silt Loam	A-4, A-6
34100	34400	Fayette Silt Loam	A-4, A-6
34400	34700	Colo-Ely Complex	Colo A-4, A-6, Ely A-7, A-6
34700	35600	Downs Silt Loam	A-4, A-6
35600	35900	Colo-Ely Complex	Colo A-4, A-6, Ely A-7, A-6
35900	37000	Downs Silt Loam	A-4, A-6
37000	37500	Colo-Ely Complex	Colo A-4, A-6, Ely A-7, A-6
37500	37700	Dickinson Fine Sandy Loam	A-4, A-2
37700	38000	Lamont Fine Sandy Loam	A-2, A-4
38000	38200	Colo-Ely Complex	Colo A-4, A-6, Ely A-7, A-6
38200	38600	Basset Loam	A-4, A-6
38600	38900	Kenyon Loam	A-6
38900	39600	Colo-Ely Complex	Colo A-4, A-6, Ely A-7, A-6
39600	40500	Basset Loam	A-4, A-6
40500	41300	Fayette Silt Loam	A-4, A-6
41300	41600	Clyde Clay Loam	A-7
41600	42200	Sparta Loamy Fine Sand	A-2, A-4
42200	43100	Fayette Silt Loam	A-4, A-6
43100	45700	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
45700	45800	Dickinson Fine Sandy Loam	A-4, A-2
45800	46100	Burkhardt - Saude Complex	Burkhardt A-2, A-4, Saude A-6
46100	47600	Kenyon Loam	A-6
47600	48800	Clyde- Floyd Complex	Clyde A-7, Floyd A-6, A-7
48800	49500	Olin Fine Sandy Loam	A-2, A-4
49500	49800	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
49800	50400	Kenyon Loam	A-6
50400	50700	Clyde - Floyd Complex	Clyde A-7, Floyd A-6, A-7
50700	51000	Kenyon Loam	A-6

Design Traffic

The portion of Iowa Highway 13 that is under research serves primarily as a farm-to-market road and as a connector road for traffic going from U.S. Highway 20 to Iowa Highway 3. Private residences and a few intersections of lightly traveled county roads exist along the project. No commercial or industrial sites are present to create large changes of traffic counts or uneven directional distribution. The average annual daily traffic (AADT) is 2,930 vehicles per day (Iowa DOT source), with 11 percent of those vehicles classified as trucks on April 30, 2002.

EXPERIMENTAL DESIGN

After analyzing the performance of past UTW projects, Iowa Highway 13 has the advantage of testing the top performing design alternatives within one roadway. The design variables that were considered in this project include ACC surface preparation (milled, one-inch hot mix asphalt [HMA] stress relief course, and broomed only); use of concrete fibers (sections of polypropylene, monofilament, proprietary structural, and no fibers); pavement thickness (3.5 and 4.5 inches); joint spacing (4.5 x 4.5, 6 x 6, and 9 x 9 foot sections); and joint/crack preparation (bridge with concrete or a #4 rebar stapled to the pavement surface). Table 4 shows the design characteristics of this project and other UTW projects.

Table 4. Design Characteristics of Current UTW Projects

Design Characteristics	Project Reference			
	A	B	C	D
Location (date)	Entrance road to waste management facility, Louisville, Kentucky (1991)	Iowa Highway 21, between Victor and Belle Plaine, Iowa (1994)	119th Street, Leawood, Kansas (1995)	Iowa Highway 13, between Manchester, Iowa, and Iowa Highway 3 (2002)
Concrete thickness (inches)	2, 3.5	2, 4, 6, 8	2	3.5, 4.5
Joint spacing (feet)	2, 6 squares	2, 4, 6, 12 squares	3, 4 squares	4.5, 6, 9 squares
Asphalt treatment	Milled	Patch and scarify, patch only, cold in-place recycle	Milled	Milled, HMA stress relief layer, broomed only
Fibers	Yes	Some	Some	Some

The project was divided into 183 sections according to the previously mentioned variables, including 91 test sections. The test sections had lengths of 400 feet except for four that had to be increased to 600 feet to accommodate changes to the project beginning and the end. Each of the test sections represents a stretch of roadway where all of the variables remained constant. The change of a variable was accomplished in the transition sections, which precede each of the test sections. Table 5 displays the design properties for the project test sections.

Table 5. Test Section Characteristics

Section		Station to Station		Base Prep.	Depth (inches)	Fiber Type**	Panel Size (ft. x ft.)	Tied Outer Joint
No.	Type							
8	Trans	51+00	52+00	Scarify	3.5	B	4.5	
9	Test	52+00	56+00	Scarify	3.5	B	4.5	
10	Trans	56+00	57+00	Scarify	3.5	B	4.5-6.0	
11	Test	57+00	61+00	Scarify	3.5	B	6	
12	Trans	61+00	62+00	Scarify	3.5	B	6	
13	Test	62+00	66+00	Scarify	3.5	B	6	Tied joint
14	Trans	66+00	67+00	Scarify	3.5	No	6	
15	Test	67+00	71+00	Scarify	3.5	C	6	
16	Trans	71+00	72+00	Scarify	3.5	C	6	
17	Test	72+00	76+00	Scarify	3.5	C	6	
18	Trans	76+00	77+00	Scarify	3.5	C	6	
19	Test	77+00	81+00	Scarify	3.5	C	6	
20	Trans	81+00	82+00	Scarify	3.5	C	6	
21	Test	82+00	86+00	Scarify	3.5	C	6	Tied joint
22	Trans	86+00	87+00	Scarify	3.5	No	6.0-4.5	
23	Test	87+00	91+00	Scarify	3.5	No	4.5	
24	Trans	91+00	92+00	Scarify	3.5	No	4.5	
25	Test	92+00	96+00	Scarify	3.5	No	4.5	
26	Trans	96+00	97+00	Scarify	3.5	No	4.5-6.0	
27	Test	97+00	101+00	Scarify	3.5	No	6	
28	Trans	101+00	102+00	Scarify	3.5	No	6	
29	Test	102+00	106+00	Scarify	3.5	No	6	Tied joint
30	Trans	106+00	107+00	Scarify	3.5	No	6	
31	Test	107+00	113+00	Scarify	3.5	A	6	Tie center 200'
32	Trans	113+00	113+50	Scarify	3.5	A	6-4.5	
33	Test	113+50	119+50	Scarify	3.5	A	4.5	
33.5	Trans	119+50	120+00	Scarify	3.5-4.5	A	4.5	
34	Test	120+00	124+00	Scarify	4.5	A	4.5	
35	Trans	124+00	125+00	Scarify	4.5	A	4.5	
36	Test	125+00	129+00	Scarify	4.5	A	4.5	Tied joint
37	Trans	129+00	130+00	Scarify	4.5	A	4.5-6.0	
38	Test	130+00	134+00	Scarify	4.5	A	6	
39	Trans	134+00	135+00	Scarify	4.5	A	6	
40	Test	135+00	139+00	Scarify	4.5	A	6	
41	Trans	139+00	140+00	Scarify	4.5	No	6.0-4.5	
42	Test	140+00	144+00	Scarify	4.5	B	4.5	
43	Trans	144+00	145+00	Scarify	4.5	B	4.5	
44	Test	145+00	149+00	Scarify	4.5	B	4.5	Tied joint
45	Trans	149+00	150+00	Scarify	4.5	B	4.5-6	
46	Test	150+00	154+00	Scarify	4.5	B	6	
47	Trans	154+00	155+00	Scarify	4.5	B	6	
48	Test	155+00	159+00	Scarify	4.5	B	6	
49	Trans	159+00	160+00	Scarify	4.5	No	6.0-9.0	
50	Test	160+00	164+00	Scarify	4.5	C	9	
51	Trans	164+00	165+00	Scarify	4.5	C	9	

52	Test	165+00	169+00	Scarify	4.5	C	9	
53	Trans	169+00	170+00	Scarify	4.5	C	9	
54	Test	170+00	174+00	Scarify	4.5	C	9	Tied joint
55	Trans	174+00	175+00	Scarify	4.5	C	9	
56	Test	175+00	179+00	Scarify	4.5	C	9	
57	Trans	179+00	181+50	Scarify	4.5	No	9.0-6.0	
58	Trans	181+50	183+75	Remove	0.0-4.5	No	6	
59	Test	183+75	186+75	Remove	4.5	No	6	
60	Trans	186+75	189+00	Remove	4.5-0.0	No	6.0-4.5	
61	Test	189+00	193+00	Scarify	4.5	No	4.5	
62	Trans	193+00	194+00	Scarify	4.5	No	4.5	
63	Test	194+00	198+00	Scarify	4.5	No	4.5	Tied joint
64	Trans	198+00	199+00	Scarify	4.5	No	4.5-6.0	
65	Test	199+00	203+00	Scarify	4.5	No	6	
66	Trans	203+00	204+00	Scarify	4.5	No	6	
67	Test	204+00	208+00	Scarify	4.5	No	6	
68	Trans	208+00	209+00	HMA S.R.	4.5-3.5	No	6.0-4.5	
69	Test	209+00	213+00	HMA S.R.	3.5	A	4.5	
70	Trans	213+00	214+00	HMA S.R.	3.5	A	4.5	
71	Test	214+00	218+00	HMA S.R.	3.5	A	4.5	
72	Trans	218+00	219+00	HMA S.R.	3.5	A	4.5-6.0	
73	Test	219+00	223+00	HMA S.R.	3.5	A	6	
74	Trans	223+00	224+00	HMA S.R.	3.5	A	6	
75	Test	224+00	228+00	HMA S.R.	3.5	A	6	Tied joint
76	Trans	228+00	229+00	HMA S.R.	3.5	No	6.0-4.5	
77	Test	229+00	233+00	HMA S.R.	3.5	B	4.5	
78	Trans	233+00	234+00	HMA S.R.	3.5	B	4.5	
79	Test	234+00	238+00	HMA S.R.	3.5	B	4.5	
80	Trans	238+00	239+00	HMA S.R.	3.5	B	4.5-6.0	
81	Test	239+00	243+00	HMA S.R.	3.5	B	6	
82	Trans	243+00	244+00	HMA S.R.	3.5	B	6	
83	Test	244+00	248+00	HMA S.R.	3.5	B	6	Tied joint
84	Trans	248+00	249+00	HMA S.R.	3.5	No	6.0-9.0	
85	Test	249+00	253+00	HMA S.R.	3.5	C	9	
86	Trans	253+00	254+00	HMA S.R.	3.5	C	9	
87	Test	254+00	258+00	HMA S.R.	3.5	C	9	
88	Trans	258+00	259+75	Remove	0.0-3.5	No	4.5	
89	Test	259+75	263+25	Remove	3.5	No	4.5	
90	Trans	263+25	265+00	Remove	3.5-0.0	No	4.5	
91	Test	265+00	269+00	HMA S.R.	3.5	C	9	
92	Trans	269+00	270+00	HMA S.R.	3.5	C	9	
93	Test	270+00	274+00	HMA S.R.	3.5	C	9	Tied joint
94	Trans	274+00	275+00	HMA S.R.	3.5	No	9.0-4.5	
95	Test	275+00	279+00	HMA S.R.	3.5	No	4.5	
97	Trans	279+00	280+00	HMA S.R.	3.5	No	4.5	
98	Test	280+00	284+00	HMA S.R.	3.5	No	4.5	
99	Trans	284+00	285+00	HMA S.R.	3.5	No	4.5-6.0	
100	Test	285+00	289+00	HMA S.R.	3.5	No	6	

101	Trans	289+00	290+00	HMA S.R.	3.5	No	6	
102	Test	290+00	294+00	HMA S.R.	3.5	No	6	Tied joint
103	Trans	294+00	295+00	HMA S.R.	3.5-4.5	No	6.0-4.5	
104	Test	295+00	299+00	HMA S.R.	4.5	A	4.5	
105	Trans	299+00	300+00	HMA S.R.	4.5	A	4.5	
106	Test	300+00	304+00	HMA S.R.	4.5	A	4.5	Tied joint
107	Trans	304+00	305+00	HMA S.R.	4.5	A	4.5-6.0	
108	Test	305+00	309+00	HMA S.R.	4.5	A	6	
109	Trans	309+00	310+00	HMA S.R.	4.5	A	6	
110	Test	310+00	314+00	HMA S.R.	4.5	A	6	
111	Trans	314+00	315+00	HMA S.R.	4.5	No	6.0-4.5	
112	Test	315+00	319+00	HMA S.R.	4.5	B	4.5	
113	Trans	319+00	320+00	HMA S.R.	4.5	B	4.5	
114	Test	320+00	324+00	HMA S.R.	4.5	B	4.5	Tied joint
115	Trans	324+00	325+00	HMA S.R.	4.5	B	4.5-6.0	
116	Test	325+00	329+00	HMA S.R.	4.5	B	6	
117	Trans	329+00	330+00	HMA S.R.	4.5	B	6	
118	Test	330+00	334+00	HMA S.R.	4.5	B	6	
119	Trans	334+00	335+00	HMA S.R.	4.5	No	6.0-9.0	
120	Test	335+00	339+00	HMA S.R.	4.5	C	9	
121	Trans	339+00	340+00	HMA S.R.	4.5	C	9	
122	Test	340+00	344+00	HMA S.R.	4.5	C	9	Tied joint
123	Trans	344+00	345+00	HMA S.R.	4.5	C	9	
124	Test	345+00	349+00	HMA S.R.	4.5	C	9	
125	Trans	349+00	350+00	HMA S.R.	4.5	C	9	
126	Test	350+00	354+00	HMA S.R.	4.5	C	9	
127	Trans	354+00	355+00	HMA S.R.	4.5	No	9.0-4.5	
128	Test	355+00	359+00	HMA S.R.	4.5	No	4.5	
129	Trans	359+00	360+00	HMA S.R.	4.5	No	4.5	
130	Test	360+00	364+00	HMA S.R.	4.5	No	4.5	Tied joint
131	Trans	364+00	365+00	HMA S.R.	4.5	No	4.5-6.0	
132	Test	365+00	369+00	HMA S.R.	4.5	No	6	
133	Trans	369+00	370+00	HMA S.R.	4.5	No	6	
134	Test	370+00	374+00	HMA S.R.	4.5	No	6	
135	Trans	374+00	375+00	Patch	4.5-3.5	No	6.0-4.5	
136	Test	375+00	379+00	Patch	3.5	A	4.5	
137	Trans	379+00	380+00	Patch	3.5	A	4.5	
138	Test	380+00	384+00	Patch	3.5	A	4.5	
139	Trans	384+00	385+00	Patch	3.5	A	4.5-6.0	
140	Test	385+00	389+00	Patch	3.5	A	6	
141	Trans	389+00	390+00	Patch	3.5	A	6	
142	Test	390+00	394+00	Patch	3.5	A	6	Tied joint
143	Trans	394+00	395+00	Patch	3.5	No	6.0-4.5	
144	Test	395+00	399+00	Patch	3.5	B	4.5	
145	Trans	399+00	400+00	Patch	3.5	B	4.5	
146	Test	400+00	404+00	Patch	3.5	B	4.5	
147	Trans	404+00	405+00	Patch	3.5	B	4.5-6.0	
148	Test	405+00	409+00	Patch	3.5	B	6	

149	Trans	409+00	410+00	Patch	3.5	B	6	
150	Test	410+00	414+00	Patch	3.5	B	6	Tied joint
151	Trans	414+00	415+00	Patch	3.5	No	6	
152	Test	415+00	419+00	Patch	3.5	C	6	
153	Trans	419+00	420+00	Patch	3.5	C	6	
154	Test	420+00	424+00	Patch	3.5	C	6	
155	Trans	424+00	425+00	Patch	3.5	C	6	
156	Test	425+00	429+00	Patch	3.5	C	6	Tied joint
157	Trans	429+00	430+00	Patch	3.5	C	6	
158	Test	430+00	434+00	Patch	3.5	C	6	
159	Trans	434+00	435+00	Patch	3.5	No	6.0-4.5	
160	Test	435+00	439+00	Patch	3.5	No	4.5	
161	Trans	439+00	440+00	Patch	3.5	No	4.5	
162	Test	440+00	444+00	Patch	3.5	No	4.5	
163	Trans	444+00	445+00	Patch	3.5	No	4.5-6.0	
164	Test	445+00	449+00	Patch	3.5	No	6	
165	Trans	449+00	450+00	Patch	3.5	No	6	
166	Test	450+00	454+00	Patch	3.5	No	6	Tied joint
167	Trans	454+00	455+00	Patch	3.5-4.5	No	6.0-4.5	
168	Test	455+00	459+00	Patch	4.5	A	4.5	
169	Trans	459+00	459+50	Patch	4.5	A	4.5	
170	Test	459+50	463+50	Patch	4.5	A	4.5	Tied joint
171	Trans	463+50	464+00	Patch	4.5	A	4.5-6.0	
172	Test	464+00	468+00	Patch	4.5	A	6	
173	Trans	468+00	468+50	Patch	4.5	A	6	
174	Test	468+50	472+50	Patch	4.5	A	6	
175	Trans	472+50	473+00	Patch	4.5	No	6.0-4.5	
176	Test	473+00	477+00	Patch	4.5	B	4.5	
177	Trans	477+00	477+50	Patch	4.5	B	4.5	
178	Test	477+50	481+50	Patch	4.5	B	4.5	Tied joint
179	Trans	481+50	482+00	Patch	4.5	B	4.5-6.0	
180	Test	482+00	486+00	Patch	4.5	B	6	
181	Trans	486+00	486+50	Patch	4.5	B	6	
182	Test	486+50	490+50	Patch	4.5	B	6	
183	Trans	490+50	491+00	Patch	4.5	No	6.0-9.0	
184	Test	491+00	495+00	Patch	4.5	C	9	
185	Trans	495+00	495+50	Patch	4.5	C	9	Tied joint
186	Test	495+50	499+50	Patch	4.5	C	9	
188	Trans	499+50	500+50	Patch	4.5	No	9-4.5	
189	Test	500+50	506+60	Patch	4.5	No	4.5	Tie center 200'
190	Trans	506+60	507+60	Patch	4.5	No	4.5-6	
191	Test	507+60	513+70	Patch	4.5	No	6	
	EOP		513+70					

*A = polypropylene fibrillated, B = polypropylene monofilament, C = W.R. Grace structural fibers, No = no fiber reinforcement.

CONSTRUCTION

The Iowa Highway 13 project consists of concrete widening and resurfacing. The previous driving surface was a 24-foot-wide ACC surface. At the completion of the current construction phase, the roadway surface is 28 feet wide with an 8-inch-thickened edge on the outer 5 feet of each side and a thin concrete surface on the middle 18 feet. Figure 4 shows the proposed cross section for Iowa Highway 13.

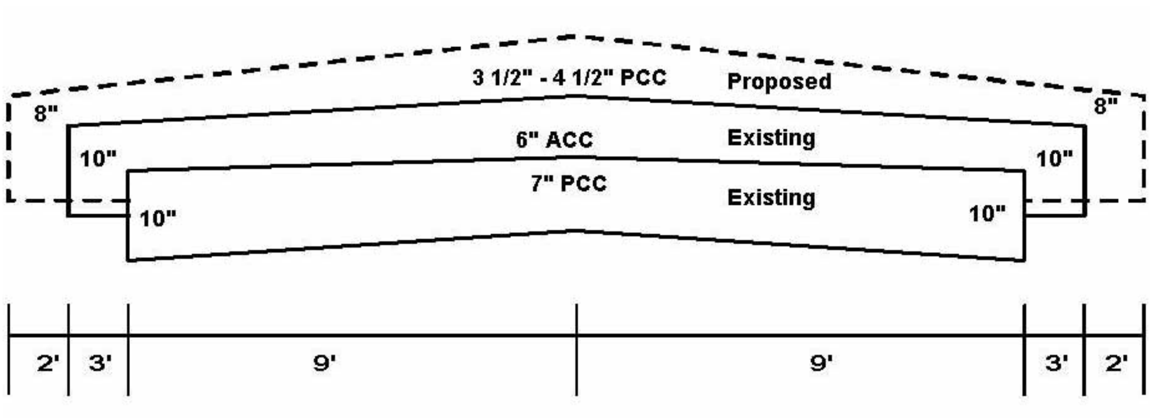

Figure 4. Typical Cross Section for the Iowa Highway 13 Project

Scarification of the asphalt surface from station 51+00 to station 208+00 was performed two months prior to the UTW. The goal of the scarification was to remove the top layer, 1/4 inches, of oils and road grime to create a surface that the concrete would bond to easily. A 6-foot-wide Wirtgen 900 DC milling machine was used to remove the upper ACC layer. The milling machine followed the crown of the road and completed the work in four passes. Debris from the scarification was transported and piled on the shoulder using a loading belt mounted to the front of the milling machine. Figure 5 shows a typical scarified pavement surface on Iowa Highway 13.

The scarification of the above-described section was completed in two days, after which the milling of the asphalt widening unit began. The outer 3 feet of the asphalt widening unit was removed in order to bring the roadway back to the original 18 feet, which has a concrete base underneath it. The depth of the milling varied from 3.5 inches to 4.5 inches, dependant upon the thickness of the concrete to be placed in the overlay, so a constant 8-inch-thickened edge was created on each side of the roadway. The milling operation was followed by a motorgrader that pushed the shoulder material into the ditch and created a stable surface for the slip-form paver tracks to be supported upon. Figure 6 shows a typical milled widening unit on Iowa Highway 13.

Figure 5. Scarified Pavement Surface

Figure 6. Completed Milling Operation

The culvert extensions and the profile survey both began one month before the placement of the UTW. The profile consisted of survey points at the 18-foot edges and the centerline every 25 feet for the scarified and the HMA stress relief sections (stations 51+00 to 374+00). The broomed section consisted of shots at the 18-foot edges, the 1/4 points, and the centerline (stations 374+00 to 513+70). These shots were used to calculate grades to create an improved driving surface and help to control the quantity of concrete used.

The HMA stress relief layer was placed three weeks prior to placement of the UTW by River City Paving. It consisted of a 1-inch lift of hot mix asphalt. It was completed in two passes over the course of one day. Figure 7 shows a typical HMA stress relief surface on Iowa Highway 13.

Figure 7. HMA Stress Relief Layer

Longitudinal subdrains were installed two weeks prior to the UTW. The longitudinal subdrains were installed adjacent to the existing asphalt widening units, so that they would be covered by the new widening unit. Table 6 shows the stationing and the side of the road of both the existing and the newly installed longitudinal subdrains.

Table 6. Stationing and Side of the Road of New/Existing Longitudinal Subdrains

Existing Subdrain Locations			Proposed Subdrain Locations		
Station to Station		Location	Station to Station		Location
39+50	43+00	Right	19+00	22+00	Right
58+00	65+00	Right	76+00	81+00	Left
116+00	119+00	Left	76+00	81+00	Right
127+75	132+50	Left	85+00	90+00	Right
138+50	143+00	Left	95+00	98+50	Right
152+00	159+00	Right	104+00	109+00	Right
208+00	220+00	Right	109+00	112+00	Right
226+00	237+00	Right	119+00	124+00	Left
265+25	275+00	Both	129+00	133+00	Right
280+00	286+00	Right	166+00	172+00	Right
280+00	287+00	Left	169+00	173+00	Left
310+00	316+00	Both	172+00	174+00	Right
325+00	330+00	Both	177+00	182+00	Left
343+00	348+50	Both	193+00	198+00	Left
353+00	361+00	Both	248+00	252+00	Right
364+00	372+00	Both	260+25	262+00	Right
375+00	381+00	Both	291+00	297+00	Right
384+00	390+00	Both	391+00	392+50	Right
393+00	400+00	Both	391+00	392+50	Left
402+00	407+00	Right	409+00	411+50	Right
422+00	431+00	Both	411+50	414+00	Right
433+00	438+00	Both	415+00	420+00	Right
439+00	444+00	Both	454+00	456+90	Right
445+00	450+00	Left	457+10	460+00	Right
445+00	451+00	Right	460+00	465+00	Right
473+00	486+00	Both	465+00	470+00	Right
			489+00	494+00	Right
			502+40	507+00	Right
			507+00	510+00	Right
			510+00	515+00	Left

In the broomed-only section of the project, a bridging technique was used determine the minimum amount of surface preparation that could be performed and still obtain desirable overlay performance. Areas of the pavement that were in extremely poor condition having multiple transverse cracks and extensive faulting existed. Six cracks with this degree of distress were bridged with #4 coated epoxy rebars stapled to the slab. The bars were 36 inches long and placed 30 inches on center perpendicular to the direction of the crack. Figure 8 show the bars stapled to the slab before they were overlaid with concrete. Table 7 shows the stations at which the transverse cracks were tied in this manner.

Figure 8. Tied Transverse Crack

Table 7. Tied Transverse Crack Locations

	1	2	3	4	5	6
Station	385+98	396+33	404+82	409+65	418+00	456+66

Due to the high number of changing variables being tested on this project, the Iowa State University staff created signs that alerted construction workers to changes in jointing patterns, fiber inclusion, and beginning and ending points of the tied outer joints. Figure 9 shows the labeling plates that were placed throughout the length of the project alerting of changes.

Figure 9. Labeling Plate

Paving operations took place from July 2 to July 23, 2002. After subtracting rain days and holidays, the 9 miles of paving was completed in 12 working days. The PCC mixes used were Quality Management–Concrete (QMC) mixes designed by Fred Carlson Company.

Materials were stored, proportioned, and mixed at a portable central mix PCC plant located at the north end of the project, in Kuhlman's Quarry on the west side of the town of Edgewood, Iowa. Agitator trucks and dump trucks transported the mix to the construction location. Power brooming was conducted just prior to the placement of the PCC. The brooming was done to remove loose pavement or contaminants on the ACC surface. Also prior to placement, in test sections that required, the 18-foot joints on either side of the pavement were tied with #4 by 3-foot epoxy coated steel bars. These bars were stapled to the pavement at 30-inch intervals in an effort to connect the 8-inch widening unit to the thin, unbonded pavement. Figure 10 shows the bars stapled to the asphalt slab prior to being covered by concrete.

Due to the high daytime temperature during the construction of this project, water was used to control the temperature of the ACC base. The Iowa State University staff monitored the temperature of the subbase with infrared temperature guns. When the base reached 100 degrees Fahrenheit, the base was sprayed with water. The water was placed on the existing surface, an adequate length in front of the slip-form paver, so that by the time the paving train would pass by, evaporation of standing water had already occurred and the pavement cooled to a safe level.

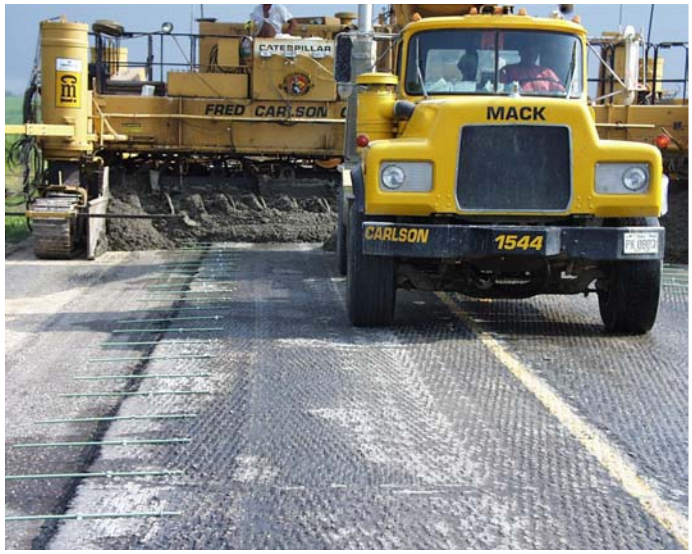

Figure 10. Stapled #4 Bar that Ties the Widening Unit to the Thin Overlay

A CMI Caterpillar SF-550 slip-form paver, with electronic horizontal and vertical grade control, was used to pave both lanes of the project simultaneously. Horizontally projected vibrators provided consolidation of the concrete. Following vibration, the PCC was struck off to achieve final thickness and a two percent crown. Attached to the bottom of the pan were two longitudinal joint forming knives. The knives separated the aggregates, leaving a weakened joint of concrete cream 2 inches deep. The knives were attached to the pan 9 feet from the centerline on each side of the pan. The use of the longitudinal joint forming knives on this project eliminated 17.5 miles of joint sawing. Figure 11 shows the longitudinal joint forming knife as it was attached to the bottom of the pan.

Figure 11. Longitudinal Joint Forming Knife

Following the paver, bullfloating and initial texturing were performed by construction workers. The construction workers were followed by a Guntert and ZimmermanTC-850, which performed the longitudinal tining and sprayed the 1600 White curing compound on the exposed portions of the slab. The outer 2.5 feet of each side of the slab was not tined in order to create a natural shoulder appearance on the slab.

The sawing of joints began as soon as the concrete was set enough to support the equipment, typically 3 to 4 hours after the application of the curing compound. Sawing of the transverse joints continued until raveling occurred; at that time the operation was paused for 30 to 60 minutes to allow for more set time. The joints were cut in a way to form 4.5 x 4.5, 6 x 6, and 9 x 9 foot square panels. Figure 12 is a diagram that shows how the joint patterns were laid out on the slab.

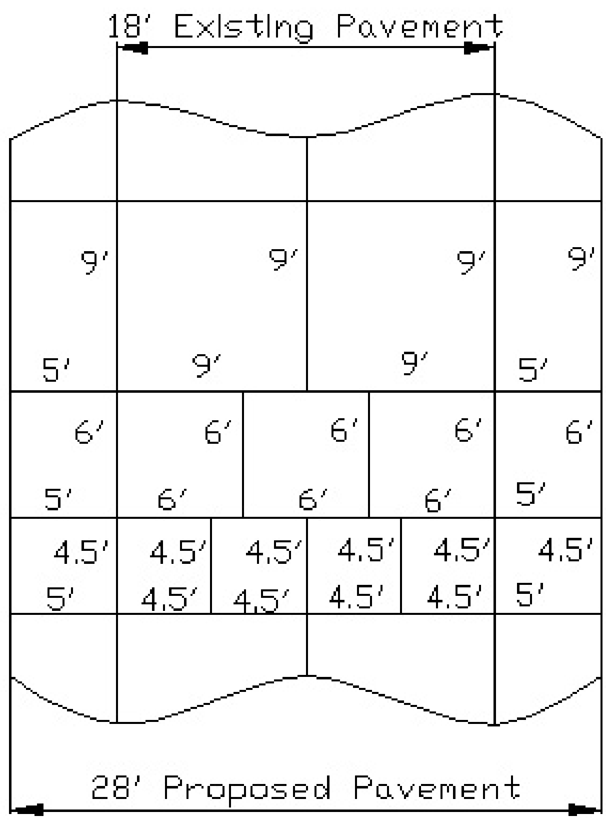

Figure 12. Typical of Panel Sizes

Longitudinal joints were sawed 3 hours after the transverse joints, and they were sawed from south to north. The rate of placement required as many as three saws being used simultaneously in order keep up with the paving operation.

Since a 1/8-inch joint width was used, the joints were not sealed, but they were cleaned. The process of cleaning the joints consisted of a high-pressure air blast, which would drive the concrete dust out of the joint and off the slab.

Three varieties of synthetic fiber reinforcement were used on this project—polypropylene fibrillated, polypropylene monofilament, and structural fibers. All fibers on this project were provided by W.R. Grace. The fibers were added at 1 pound of monofilament per cubic yard of concrete, 3 pounds of fibrillated polypropylene fibers per cubic yard of concrete, and 3 pounds of structural fibers per cubic yard of concrete. The fibers were blown into the concrete mixing drum by use of a hopper system supplied by W.R. Grace. Figure 13 shows the operation of the fiber inclusion system.

Figure 13. Fibers Being Blown into the Concrete Mixing Drum

The strength development for this project was measured using the maturity method. Temperature probes were inserted 100 feet from the end point of each test section. A 7.5-inch probe was inserted one foot from the pavement edge and monitored the temperature at depths of 1, 4, 7.5 inches. Another probe was placed in the thin overlay section six feet from the pavement edge and monitored the temperature at depths of 1 and 2 inches. One set of probes was placed 100 feet from the end of each of the 91 test sections. The temperature was read from these probes four times daily, Monday through Friday, to determine the time-temperature factor, which can be correlated to concrete flexural strength. The center portion of the new roadway was open to local traffic at a flexural strength of 350 psi, and construction traffic was allowed on the slab at 500 psi as determined by the maturity probes. The slab could be opened to local traffic the day after it was placed; however, local traffic was not allowed on until two days after in an effort to protect the paving equipment and the workers.

A separate agreement was made with the Federal Highway Administration–Iowa Division to test multiple maturity devices on the same project. The objectives of this work were to provide an evaluation of various types of maturity measuring equipment in a side-by-side demonstration of the materials and methods. For a full report about the testing and evaluation of these devices, see Appendix A.

Construction Concerns

Difficulties were encountered on numerous occasions in trying to reach a balance between overrun, achieving the appropriate thickness, and maintaining a smooth ride. These problems were the result of the survey/grade not being finished until after paving began. The grades had to be calculated in a rush, not allowing time to input corrective measures into the design of the new roadway. In an effort to control the concrete overrun, the Iowa DOT lowered the grades, and as a result the ride measured by the profilograph suffered.

The use of fibers caused concerns for construction workers who were trying to finish the slab, especially when using the structural fibers at the end-of-day joints. As a result, the fiber inclusion was stopped both in and out of the headers at the conclusion and the beginning of each day. If the paving was stopped in a test section that included fibers, the last two truckloads of the day were mixed without fibers. The same was true for the first two truckloads that were mixed in the morning. This change allowed for smoother headers and easier finishing. The tining process caused the fibers to stand up making the surface of the slab look "hairy." All of the surface fibers were worn away after a few days of highway traffic. During the second day of paving, large concentrations of fiber were seen in the concrete. This was found to be caused by a lack of suction in the blower to evenly distribute the fibers throughout the concrete in the mixing drum. To create more suction, a small cardboard piece was held over the opening of the blower after the fibers had been emptied into the blower. All clumps disappeared after use of the cardboard piece. Figure 14 shows how the cardboard piece was used to create increased blowing power.

Figure 14. Adjustment to Blower for Better Fiber Dispersion

The 1-inch HMA stress relief layer that was placed over the existing asphalt retained a large amount of heat in the midday sun. Even after one application of water, the temperature of that surface was measured to be 120 to 130 degrees Fahrenheit. Questions arose as to what effect the heat would have on bond between the slabs and the strength gain of the slab.

The longitudinal joint forming knife was leaving a wide gap behind the paver. As a result, it required extra passes from the workers using the bullfloats to properly close the gap. In an experiment, the joint forming knife on the right side of the pan was cut off at the backside of the pan on July 16, 2002. The aggregates were still being separated and the workers were able to properly close the gap with one pass. Due to the success of the previous day, the left knife was cut off at the back of the pan on the next day.

At station 81+00 to station 81+50, the right-side pad of the paver was stuck in the mud; as a result, the paver pivoted, bringing the left pad into the edge of the fresh concrete. The excess concrete during the pivot forced the paver pan upward, creating a bump. A great deal of handwork was required to finish the slab, which was particularly difficult because of the use of the structural fibers. From station 85+00 to station 96+00, a sudden rainstorm saturated the slab before it could be covered. The slab from 87+50 to 96+00 was able to be longitudinally tined and resprayed with curing compound. The slab from 85+00 to 87+50 was too set to re-tine and sustained visible damage to the surface. From 101+75 to 102+75, plant problems caused the concrete to sit in front of the paver for about one hour before it was finished. After the plant was repaired, the concrete was sprayed with water and progress resumed.

Other construction concerns were quickly remedied, causing only minor delays. Other concerns included rainstorms, running out of fibers, and other equipment breakdowns.

Field Changes

Since the fiber inclusion cannot be started and stopped immediately, it sometimes ran short or over the beginning or end of the test section. Table 8 shows the adjusted beginning and ending stations and which types of fibers were used.

During construction, questions were raised on the validity of blowing the concrete dust out of the joints after they had been sawed. Like the longitudinal joint forming knife, the saw had already created a plane of weakness for the concrete to crack if needed. Since the joints were not going to be filled, the cleaning of the joints may be unnecessary. As a result, the Iowa State University staff set out two test sections along the project to test the effects of not cleaning the joints. These test sections were located from 258+00 to 265+00 and from 495+00 to 513+66.

On the first day of paving, there was confusion between the specifications for the width of the concrete joints. As a result, the joints in the first and second day of paving were sawed with a 1/4-inch blade instead of the specified 1/8-inch blade. The 1/4-inch joints were not sealed and the problem was eliminated before the third day's paving was sawed. The 1/4-inch blade was used from station 51+02 to station 97+35.

The original proposal had called for surface patching of rough areas as one of the asphalt surface preparations. This was not done because of the overall good condition of the existing asphalt surface. As a result, the sections that were identified to be surface patched were simply broomed prior to construction.

The original proposal had also called for the existing joint to be either bridged with concrete or cut to match the cracks of the base PCC layer. All of the joints on this project were bridged with concrete.

Table 8. Adjusted Beginning and Ending Stations of Fiber Inclusion

Section	Station to Station		Length	Fiber Type
3-8	51+02	66+00	1,498	B
14	66+00	66+90	90	No
15-21	66+90	86+00	1,910	C
22-30	86+00	107+75	2,175	No
31-40	107+75	139+15	3,140	A
41	139+15	140+10	95	No
42-48	140+10	158+75	1,865	B
49	158+75	159+80	105	No
50-56	159+80	179+25	1,945	C
57-68	179+25	209+00	2,975	No
69-75	209+00	229+00	2,000	A
76	229+00	230+05	105	No
77-83	230+05	247+55	1,750	B
84	247+55	248+60	105	No
85-87	248+60	258+25	965	C
88-92	258+25	270+31	1,206	No
93	270+31	274+25	394	C
94-103	274+25	294+65	2,040	No
104-110	294+65	314+25	1,960	A
111	314+25	315+25	100	No
112-116	315+25	326+44	1,119	B
	326+44	326+44	0	Header - two loads in and two out with no fibers
116-118	326+44	334+25	781	B
119	334+25	335+50	125	No
120-126	335+50	354+00	1,850	C
127-135	354+00	374+98	2,098	No
136-142	374+98	393+75	1,877	A
143	393+75	395+00	125	No
144-150	395+00	414+00	1,900	B
151	414+00	414+75	75	No
152-153	414+75	419+45	470	C
	419+45	419+45	0	Header – two loads in and two out with no fibers
153-158	419+45	434+50	1,505	C
159-167	434+50	458+01	2,351	No
168-174	458+01	472+00	1,399	A
175	472+00	472+50	50	No
176-182	472+50	490+80	1,830	B
183	490+80	491+50	70	No
184-186	491+50	497+25	575	C - ran out of C fibers
187-191	497+25	513+66	1,641	No

TEST FREQUENCY AND METHODS

Lab Shear Testing

Lab testing involved shear testing on cores from the length of the project to test the bond between the new concrete overlay and the existing asphalt overlay. Three cores were taken from each of the specified locations to be tested in the lab. The cores were removed from the center of three consecutive panels within the given test section at the specified stationing. The cores were tested using the Iowa DOT Office of Materials Test Method #Iowa 406-C. Table 9 shows the results of the shear test and information about where the cores were taken from.

Table 9. Information and Results of Shear Test

Sample	Station	Lane	Thickness				Shear Strength (psi)
			Overlay	ACC	Old PCC	Total	
1	58+00	NBL	3.75	2.75	8.00	14.50	207
2	58+00	NBL	3.75	2.75	7.75	14.25	194
3	58+00	NBL	3.75	2.75	8.25	14.75	180
1	73+00	NBL	4.75	3.50	7.50	15.75	184
2	73+00	NBL	4.75	3.75	7.50	16.00	156
3	73+00	NBL	4.50	3.75	7.00	15.25	200
1	98+00	NBL	6.00	3.75	7.00	16.75	152
2	98+00	NBL	5.75	4.00	7.00	16.75	175
3	98+00	NBL	5.75	3.75	7.00	16.50	200
1	115+00	NBL	4.75	2.75	7.50	15.00	183
2	115+00	NBL	4.50	2.50	—	7.00	204
3	115+00	NBL	4.50	2.75	7.00	14.25	150
1	215+00	SBL	4.50	4.00	7.50	16.00	177
2	215+00	SBL	4.50	4.50	7.50	16.50	203
3	215+00	SBL	4.50	4.00	7.25	15.75	153
1	235+00	SBL	4.25	3.25	7.25	14.75	120
2	235+00	SBL	4.25	3.25	7.50	15.00	135
3	235+00	SBL	4.25	3.25	7.75	15.25	158
1	271+00	SBL	3.75	4.25	6.75	14.75	110
2	271+00	SBL	4.00	4.25	6.75	15.00	197
3	271+00	SBL	4.00	4.25	6.75	15.00	168
1	281+00	SBL	4.50	4.25	7.00	15.75	139
2	281+00	SBL	4.50	4.25	7.00	15.75	144
3	281+00	SBL	4.50	4.25	7.00	15.75	153
1	376+00	NBL	4.00	5.25	8.50	17.75	282
2	376+00	NBL	4.00	5.00	8.00	17.00	300
3	376+00	NBL	4.00	5.00	8.00	17.00	475
1	401+00	NBL	4.25	4.75	7.75	16.75	211
2	401+00	NBL	4.25	4.75	7.50	16.50	212
3	401+00	NBL	4.25	4.50	7.75	16.50	264
1	426+00	NBL	5.00	4.50	7.00	16.50	360
2	426+00	NBL	5.00	4.50	7.25	16.75	460
3	426+00	NBL	5.00	4.50	7.00	16.50	290
1	436+00	NBL	4.25	7.50	—	11.75	269
2	436+00	NBL	4.50	7.50	—	12.00	270
3	436+00	NBL	4.25	7.00	—	11.25	228

Field Testing

Falling Weight Deflectometer Testing

Falling weight deflectometer (FWD) testing was conducted before and after the construction of the project. It will be done biannually, once in the fall and once in the spring, for the next five years. Before construction, the original pavement structure was tested in the outer wheel path of the north and southbound lanes. Each location was tested once. After construction, the new pavement was tested in the same spots twice a year, once in October and once in April.

Testing is conducted by the Iowa DOT Ames Office using a Foundation Mechanics JILS-20-FWD with a 6-inch load plate and nine displacement measuring sensors. One transducer is located at the center of the load plate, and the remaining transducers are spaced at varying intervals from the plate. Figure 15 shows the location of the deflection sensors in relation to the load.

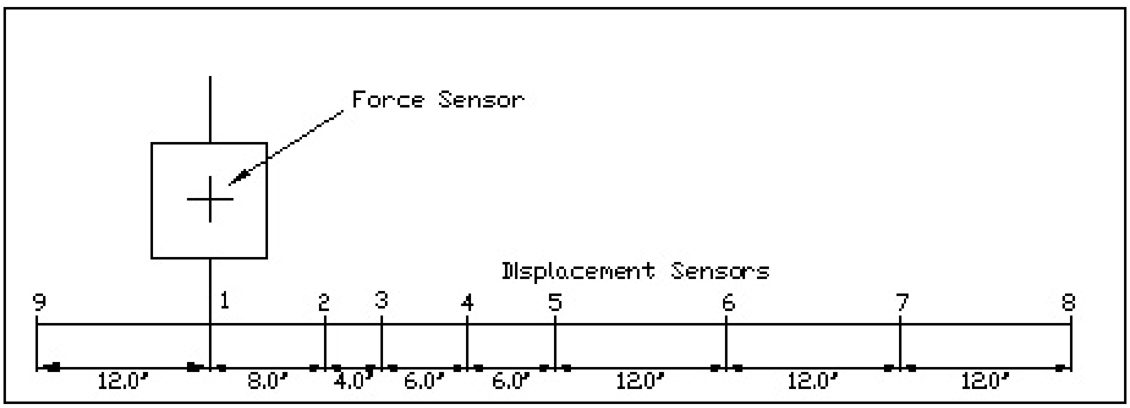

Figure 15. Schematic of FWD Deflection Sensors

The computer and system processor controlled testing operations and recorded maximum deflection responses measured by each transducer. At each of the test locations, drops were made at a target load of 9,000 pounds. A drop sequence was performed at each test location at the transverse joint and at the slab center along the outer wheel path. Appendix B contains the data for the FWD testing that was done before construction and after construction. Test locations were established to provide replicates of the test variable combinations and direction of travel. Testing locations are also shown in Appendix B with the FWD data.

Joint Openings and Faulting Measurements

Twice a year the staff from Iowa State University measures the joint openings and the faulting of 10 consecutive transverse joints located at the center of each test sections. During the construction process, nails were placed on each side of the transverse joints 10 inches apart and 1 foot from the edge of the northbound lane. The distance between the nails is measured and recorded to determine the effects of the changing climate on the pavement surface. The faulting is measured using a faultmeter at the same 10 transverse joints that were measured for joint openings. The faulting is read 4.5 feet from the outer edge of both the northbound and southbound lanes. Appendix C contains joint opening data and the faulting data that have been collected since construction.

Visual Distress Surveys

Following the construction of the project, visual distress surveys have been conducted. The types of distresses considered in the survey include transverse cracks, longitudinal cracks, corner cracks, diagonal cracks, popouts, joint spalls, and fractured panels. Surveys are conducted twice per year, one in October and the other in April. The tests were performed to identify the impact of the freeze thaw cycles and the impact of heavy loads on pavement performance.

Visual distress survey results from two walking surveys are not conclusive, but provide some insight into long-range performance related to overlay design features. Working centerline joints cannot be bridged with concrete up to 4.5 inches in depth without expecting some reflective cracking. One such instance has occurred in the first year in a 6-foot-wide panel that bridges the only centerline.

In one area of the project, the existing ACC materials were almost completely removed to allow the new surface to meet and existing concrete road at an intersection. This was the tradeoff to removal of a large amount of relatively new county road approach PCC. This resulted in effectively building a bonded overlay in this short area. It is performing well, but care should have been taken to match new and existing joints. By continuing the normal joint pattern for the test section, we have observed two transverse cracks and one longitudinal centerline crack.

Weigh-in-Motion Device Measurements

A weigh-in-motion device was installed at station 340+00. It records the number of axels and the weight of the axels that pass that particular point. The device monitors the traffic in both the northbound and southbound lanes. The data will be useful in future analysis of the overlay variables versus pavement performance.

Cross Sectional Structural Analysis

During the course of the planning and construction of this project, the project team questioned the design and purpose of the widening units to the overall performance of the overlay. The widening units appeared to contain the overlay and provide edge support or act as a paved shoulder for the existing pavement width. A finite elemental structural analysis was conducted to determine the value of the overlay and widening units in the reduction of stress and strain applied to the original pavement. The intent of this work was to aid in determining some of the expected performance enhancements from the overall design.

The pavement was analyzed in terms of two designs, one without the widening units and one with the widening units of PCC. The study considered variations in subgrade support, cross slope, and joints at each edge of the original pavement width.

Results of the deflection analysis indicate a 40 percent reduction in stresses as the subgrade support value is doubled or the assumed values for design are reached. A 60 percent reduction in deflection values is noted when the widening units are added to the pavement cross section. See Appendix D for additional information regarding the cross sectional structural analysis.

SUMMARY

The Iowa Highway 13 project was developed efficiently and according to acceptable construction practices. The team of the Iowa DOT, Iowa State University, and Fred Carlson Company created an award-winning project. Due to the constant interaction with neighbors affected by the construction and the timely opening of the road to traffic, the project won the Traffic Management Award from the Iowa Concrete Paving Association. The construction concerns were relatively minor, with the exception of the difficulty in maintaining a balance between pavement thickness, concrete overruns, and ride.

Proper construction and recording of the project performance measures should provide a solid basis for data collection and analysis. Ultimately, it is desired to develop a construction specification on how to design a thin, unbonded concrete overlay in terms of joint spacing, PCC thickness, surface preparation, use of fibers, and the sealing of joints. The number and range of design variables will prove valuable to such research efforts.

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APPENDIX A

MATURITY MEASUREMENT EQUIPMENT EVALUATION: FINAL REPORT

J.K. Cable, M.L. Anthony

Maturity Measurement Equipment Evaluation

Final Report

May 2003

Sponsored by the
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16. Abstract

Since 1995, Iowa has been leading the way to greater use of the maturity concept in portland cement concrete pavement construction. New technologies have emerged to further that concept. The Federal Highway Administration and Iowa State University teamed to evaluate four temperature-monitoring systems: (1) Iowa Maturity Device, (2) Total Environmental Management for Paving System (Transtec Group, Inc.), (3) IRD Concrete Maturity Monitor (International Road Dynamics), and (4) IntelliROCK System (Nomadics Construction Laboratory).

Side-by-side evaluation was conducted on 12 sites in a nine-mile pavement overlay project. Each device performed well and gave corresponding temperature values. The attributes and limitations of each device are described in this report. The specific devices with memory are well suited to structural concrete temperature monitoring. In the case of highway pavements, ease of installation and operation, wireless remote data transmittal, and minimal cost remain the goals to be achieved.

17. Key Words		18. Distribution Statement	
portland cement concrete pavement overlays, maturity, temperature-monitoring systems		No restrictions.	
19. Security Classification (of this report)	**20. Security Classification (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified.	Unclassified.	16	NA

INTRODUCTION

Background

In recent years, the Iowa Department of Transportation has conducted research through Iowa State University (ISU) that resulted in the implementation of the maturity concept for estimating the strength of portland cement concrete pavements in the field. This work has allowed the department and the contracting industry to reduce the amount of time between concrete placement and opening of the pavement to traffic from seven days to two or less in many cases. Contractors have embraced the concept and it is employed on a majority of state projects in Iowa at this time.

ISU, through its Department of Civil, Construction, and Environmental Engineering and Center for Portland Cement Concrete Pavement Technology, is currently under contract to conduct research on the “Evaluation of Composite Pavement Unbonded Overlays.” As part of this work, maturity is to be used to measure estimated strength gain in the concrete to allow for early opening. The project team and the Federal Highway Administration (FHWA) Iowa Division entered into a separate agreement to test multiple maturity devices on the above-described project.

Objectives

The objectives of this work are to provide an evaluation of various types of maturity measuring equipment in a side-by-side demonstration of the materials and methods. The methods considered are as follows:

1. **Iowa Maturity Device**—conventional thermocouple wires and digital thermometers (part of the current research contract) employing the Iowa Maturity Device.
2. **Total Environmental Management for Paving (TEMP) System**—Electronic buttons with wire antennas and remote access (provided by Transtec Group, Inc., as a subcontract in current research).
3. **IRD Concrete Maturity Monitor**—Concrete maturity monitor by International Road Dynamics (IRD) with memory and remote access (under evaluation by the FHWA Midwest Resource Center).
4. **IntelliROCK System**—IntelliROCK System by Nomadics Construction Laboratory, including sensors with memory capability and lead wires and a physical logger system.

RESEARCH METHODOLOGY

The current research was conducted on Iowa Highway 13 in Delaware County between the north city limits of Manchester, Iowa, and Iowa Highway 3 (9.45 miles). There were 92 separate test sections provided to test base preparation methods, overlay depth, joint spacing, and fiber inclusion. The 28-foot roadway was constructed with one pass of a slip-form paver over the top of an existing 18-foot concrete roadway overlaid with two asphalt layers. The four types of maturity monitoring equipment were employed in 12 consecutive test sections to provide side-by-side analysis of each of the maturity devices. They were placed at mid-depth of the 8-inch slab, 1 foot from the outer edge of the roadway. The TEMP System, IRD Concrete Maturity Monitor, and IntelliROCK System maturity devices were all attached to a bent 90° epoxy-coated, #4 bar; the bar was then placed in front of the paving operation. Figure A.1 shows all of the devices as they were attached to a single bent bar before installation.

Figure A.1. Maturity Device Installation

The Iowa Maturity Device was placed after the paving operation had passed. It was pushed through the surface of the concrete. (See Figure A.2.)

Figure A.2. Iowa Maturity Device Installation

The ISU staff monitored all of the devices. The Iowa Maturity Device required manual readings that were taken four times daily excluding Saturday and Sundays on which no readings were taken. The remaining devices had memory capabilities, which allowed them to record the temperature at their default time intervals. These recorded values were then downloaded into a computer for analysis. Figure A.3 shows the beginning and ending station of the construction project as well as the approximate limits of the maturity equipment evaluation.

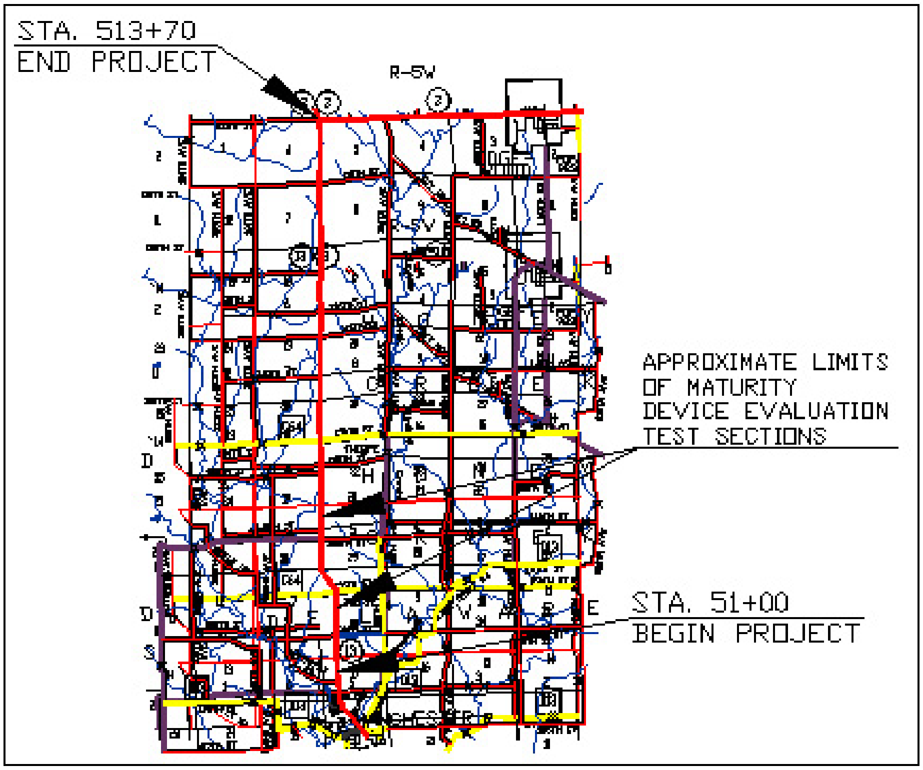


Figure A.3. Project Map

MATERIALS

Iowa Maturity Device

Figure A.4. Iowa Maturity Device

The Iowa Maturity Device (see Figure A.4) is a 4-inch wood dowel with two sets of thermocouple wires attached to it. The device is able to measure the real-time temperature of the concrete at depths of 1 inch and 4 inches when a digital thermometer is connected to the proper leads. In the comparison with the other maturity monitors, the 4-inch depth was used. The 4-inch depth was selected because it was located in the middle of the 8-inch-thick widening unit as well as being the same depth the other maturity monitors were installed. The Iowa Maturity Device requires manual reading and recording of all temperature values. These reading are placed into a spreadsheet that calculates the time-temperature factor (TTF). It is a destructive testing method that is employed after the paving train has already gone by. The Iowa Maturity Device was used to monitor the strength gain of the concrete to control opening times for this project. The concrete was monitored up until a 500-psi flexural strength was attained. At this point, the wires were cut at the pavement surface, and only the buried wooden dowel was left in the concrete. As a result, the Iowa Maturity Device controlled the amount of data provided in the graphs of time vs. temperature and time vs. TTF, which only include data up through 100 hours.

TEMP System (Transtec Group, Inc.)

Figure A.5. TEMP System (Transtec Group, Inc.)

The Total Environmental Management for Paving (TEMP) System (see Figure A.5) is comprised of concrete temperature gages similar to those used by modern maturity systems, as well as an inexpensive laptop or handheld computer loaded with the TEMP System software product. An optional antenna station can be included as an add-on to the system in order to transmit downloaded data to a location within a one-mile radius.

The sensor currently used by the TEMP System is an iButton, manufactured by Dallas Semiconductor and modified for use in concrete construction. Each iButton is a rugged, self-sufficient system that records up to 2,048 temperature values taken at uniform time intervals ranging from 1 to 255 minutes. An interval of 5 minutes was used during this project. If the temperature leaves a user-programmable range, the iButton will also record when this happened, for how long the temperature stayed outside the permitted range, and if the temperature was too high or too low. A total of 24 such events can be recorded, 12 exceeding each temperature limit. Data are transferred via a serial connection on a personal computer (PC). The TEMP System is a nondestructive monitoring device that is placed in the flow of concrete in front of the paving train. However, it does contain wire leads that need to be protected for the remainder of the construction process. The wires are cut at the pavement surface when testing is complete, and only the buried iButton is left in the concrete.

IRD Concrete Maturity Monitor (International Road Dynamics)

Figure A.6. IRD Concrete Maturity Monitor (International Road Dynamics)

The IRD Concrete Maturity Monitor (see Figure A.6) is a 1-1/4 inch by 5 inch by 1 inch tag that contains a thermometer, memory for storage, and a remote transmitter. The default setting is to record the temperature every half hour, but this can be changed to any desired interval. The default half-hour interval was used for this research. The required iPaq Pocket PC with antenna iCard, dimensions 3-1/2 inches by 5-1/4 inches by 2 inches, is able to download data from the tag into the Pocket PC’s memory via a wireless transmission. The data can be exported in a comma-separated file to be used with Microsoft Excel on any computer. The tag records and exports the following data:

- Tag serial number
- Location of the tag (if saved to the tag during construction)
- Logging interval
- Start/end time of the tags recording
- Number of times recording was taken
- Average temperature of all the records
- High temperature of all the records
- Low temperature of all the records
- Time and temperature data for every interval from start/end time

The tags are initialized before being placed in front of the paving train. After initialization, the tags will record the temperature at the set interval. The tag is a nondestructive monitoring device that is placed in the flow of concrete in front of the paving train. It does not need to be pushed into the surface of the concrete, nor does it contain wire leads that need to be protected. The tags have a limited memory dependant upon the logging interval, but can be reinitialized and begin recording again until battery failure.

IntelliROCK System (Nomadics Construction Laboratory)

Figure A.7. IntelliROCK System (Nomadics Construction Laboratory)

The IntelliROCK System (see Figure A.7) is a 1-1/2 inch by 1-1/8 inch cylinder that contains a thermometer and memory for storage. The logger is programmed to record the temperature of the concrete at 0, 4, 12, 24, 48, 72, 96, 120, 144, and 168 hours. The logger uses these recorded temperatures to calculate the maturity of the concrete using the Nurse-Saul Method at a user-selected datum (-10°C was the datum for this project). The IntelliROCK System also records the minimum and maximum temperature and the time that it occurred. The required maturity reader is used to download the data from the loggers using a wire connection. This data can be exported from the reader to a computer in a Microsoft Excel file. The IntelliROCK System records and exports the following data:

- Serial number
- Datum temperature that was used
- Temperature and calculated maturity (degree-hours) at 0, 4, 12, 24, 48, 72, 96, 120, 144, and 168 hours
- Maximum temperature and time it occurred
- Minimum temperature and time it occurred
- Current temperature and maturity at time of download

The IntelliROCK logger is a nondestructive monitoring device that is placed in the flow of concrete in front of the paving train. However, it does contain wire leads that need to be protected for the remainder of the construction process. The wires are cut at the pavement surface when testing is complete, and only the buried logger is left in the concrete. The IntelliROCK loggers are initialized after they have been paved over and have a battery life of 3 months from that time.

ANALYSIS

Table A.1 ranks each of the maturity devices on six characteristics of their use. A “5” means the device is excellent, and a “1” means the device performed poorly when compared to the other maturity devices.

Table A.1. Equipment Comparison

Equipment	Iowa Maturity Device	TEMP System	IRD Concrete Maturity Monitor	IntelliROCK System
Ease of installation	2	3	4	3
Ease of use	3	4	2	5
Training requirements	4	3	2	4
Durability	2	3	4	3
Flexibility	2	3	4	3
Total	13	16	16	18

Ease of Installation and Use

Iowa Maturity Device

Ease of Installation 2

Ease of Use 3

The Iowa Maturity Device was installed after the paving train had passed, by pressing it into the surface of the concrete. It is a destructive testing method that mars the surface of the concrete. It does not contain memory for storage; therefore, it must be read by manual means at the specified interval.

TEMP System

Ease of Installation 3

Ease of Use 4

The TEMP System is made up of a small, button-sized recorder that was attached to a #4 rebar ahead of the paving operation. The recorder contained wire leads that needed to be buried in order for the paving operation to pass by safely. After the concrete is placed, the

TEMP System contains a memory system in which it records the temperature of the concrete at the user specified interval. The temperature data are stored and can be downloaded straight into a software program. The TEMP System has the option of connecting an antenna to the wire leads in order to transmit the downloaded data to a location within a one-mile range. The software is programmed to calculate the maturity in both Fahrenheit and Celsius degree-hours.

IRD Concrete Maturity Monitor

Ease of Installation *4*

Ease of Use *2*

The IRD Concrete Maturity Monitor, a remote system, was also attached to a #4 rebar ahead of the paving operation. It also contains a memory system that records the temperature of the concrete at the user-specified interval. The temperature data were stored and available for download at anytime. The IRD system uses an iPaq Pocket PC in order to communicate with the buried tag. The tag must be initialized before they are buried in order to begin recording temperatures. After initialization, the Pocket PC should be held directly above the tag in order to download the temperature data from the tag via radar. However, the research crew had a number of problems communicating with the tags. Once the tags were buried in the concrete, it often took 8–10 attempts before a connection was established between the tag and the Pocket PC. The software has the ability to calculate the maturity in both Fahrenheit and Celsius degree-hours. It can also calculate the flexural strength of the slab if the proper data were inputted to the tag. All of the location and mix information is saved to the tag, but the research team had a major problem with the tags not saving the data. When future readings were made, the saved location data and mix information was not on file.

IntelliROCK System

Ease of Installation *3*

Ease of Use *5*

The IntelliROCK System was placed ahead of the paving operation in the same manner as the TEMP System. It contains a memory system that records the temperature of the concrete, but at programmed intervals of 0, 4, 12, 24, 48, 72, 96, 120, 144, and 168 hours. The IntelliROCK System also needs to be initialized in order to begin recording temperature data. The IntelliROCK System comes with an easy-to-use reader that can be connected to the wire leads. Once connected, one button operation allows the user to download the data into a self-contained spreadsheet, which calculates the maturity in Celsius degree-hours. The IntelliROCK System comes with software that can be loaded onto a desktop PC that facilitates reception of the downloaded data.

Training Requirements

Iowa Maturity Device

Training Requirements *4*

The Iowa Maturity Device is a very basic system. All that is required is knowledge of how to connect the thermocouple wires to a digital thermometer. The digital thermometer display gives a visual readout of the temperature for manual recording.

TEMP System

Training Requirements *3*

Information on the training requirements was not available for the TEMP System at the time of this test. A representative was on site during the research testing to complete all of the necessary procedures.

IRD Concrete Maturity Monitor

Training Requirements *2*

The IRD Concrete Maturity Monitor comes with software that must be loaded onto the iPaq Personal PC. The tags and the software come with a nine-section instruction manual that explains the requirements and procedures for use. The IRD system also requires that the user be familiar with how to use an iPaq Personal PC. A moderate amount of technological knowledge was required to use the system, combined with a couple of hours of reading the supplied instruction manuals.

IntelliROCK System

Training Requirements *4*

The IntelliROCK System comes with a short instructional manual and unlike the IRD Concrete Maturity Monitor is very simple to use. The supplied reader has a very simple display and allows the user to complete most commands with the press of one button. The supplied IntelliROCK software package can download the saved data to a computer with the press of one button. A minimal amount of technological knowledge was required to use the IntelliROCK System.

Durability

Iowa Maturity Device

Durability *2*

The Iowa Maturity Device is very susceptible to damage from the construction process. The Iowa Maturity Device uses very lightweight thermocouple wires; as a result, the wires were often damaged while lying on the pavement surface. Another problem was the wires losing contact with each other when being inserted into the concrete. These two problems resulted in the loss of temperature data and therefore an unknown concrete maturity. However, of the 12 sites that were monitored for this project, none of the wire leads was damaged by construction traffic.

TEMP System

Durability *3*

The TEMP System also uses a wire lead that is susceptible to damage. However, the wire lead is much thicker than the one used in the Iowa Maturity Device and was able to withstand damage from the construction process. None of the wire leads used on this project was damaged by construction traffic.

IRD Concrete Maturity Monitor

Durability *4*

The IRD Concrete Maturity Monitor does not contain any wire leads that can be damaged. Once safely placed in the concrete, it was not affected by any part of the construction process. The IRD system had problems obtaining readings through concrete of depths greater than 4 inches or containing large amounts of water. The thicker and the wetter the concrete, the harder it was to get a reading from the tag. Obtaining readings through the concrete could be completed after several trials, but the researcher must always be aware of how deep the tag is being placed to ensure that a proper reading can be obtained.

IntelliROCK System

Durability *3*

The IntelliROCK System is much like the TEMP System in that it has a wire lead that needs to be protected. The wire lead is also much thicker then the one used with the Iowa Maturity Device, but the research team did have some problems with a couple of the IntelliROCK wires being damaged during construction. Of the 12 sites that were monitored for this project, two of the wire leads were damaged by construction traffic and data were unable to be downloaded from these sites.

Flexibility

Iowa Maturity Device

Flexibility *2*

The quality of thermocouple wires that are used and the type of digital thermometer limit the Iowa Maturity Device's effectiveness. The personnel that are available to read the devices also limit it. The device can, however, be employed on a variety of projects from highway to structural.

TEMP System

Flexibility *3*

The TEMP System is a nondestructive test. The user can also set it to record temperature data at any time increment from 1 to 255 minutes. Its versatility allows it to be utilized on a variety of projects, from highway to structural.

IRD Concrete Maturity Monitor

Flexibility *4*

The IRD Concrete Maturity Monitor is also a nondestructive test. Because it does not have wires that need to be protected, it is more flexible. Like the TEMP System, it can be set to record temperature data at any time increment that is desired by the user. It is easily attached to structural rebar and can be employed in all aspects of concrete construction.

IntelliROCK System

Flexibility *3*

The IntelliROCK System is a nondestructive test that requires the protection of the wire leads. However, it limits temperature readings to 0, 4, 12, 24, 48, 72, 96, 120, 144, and 168 hours. It could be utilized on a variety of projects, from highway to structural.

Limitations

Iowa Maturity Device

The simplicity limits the Iowa Maturity Device. The Iowa Maturity Device was monitored regularly and provided effective results in predicting concrete strength. However, it requires personnel to be on site to take readings at the prescribed interval.

TEMP System

The only limitation with the TEMP System was the wire leads that need to be protected.

IRD Concrete Maturity Monitor

After working with the IRD Concrete Maturity Monitor, it was evident that the software was trying to do too much. The software has many features, but one of its flaws is in saving data to the tags. Most of the time, the information that was sent to the tags was not recorded. Another problem was communicating with the tags. After burying the tags in the concrete, it often took repeated trials in order to connect with the tag. Finally, to ensure a proper reading, the PC had to be placed right on top of the slab.

IntelliROCK System

Like the TEMP System, the IntelliROCK System has wire leads that need to be protected. Another limitation was the low number of times that temperatures were recorded in the first 72 hours of initial pavement curing. However, IntelliROCK System also makes a logger that records temperatures at intervals that are more frequent. This type of device would have improved the comparison of data between maturity devices.

Cost

Table A.2 presents a cost comparison.

Table A.2. Cost of the Maturity Monitor Components

Component	Iowa Maturity Device	TEMP System	IRD Concrete Maturity Meter	IntelliROCK System
Reading meter or computer	$100.00	$1,000.00	$800.00	$875.00
Antenna support system	$0.00	$495 each (optional)	$1,083.00	$0.00
Software	$0.00	$795.00	$775.00	$0.00
Logging device	$5.00 each	$30.00 each	$4.87 each	$25.00 each
Number of sites used at	12	5	12	12

Contractor Evaluation of Potential Use

At the current time, it is the feeling of a number of the contractors in Iowa that the industry is not ready to move to computer-managed products. The contractors that were questioned about their use said that they would be better suited for use in structural applications. What they would like to see is an inexpensive device that can continually monitor temperatures. Another wish is to get the maturity monitoring off the slab to avoid damage during the construction process.

CONCLUSIONS

- Each of the devices evaluated yield comparable results.
- Differences in maturity for each device are primarily associated with the frequency of data collection.
- Maturity required to open the pavement to traffic can be accurately obtained with a minimum of four temperature values per day to collect the maximum and minimum temperature values.
- The current Iowa method is most widely accepted for pavements due to minimum cost and labor availability.
- Devices with memory (e.g., the TEMP System, IRD Concrete Maturity Meter, and IntelliROCK System) are well suited to structural monitoring for temperature maintenance.
- Future direction should focus on reduced cost and wireless sensors with a 1–10 mile range for construction applications.

APPENDIX B

FALLING WEIGHT DEFLECTOMETER DATA

Table B.1. Preconstruction FWD Data (Performed on 5/21/2002 on Previous Existing Asphalt Roadway Surface)

Test #	Lane	Station	Load (kips)	Sensor Number									Temp (ºF)
				1	2	3	4	5	6	7	8	9	
1	North	43+02	9.06	4.75	3.91	3.67	3.49	3.25	2.76	2.3	1.79	3.56	53.1
2	North	52+94	9.17	5.53	5.43	5.25	4.99	4.68	4.05	3.41	2.79	4.99	53.5
3	North	63+03	9.06	6.59	5.74	5.4	4.96	4.51	3.62	2.87	2.21	5.75	53.8
4	North	73+08	9	7.55	7.41	7.24	6.92	6.52	5.6	4.66	3.75	7.21	53.5
5	North	83+13	8.89	7.43	7.31	7.29	7.18	7.05	5.57	4.32	3.24	6.64	54.2
6	North	93+00	8.79	0.52	9.53	9.21	8.66	8.26	7.12	5.85	4.45	9.3	53.5
7	North	103+09	8.65	7.52	7.13	6.79	6.29	5.86	4.84	3.9	3.31	5.94	54.6
8	North	113+27	8.97	6.39	5.97	5.86	5.61	5.34	4.67	3.95	3.28	5.77	54.2
9	North	123+09	8.78	6.65	6.36	6.23	5.91	5.58	4.81	4.01	3.26	5.96	54.2
10	North	133+03	8.8	3.78	3.66	3.58	3.44	3.3	2.99	2.69	1.71	3.29	53.8
11	North	143+00	8.81	3.37	3.13	2.96	2.81	2.69	2.38	2.07	1.77	2.88	52.4
12	North	152+80	8.83	6	5.24	5.06	4.89	4.65	4.06	3.45	2.85	5.01	55.7
13	North	163+02	8.78	7	6.6	6.3	5.96	5.38	4.57	3.79	3.09	5.47	55.7
14	North	173+12	8.8	6.71	5.79	5.41	5.04	4.71	3.85	3.15	2.44	5.32	54.6
15	North	186+22	8.94	7.04	6.03	5.71	5.37	5.01	4.19	3.35	2.61	5.8	55.3
16	North	195+10	8.9	7.4	6.24	5.78	5.38	4.97	4.11	3.26	2.56	6.24	55.7
17	North	205+12	8.34	7.2	6.91	6.59	6.16	5.63	4.57	3.63	2.8	5.83	54.6
18	North	215+22	8.51	7.92	7.27	7.09	6.78	6.35	5.38	4.42	3.48	6.99	54.2
19	North	225+34	8.35	6	5.85	5.8	5.59	5.17	4.28	3.48	2.77	5.41	56
20	North	235+41	8.46	7.43	6.93	6.67	6.28	5.87	5.01	4.2	3.51	7.64	57.1
21	North	245+64	8.4	5.53	5.2	5.11	4.91	4.66	4.03	3.38	2.71	4.9	56.4
22	North	255+59	8.33	6.29	5.69	5.22	4.55	3.94	2.85	2.07	1.61	5.07	54.6
23	North	268+29	8.03	10.3	10.18	10.13	10.06	9.95	6.59	5.48	4.43	9.29	56.8
24	North	278+47	8.41	8.3	8.21	8.12	7.94	7.72	6.68	5.4	4.19	7.64	55.7
25	North	289+31	8.48	6.88	6.32	6.06	5.83	5.58	4.93	4.25	3.52	6.01	56
26	North	298+06	8.47	6.61	6.56	6.54	6.46	6.39	5.79	4.85	3.97	6.18	54.9
27	North	308+11	8.53	6.75	6.13	5.9	5.69	5.46	4.87	4.3	3.69	6.04	55.7
28	North	328+10	8.24	8.4	7.73	7.35	7.01	6.71	6.11	5.43	4.78	7.03	55.3
29	North	328+17	8.36	7.94	6.99	6.64	6.3	5.98	5.32	4.48	3.73	6.61	55.3
30	North	338+19	8.48	8.64	7.84	7.44	7.1	6.85	6.17	5.29	4.48	7.27	55.7
31	North	348+23	8.4	11.05	10.35	10.18	9.93	9.62	8.87	7.95	7.05	10.34	51.6
32	North	358+32	8.22	8.96	8.12	7.84	7.53	7.19	6.32	5.42	4.47	7.82	55.3
33	North	368+44	8.3	8.47	7.22	6.78	6.4	6.03	5.25	4.44	3.61	7.11	52.7
34	North	377+94	8.35	13.32	11.54	10.97	10.45	9.98	8.88	7.72	6.56	11.58	51.6
35	North	388+04	8.36	9.06	7.64	7.16	6.68	6.22	5.27	4.41	3.63	7.96	56
36	North	398+59	8.31	7.45	6.55	6.12	5.71	5.37	4.66	3.97	3.32	6.25	56.4
37	North	408+09	8.25	5.63	5.11	4.96	4.82	4.59	4.03	3.4	2.85	4.85	56
38	North	417+89	7.89	5.47	5.59	5.26	4.94	4.5	3.59	2.74	2.22	4.46	56.4
38	North	419+49	8.39	13.51	11.06	9.38	7.65	6.27	4.29	3.1	2.23	9.9	55.7
39	North	428+02	8.37	7.64	6.96	6.76	6.55	6.3	5.63	4.9	4.24	6.71	56
40	North	437+08	8.12	12.11	11.23	10.83	10.26	9.69	8.43	7.27	6.19	12.25	56.8
41	North	447+90	8.34	8.47	7.64	7.22	6.77	6.34	5.44	4.52	3.61	8.25	56
42	North	459+03	8.11	10.02	9.04	8.7	8.35	7.96	7.06	6.13	5.17	9.2	54.6
43	North	465+36	8.41	9.43	8.39	7.82	7.31	6.91	6.02	5.1	4.26	8.22	57.9
44	North	475+02	8.18	6.28	6.1	5.92	5.74	5.54	5	4.4	3.74	5.8	59.7

45	North	484+11	8	9.2	8.67	8.51	8.2	7.79	6.86	5.76	4.7	8.52	58.2
46	North	491+10	8.12	7.79	7.34	7.19	6.9	6.55	5.66	4.72	3.81	6.93	58.2
47	North	500+16	8.39	7.19	6.89	6.74	6.47	6.13	5.31	4.47	3.67	6.69	59.7
48	North	508+19	8.35	5.15	5.01	4.89	4.67	4.43	3.85	3.26	2.7	4.9	59.7
49	North	517+42	8.23	8	7	6.33	5.4	4.57	3.18	2.18	1.8	7.06	56.4
50	North	518+92	8.24	6.03	5.36	4.93	4.35	3.82	2.84	2.09	1.69	4.74	57.9
1	South	525+02	8.18	6.15	5.6	5.17	4.57	4	2.91	2.07	1.66	4.89	58.2
2	South	508+30	8.39	8.57	7.95	7.68	7.25	6.75	5.73	4.77	3.86	8.48	58.2
3	South	498+74	8.56	9.34	8.69	8.46	8.05	7.64	6.66	5.65	4.7	8.86	57.9
4	South	489+67	8.33	8.39	7.92	7.63	7.34	7.03	6.18	5.13	2.55	7.37	57.1
5	South	480+01	8.04	6.41	5.8	5.61	5.46	5.26	4.73	4.11	3.47	5.34	58.2
6	South	470+04	8.24	7.3	6.36	5.9	5.41	4.99	4.11	3.28	2.5	6.11	58.6
7	South	462+84	8.28	8.54	7.45	7.12	6.88	6.58	5.81	5.05	4.27	7.28	58.6
8	South	450+85	8.01	6.9	6.22	5.8	5.44	5.21	4.71	4.03	3.45	5.61	57.5
9	South	441+05	8.41	9.51	9.04	8.9	8.62	8.29	7.4	6.46	5.44	8.91	58.6
10	South	431+08	8.19	7.36	6.84	6.34	5.98	5.71	5.11	4.47	3.78	5.95	60.1
11	South	420+99	8.45	6.85	6.24	6.04	5.78	5.48	4.73	3.97	3.22	6.22	59.7
12	South	411+34	8.34	8.13	7.53	7.29	7.01	6.74	6.06	5.29	4.56	7.74	59.7
13	South	401+13	8.53	6.73	5.91	5.67	5.44	5.16	4.51	3.82	3.22	5.73	58.6
14	South	391+07	7.96	8.96	8.21	7.8	7.42	7.07	6.2	5.33	4.47	8.71	59.7
15	South	381+43	8.31	7.84	7.37	7.23	6.99	6.7	5.98	5.19	4.39	7.26	59.7
16	South	371+00	8.22	8.03	7.07	6.54	5.96	5.49	4.68	3.89	3.15	6.5	59.7
17	South	360+76	8.14	7.64	7.37	6.78	6.31	5.9	4.92	4.02	3.22	6.34	59.7
18	South	350+83	8.15	8.62	7.73	7.43	7.08	6.72	5.9	5.05	4.22	7.34	60.1
19	South	340+67	8.51	8.61	8.18	8	7.74	7.48	6.75	5.91	5.09	8.14	59.7
20	South	331+00	8.48	7.14	6.63	6.44	6.23	6.01	5.38	4.7	3.99	6.37	59.7
21	South	321+05	8.09	8.24	7.65	7.53	7.35	7.1	6.38	5.56	4.74	7.43	59.3
22	South	310+86	8.28	7.54	6.48	6.22	5.93	5.6	4.84	4.08	3.38	6.17	60.8
23	South	300+87	8.11	9.04	8.75	8.59	8.27	7.91	7.03	5.97	4.57	8.63	59.7
24	South	291+14	8.31	5.85	5.47	5.29	5.05	4.78	4.18	3.57	3	5.5	53.1
25	South	279+94	8.01	9.45	8.65	8.26	7.91	7.42	6.37	5.33	4.33	7.78	63
26	South	270+96	8.06	12.63	10.73	10.04	9.15	8.29	6.62	5.25	4.06	10.86	63
27	South	260+26	8.03	7.14	6.42	5.89	5.18	4.54	3.38	2.5	2.09	7.01	60.4
28	South	250+05	8.03	6.5	6	5.84	5.51	5.16	4.37	3.59	2.86	6.04	62.6
29	South	240+08	8.36	5.63	5.42	5.31	5.1	4.73	3.83	3.05	2.34	5.09	62.6
30	South	230+05	7.96	6.19	6.15	6.09	5.96	5.73	4.77	3.95	3.26	5.71	51.6
31	South	219+35	8.14	8.56	8.49	8.49	8.35	7.66	6.14	4.85	3.7	7.2	64.8
32	South	209+93	8.03	6.2	5.97	5.83	5.57	5.26	4.47	3.68	2.93	5.74	63.7
33	South	199+95	8.26	7.51	5.8	5.03	4.52	4	3.09	2.39	1.77	4.92	65.2
34	South	189+83	8.11	5.63	4.81	4.61	4.42	4.18	3.57	2.92	2.33	4.56	64.5
35	South	175+90	8.11	6.21	6.05	5.94	5.74	5.49	4.93	4.37	2.26	5.88	63.4
36	South	165+87	8.44	5.64	5.2	5.07	4.87	4.65	4.04	3.4	2.75	5.05	64.5
37	South	155+59	7.92	3.48	3.28	3.18	3.04	2.92	2.69	2.5	2.37	3.02	64.5
38	South	144+80	7.92	7.93	7.21	6.74	6.25	5.82	4.88	4.02	3.15	6.68	66.3
39	South	136+24	8.34	5.61	4.96	4.81	4.64	4.44	3.9	3.36	2.76	4.59	63.4
40	South	126+07	8	8.02	7.72	7.58	7.26	6.91	6.05	5.2	2.66	7.4	66.3
41	South	116+26	8.07	6.19	6.05	5.91	5.67	5.35	4.56	3.77	3.03	5.76	67
42	South	106+06	8.28	6.25	5.54	5.34	5.14	4.92	4.29	3.64	2.97	5.35	67.7

43	South	95+29	8.11	6.24	6.16	6.01	5.83	5.6	4.95	4.23	3.48	5.6	66.7
44	South	85+34	8.45	10.16	8.67	8.11	7.41	6.69	5.33	4.14	3.06	8.63	71.4
45	South	75+41	8.17	6.75	6.1	5.9	5.62	5.3	4.51	3.72	3	6.15	71.8
46	South	65+97	8.39	4.65	4.13	3.94	3.69	3.42	2.83	2.27	1.76	4.22	69.9
47	South	55+95	8.4	8.45	7.77	7.29	6.59	5.89	4.55	3.31	2.11	6.97	70.7
48	South	45+84	7.91	2.56	2.41	2.34	2.26	2.12	1.81	1.5	0	2.14	57.5

Table B.2. Postconstruction FWD Data (Performed on 8/7/2002)

Test #	Lane	Station	Location *	Load (kips)	Sensor Number 1	2	3	4	5	6	7	8	9	Temp (ºF)
1	North	53+25	2	8.97	3.17	2.83	2.61	2.37	2.2	1.87	1.61	1.36	2.69	89
2	North	53+27	1	8.94	2.89	2.68	2.54	2.39	2.25	1.97	1.7	1.43	2.52	89
3	North	63+25	2	8.81	2.71	2.51	2.34	2.19	2.02	1.78	1.51	0	2.36	89.4
4	North	63+29	1	8.79	2.82	2.64	2.51	2.34	2.17	1.85	1.55	0	2.35	90.1
5	North	73+25	2	8.89	3.19	2.97	2.85	2.7	2.55	2.29	2	1.75	2.78	89.7
6	North	73+28	1	8.78	3.48	3.24	3.12	2.97	2.74	2.41	2.03	1.74	2.98	89.4
7	North	83+30	2	8.54	4.41	3.43	3.26	3.02	2.82	2.39	1.97	1.65	3.36	89
8	North	83+33	1	8.69	3.46	3.19	2.95	2.75	2.57	2.25	1.92	1.61	3.03	89.7
9	North	93+32	2	8.76	3.16	2.92	2.72	2.53	2.37	2.07	1.78	1.66	2.76	86.1
10	North	96+64	1	8.52	2.8	2.61	2.48	2.33	2.2	1.97	1.73	1.71	2.46	91.2
11	North	103+32	2	8.67	3.65	3.49	3.19	2.92	2.72	2.37	2.02	1.67	2.97	89.7
12	North	103+35	1	8.31	3.35	3.12	2.91	2.63	2.47	2.18	1.9	1.73	2.83	91.6
13	North	113+41	2	8.53	4.42	3.44	3.26	3.03	2.84	2.41	2.04	1.81	3.47	90.1
14	North	113+44	1	8.73	4.14	3.08	2.9	2.72	2.58	2.27	1.95	1.7	3.04	90.1
15	North	123+40	2	8.7	4.09	3.89	3.66	3.45	3.25	2.88	2.39	1.88	3.53	91.9
16	North	124+44	1	8.61	4.97	4.66	4.31	3.83	3.41	2.76	2.27	1.87	4.12	93.8
17	North	133+41	2	8.64	2.7	2.55	2.38	2.23	2.08	1.91	1.75	0	2.27	90.8
18	North	133+43	1	8.47	3.27	3.12	2.94	2.68	2.41	2.07	1.79	0	2.69	91.2
19	North	143+48	2	8.69	2.79	2.59	2.36	2.08	1.86	1.51	1.3	0	2.18	92.3
20	North	143+56	1	8.72	3.01	2.61	2.35	2.09	1.9	1.67	1.45	0	2.37	91.9
21	North	153+52	2	8.69	2.58	2.32	2.12	1.93	1.79	1.57	1.38	0	2.18	92.3
22	North	153+52	1	8.75	2.47	2.17	2.03	1.88	1.74	1.57	1.35	0	2.07	93
23	North	163+44	2	8.61	3.03	2.77	2.58	2.36	2.22	1.99	1.78	0	2.54	94.1
24	North	163+47	1	8.29	3	2.79	2.63	2.43	2.28	2.06	1.85	0	2.55	93.4
25	North	173+51	2	8.29	4.72	3.65	3.33	2.94	2.64	2.12	1.73	1.45	3.44	94.8
26	North	174+24	1	8.37	3.9	3.44	3.13	2.78	2.53	2.1	1.72	1.42	3.16	96.3
27	North	183+52	2	8.62	3.99	3.83	3.52	3.22	3	2.57	2.15	1.97	3.33	97
28	North	183+56	1	8.62	3.15	3.04	2.98	2.89	2.78	2.51	2.17	2.09	2.95	96.7
29	North	186+57	2	8.11	4.07	3.29	3.02	2.72	2.47	2.04	1.67	0	3.21	97
30	North	186+60	1	8.39	3.99	3.51	3.19	2.79	2.49	2.06	1.75	1.48	3.27	97
31	North	195+51	2	8.75	5.01	4.02	3.62	3.17	2.87	2.36	1.95	1.53	3.75	90.8
32	North	195+54	1	9.05	4.71	4.16	3.77	3.27	2.88	2.31	1.85	1.46	3.66	93
33	North	205+54	2	8.8	3.84	3.55	3.18	2.8	2.55	2.15	1.8	1.54	2.97	94.1
34	North	206+08	1	8.65	3.27	2.92	2.72	2.55	2.38	2.04	1.76	1.26	2.78	97.8
35	North	215+53	2	9.05	3.12	2.85	2.65	2.46	2.3	2.02	1.74	1.48	2.6	92.7
36	North	215+55	1	9.17	3.14	2.89	2.68	2.5	2.34	2.06	1.74	0	2.63	93
37	North	225+63	2	8.85	4.63	3.02	2.85	2.65	2.46	2.07	1.72	0	3.03	76.5
38	North	225+63	1	8.97	2.92	2.62	2.46	2.3	2.16	1.86	1.57	0	2.57	76.2
39	North	235+56	2	9.07	3.52	2.95	2.8	2.64	2.44	2.09	1.77	0	2.83	92.7
40	North	235+60	1	8.89	2.93	2.68	2.48	2.32	2.17	1.92	1.71	0	2.6	94.1
41	North	245+65	2	8.58	2.57	2.41	2.27	2.09	1.96	1.71	0	0	2.17	90.1
42	North	245+67	1	8.95	2.62	2.43	2.31	2.15	2.05	1.85	1.64	1.39	2.28	91.2
43	North	255+65	2	8.42	4.16	3.9	3.5	2.96	2.55	1.89	1.47	0	3.27	92.3
44	North	255+68	1	8.96	3.81	3.44	3.19	2.81	2.51	1.96	1.57	0	3.21	91.9
45	North	268+68	2	8.3	4.72	4.38	4.1	3.76	3.5	3.05	2.64	2.29	4.06	94.1

46	North	268+72	1	8.65	3.52	3.33	3.22	3.08	2.94	2.68	2.43	2.15	3.29	94.1
47	North	278+68	2	9.16	3.92	3.77	3.55	3.31	3.08	2.72	2.4	2.05	3.43	94.8
48	North	278+71	1	8.42	3.44	3.3	3.16	2.99	2.74	2.4	2.09	0	3.11	93.8
49	North	288+69	2	8.73	3.24	2.97	2.75	2.51	2.32	2	1.74	0	2.75	95.9
50	North	288+73	1	9.08	3.19	2.95	2.78	2.58	2.41	2.06	1.8	0	2.75	95.2
51	North	298+70	2	9	3.01	2.84	2.71	2.58	2.48	2.25	2.04	1.84	2.72	93
52	North	299+65	1	8.83	3.01	2.84	2.73	2.6	2.49	2.26	2.03	1.81	2.71	97
53	North	308+68	2	8.92	3.24	2.94	2.84	2.68	2.54	2.21	1.91	0	2.81	94.5
54	North	308+71	1	8.59	3.37	3.1	2.9	2.61	2.42	2.11	1.86	1.7	2.87	93.4
55	North	318+72	2	9	3.64	3.41	3.26	3.09	2.94	2.69	2.43	2.19	3.22	94.8
56	North	318+00	1	8.25	3.56	3.38	3.23	3.07	2.95	2.56	2.25	1.95	3.11	94.1
57	North	327+97	2	8.69	5.12	4.61	4.18	3.7	3.34	2.8	2.37	2.04	4.38	95.2
58	North	327+99	1	8.85	4.49	4.1	3.8	3.42	3.17	2.72	2.32	1.96	3.76	94.8
59	North	337+94	2	8.73	4.34	4.06	3.8	3.51	3.32	3	2.63	2.39	3.71	94.5
60	North	337+98	1	8.7	4.58	4.29	4.03	3.71	3.49	3.06	2.63	2.32	3.89	96.3
61	North	348+03	2	8.86	5.71	5.48	5.19	4.86	4.56	3.91	3.25	2.73	5.1	93
62	North	348+07	1	8.69	5.84	5.48	5.16	4.74	4.39	3.75	3.17	2.71	5.22	93
63	North	358+05	2	8.75	3.77	3.57	3.38	3.2	3.05	2.76	2.44	2.13	3.34	96.7
64	North	358+09	1	8.79	3.87	3.65	3.49	3.25	3.05	2.65	2.3	2.01	3.4	95.9
65	North	368+04	2	8.8	4.15	3.89	3.55	3.21	2.93	2.45	2.06	1.68	3.39	79.8
66	North	368+07	1	8.81	5.27	3.73	3.44	3.1	2.85	2.37	1.97	1.62	3.42	80.2
67	North	378+02	2	8.63	5.53	4.94	4.63	4.28	3.98	3.47	3	2.58	4.64	97.8
68	North	378+06	1	8.86	5.05	4.75	4.51	4.2	3.94	3.47	3.02	2.64	4.54	94.8
69	North	388+06	2	8.7	5.01	4.59	4.25	3.88	3.58	2.98	2.45	2	4.12	97.4
70	North	388+09	1	8.79	5.32	4.69	4.27	3.76	3.37	2.75	2.27	1.88	4.42	97
71	North	398+07	2	8.18	3.89	3.54	3.23	2.88	2.66	2.33	2.01	1.77	3.18	97.8
72	North	398+09	1	8.15	3.95	3.56	3.26	2.93	2.71	2.36	2.04	1.89	3.19	98.1
73	North	408+04	2	8.64	4.96	4.37	4.06	3.72	3.48	2.98	2.46	2.04	4.03	97
74	North	408+08	1	8.12	4.75	4.24	3.93	3.59	3.32	2.83	2.36	1.93	3.99	96.3
75	North	418+06	2	8.58	7.28	6.23	5.29	4.34	3.65	2.77	2.19	1.87	4.92	94.1
76	North	418+09	1	8.78	4.88	4.37	4.03	3.61	3.23	2.63	2.11	1.75	4.26	93.8
77	North	428+13	2	8.42	4.44	3.9	3.62	3.3	3.09	2.74	2.41	2.14	3.56	93.4
78	North	428+15	1	8.69	4	3.68	3.47	3.23	3.04	2.72	2.43	2.15	3.54	93.4
79	North	438+09	2	8.61	5.98	4.92	4.6	4.25	3.94	3.42	2.97	2.59	4.96	93
80	North	438+13	1	8.75	4.25	3.94	3.8	3.62	3.49	3.12	2.78	2.49	4.12	93
81	North	448+13	2	8.81	5.16	4.58	4.32	4.03	3.79	3.39	2.97	2.54	4.38	93.4
82	North	448+16	1	8.89	5.22	4.95	4.69	4.31	3.98	3.45	2.96	2.56	4.53	92.3
83	North	458+13	2	8.72	4.23	4	3.79	3.56	3.35	3.03	2.71	2.46	3.79	93.8
84	North	458+15	1	8.84	4.36	4.15	3.96	3.75	3.54	3.14	2.76	2.44	3.84	94.1
85	North	465+11	2	8.7	4.69	4.42	4.16	3.84	3.57	3.1	2.68	2.37	4.16	94.5
86	North	465+13	1	8.4	4.24	3.99	3.78	3.52	3.29	2.88	2.57	2.32	3.82	94.5
87	North	475+15	2	8.14	3.32	3.2	3	2.77	2.6	2.23	2.11	1.83	2.84	98.1
88	North	475+21	1	8.74	4.04	3.79	3.53	3.19	2.91	2.47	2.12	2.03	3.41	99.6
89	North	485+21	2	8.7	4.58	4.25	3.96	3.7	3.51	3.07	2.62	2.22	3.94	98.5
90	North	485+23	1	8.04	3.95	3.66	3.44	3.2	3.04	2.68	2.35	2.08	3.49	97.4
91	North	492+20	2	8.8	3.69	3.51	3.31	3.13	2.97	2.59	2.23	1.88	3.3	96.7
92	North	492+22	1	8.81	3.79	3.53	3.38	3.18	3.03	2.65	2.24	1.88	3.32	95.9
93	North	501+24	2	8.7	3.12	2.94	2.82	2.69	2.58	2.3	2.05	1.8	2.81	97.4

94	North	501+27	1	8.78	3.09	2.91	2.81	2.68	2.55	2.3	2.05	1.86	2.81	97.4
95	North	509+23	2	8.4	3	2.78	2.67	2.53	2.41	2.12	1.87	1.79	2.68	96.7
96	North	509+25	1	9.03	3.05	2.87	2.74	2.61	2.48	2.21	1.94	1.71	2.75	95.9
1	South	510+99	2	8.74	4.34	4.06	3.86	3.68	3.51	3.13	2.73	2.35	3.97	95.9
2	South	510+96	1	8.84	4.07	3.88	3.72	3.55	3.38	3.04	2.65	2.3	3.72	95.9
3	South	499+01	2	8.64	4.36	4.13	3.88	3.66	3.49	3.09	2.65	2.28	3.86	97.4
4	South	498+98	1	8.79	4.88	4.61	4.36	4.06	3.78	3.25	2.79	2.35	4.17	98.5
5	South	490+00	2	8.69	5.2	5.07	4.83	4.45	4.04	3.24	2.58	2.06	4.41	99.2
6	South	489+97	1	8.69	5.72	5.17	4.81	4.39	4.05	3.4	2.8	2.32	4.92	100
7	South	479+91	2	8.91	4.44	3.89	3.43	2.95	2.62	2.2	1.87	1.58	3.42	101.8
8	South	479+89	1	8.85	3.61	3.26	3.01	2.77	2.59	2.24	1.98	1.7	3.03	99.2
9	South	469+93	2	8.87	4.07	3.84	3.59	3.3	3.05	2.58	2.19	1.86	3.5	95.2
10	South	469+91	1	8.74	4.08	3.75	3.49	3.21	2.96	2.5	2.13	1.77	3.47	96.3
11	South	462+25	2	8.94	4.76	4.45	4.16	3.88	3.64	3.23	2.86	2.44	4.17	99.2
12	South	462+22	1	8.85	4.65	4.36	4.11	3.83	3.6	3.18	2.81	2.46	4.1	96.7
13	South	450+26	2	8.84	4.78	4.35	4.03	3.69	3.46	3.1	2.73	2.32	4.03	99.2
14	South	450+24	1	8.87	4.76	4.46	4.2	3.9	3.67	3.21	2.75	2.31	4.07	99.2
15	South	440+26	2	8.85	4.07	3.99	3.86	3.71	3.52	3.15	2.79	2.45	3.78	101.1
16	South	440+23	1	8.89	4.22	4	3.87	3.71	3.52	3.19	2.84	2.52	3.91	100.7
17	South	430+27	2	8.73	3.9	3.64	3.38	3.17	2.98	2.65	2.32	1.96	3.34	103.3
18	South	430+25	1	8.54	3.78	3.5	3.3	3.08	2.89	2.52	2.14	1.75	3.19	102.5
19	South	420+24	2	8.15	3.95	3.65	3.45	3.24	3.07	2.74	2.38	2.06	3.43	101.8
20	South	420+19	1	8.89	4.54	4.22	3.97	3.73	3.53	3.18	2.79	2.45	3.99	101.8
21	South	410+29	2	8.79	5.05	4.78	4.54	4.29	4.1	3.71	3.23	2.86	4.53	101.4
22	South	410+26	1	8.57	5.44	5.02	4.74	4.38	4.14	3.73	3.3	2.96	4.7	101.4
23	South	400+24	2	8.64	3.63	3.39	3.14	2.87	2.7	2.43	2.14	1.86	3.03	101.1
24	South	400+21	1	8.23	3.46	3.21	3.02	2.82	2.64	2.35	2.07	1.84	2.95	100
25	South	390+23	2	8.72	5.73	5.4	4.94	4.4	3.98	3.4	2.93	2.49	4.79	98.5
26	South	390+20	1	8.76	5.08	4.67	4.39	4.05	3.77	3.36	2.85	2.48	4.53	97
27	South	380+21	2	9.03	4.91	4.46	4.12	3.82	3.56	3.09	2.58	2.06	4.22	98.9
28	South	380+19	1	8.68	4.92	4.49	4.11	3.63	3.24	2.61	2.13	1.82	3.97	98.5
29	South	371+00	2	8.86	3.85	3.49	3.28	3.06	2.84	2.45	2.12	1.84	3.27	103.3
30	South	370+99	1	8.64	3.74	3.53	3.29	2.99	2.79	2.39	2.1	1.84	3.19	101.4
31	South	360+97	2	8.9	3.33	3.16	3.01	2.81	2.65	2.36	2.08	1.88	2.94	102.9
32	South	360+93	1	8.79	3.27	3.11	2.96	2.78	2.62	2.33	2.09	1.91	2.89	102.9
33	South	350+94	2	8.79	3.95	3.67	3.45	3.2	2.99	2.59	2.25	1.97	3.46	104.4
34	South	350+92	1	8.9	4.04	3.73	3.47	3.19	2.93	2.54	2.17	1.9	3.51	104.4
35	South	340+93	2	8.81	4.75	4.15	3.88	3.59	3.38	2.99	2.63	2.31	4.08	104
36	South	340+91	1	8.91	4.26	3.94	3.7	3.45	3.22	2.93	2.58	2.29	3.77	104
37	South	330+97	2	8.83	2.66	2.52	2.37	2.21	2.09	1.87	1.68	0	2.37	105.5
38	South	330+95	1	8.11	2.58	2.42	2.3	2.19	2.1	1.91	1.71	0	2.26	104
39	South	320+95	2	8.57	3.62	3.39	3.21	3.02	2.84	2.54	2.25	2.09	3.24	107.3
40	South	320+92	1	8.78	3.7	3.4	3.2	3.01	2.88	2.61	2.34	2.09	3.27	108
41	South	310+96	2	8.8	3.97	3.63	3.31	2.99	2.76	2.4	2.06	1.75	3.25	107.3
42	South	310+94	1	8.68	3.92	3.52	3.26	2.97	2.78	2.42	2.07	1.74	3.23	104.7
43	South	301+00	2	8.72	4.54	4.38	4.2	3.93	3.7	3.28	2.86	2.53	4.07	104
44	South	300+97	1	8.08	4.09	3.84	3.68	3.47	3.3	2.93	2.62	2.32	3.76	104.4
45	South	291+00	2	8.81	4.4	3.95	3.63	3.32	3.08	2.71	2.35	2.19	3.57	103.6

46	South	290+97	1	8.75	4.26	3.91	3.65	3.34	3.14	2.75	2.42	2.13	3.6	101.8
47	South	280+94	2	8.07	4.27	3.98	3.74	3.48	3.26	2.8	2.36	1.93	3.69	103.6
48	South	280+91	1	8.7	5.08	4.71	4.39	4.02	3.69	3.12	2.65	2.23	4.22	103.3
49	South	259+90	2	8.63	3.66	3.23	2.94	2.59	2.31	1.8	1.46	0	3.02	102.5
50	South	259+88	1	8.78	3.47	3.13	2.86	2.55	2.27	1.76	1.4	0	2.84	103.3
51	South	249+97	2	8.73	4.37	3.99	3.68	3.39	3.16	2.67	2.23	1.82	3.64	104.4
52	South	249+94	1	8.86	4.03	3.7	3.46	3.22	3.06	2.6	2.08	1.7	3.41	103.3
53	South	239+91	2	8.75	3.96	3.64	3.33	3.06	2.84	2.35	1.95	1.59	3.27	99.6
54	South	239+89	1	8.68	3.95	3.51	3.19	2.94	2.74	2.34	1.98	1.64	3.19	98.9
55	South	229+90	2	8.76	3.51	3.29	3.07	2.87	2.69	2.35	2.07	1.9	2.95	104.7
56	South	229+87	1	8.51	3.5	3.31	3.16	3.02	2.81	2.51	2.21	1.96	3.02	102.9
57	South	219+91	2	8.08	3.74	3.42	3.19	3.01	2.87	2.5	2.14	1.84	3.12	102.9
58	South	219+88	1	8.75	4.22	3.85	3.62	3.39	3.2	2.8	2.33	1.99	3.48	103.3
59	South	209+94	2	8.75	4.33	4	3.73	3.45	3.2	2.78	2.35	2	3.66	102.5
60	South	209+92	1	8.95	4.39	4.06	3.8	3.52	3.29	2.86	2.43	2.07	3.75	101.8
61	South	199+91	2	8.74	4.56	4.28	3.94	3.56	3.27	2.77	2.34	1.95	3.73	103.3
62	South	199+90	1	9	4.93	4.62	4.27	3.89	3.58	3.06	2.56	2.1	4.06	102.9
63	South	189+92	2	8.81	4.38	4.11	3.8	3.45	3.18	2.7	2.26	1.89	3.73	99.2
64	South	189+89	1	9	4.06	3.82	3.6	3.36	3.14	2.67	2.26	1.91	3.51	100.3
65	South	175+91	2	9.01	4.04	3.66	3.49	3.28	3.1	2.73	2.38	2.02	3.49	102.5
66	South	175+88	1	9.09	4.11	3.89	3.71	3.49	3.25	2.71	2.33	1.99	3.59	102.9
67	South	165+85	2	8.89	3.96	3.46	3.27	3.09	2.93	2.58	2.26	1.93	3.37	103.3
68	South	165+83	1	9.06	3.67	3.4	3.22	3.05	2.88	2.54	2.23	1.92	3.25	100.3
69	South	155+80	2	9.25	2.76	2.61	2.45	2.29	2.11	1.83	0	0	2.42	97.4
70	South	155+77	1	9.45	2.74	2.54	2.39	2.25	2.08	1.82	0	0	2.39	98.1
71	South	145+78	2	8.91	4.75	4.51	4.17	3.78	3.45	2.87	2.4	2.03	4	106.2
72	South	145+74	1	9.02	4.52	4.28	4.02	3.73	3.44	2.9	2.4	1.98	3.89	105.8
73	South	135+84	2	8.85	3.2	2.93	2.7	2.46	2.27	1.95	1.76	0	2.67	106.2
74	South	135+83	1	9.18	3.2	2.94	2.75	2.53	2.33	2.06	1.84	0	2.76	105.8
75	South	125+88	2	8.9	4.43	4.18	3.97	3.79	3.62	3.23	2.77	2.38	3.89	101.1
76	South	125+84	1	9.48	5.8	5.31	4.98	4.54	4.19	3.58	3.06	2.59	4.81	101.8
77	South	115+88	2	9.11	3.93	3.68	3.47	3.27	3.14	2.7	2.28	1.86	3.47	103.3
78	South	115+87	1	9.11	3.93	3.68	3.53	3.3	3.08	2.61	2.2	1.85	3.42	102.5
79	South	105+89	2	8.69	4.86	4.27	3.82	3.41	3.16	2.79	2.4	2.04	3.9	104
80	South	105+87	1	8.69	4.67	4.09	3.76	3.44	3.22	2.87	2.45	2.08	3.77	102.9
81	South	95+85	2	9.31	3.95	3.62	3.37	3.13	2.88	2.43	2.03	1.7	3.69	102.9
82	South	95+82	1	9.27	3.62	3.35	3.17	2.99	2.79	2.39	2.02	1.81	3.12	101.4
83	South	85+86	2	8.37	6.13	5.36	4.84	4.37	3.99	3.26	2.62	2.06	5.21	103.6
84	South	85+84	1	9.14	6.3	5.36	4.86	4.37	4.05	3.37	2.67	1.98	5.14	102.9
85	South	75+84	2	9.07	4.87	4.46	4.16	3.87	3.66	3.22	2.77	2.34	4.1	103.6
86	South	75+82	1	9.05	4.87	4.46	4.2	3.94	3.77	3.3	2.78	2.26	4.12	103.3
87	South	65+82	2	9	3.37	3.05	2.85	2.65	2.48	2.11	1.83	1.52	2.88	105.1
88	South	65+79	1	9.22	3.06	2.81	2.69	2.5	2.35	2.04	1.75	0	2.71	105.5
89	South	55+83	2	9.25	4.35	3.96	3.63	3.32	3.05	2.6	2.24	1.85	3.56	105.5
90	South	55+81	1	9	3.37	3.16	2.99	2.83	2.7	2.38	2.08	1.89	3.08	104

* 1 = midpanel deflection test, 2 = joint transfer deflection test.

APPENDIX C:

JOINT OPENING AND FAULTING DATA

Table C.1. Joint Opening and Fault Data

		Joint Opening (inches)				Faulting Measurement			
						NBL	SBL	NBL	SBL
	Date	7/25/2002	10/11/2002	4/11/2003		10/12/2002	10/12/2002	4/12/2003	4/12/2003
Section	Station								
9	54+00.	9.81	9.82	9.76		-0.2	-0.3	-0.2	0.0
	54+04.5	10.01	10.05	10.07		-0.1	-0.1	-0.5	0.0
	54+09.	9.88	9.95	9.94		-0.2	0.5	-0.1	0.0
	54+13.5	10.03	10.10	9.92		1.1	-0.3	-0.9	-1.0
	54+18.	10.13	10.11	10.12		-0.3	-0.6	-0.8	0.0
	54+22.5	9.99	10.03	9.99		1.1	0.4	-0.2	-1.0
	54+27.	10.05	10.12	10.06		0.8	0.2	0.1	0.0
	54+31.5	10.11	10.13	10.11		-0.8	1.0	-1.0	-2.0
	54+36.	9.93	9.96	9.99		-0.4	-1.0	-1.0	0.0
	54+40.5	10.15	10.20	10.08		0.2	0.1	-0.6	0.0
11	59+00.	9.95	9.97	9.95		1.1	0.1	-0.5	0.0
	59+06.	9.98	10.01	9.96		-1.1	-0.8	-1.1	-1.0
	59+12.	10.27	10.30	10.30		-0.2	0.0	0.2	0.0
	59+18.	9.95	9.97	10.07		0.2	0.1	-0.6	0.0
	59+24.	9.95	9.98	10.08		0.5	0.2	-0.5	0.0
	59+30.	9.92	9.94	9.96		0.7	-1.3	-0.1	0.0
	59+36.	9.98	10.03	10.02		0.2	-0.8	0.1	0.0
	59+42.	9.94	9.94	9.96		0.7	-1.5	-0.2	0.0
	59+48.	9.76	9.80	9.79		-0.8	0.3	-0.8	0.0
	59+54.	10.15	10.19	10.19		-0.9	0.1	-1.2	-1.0
13	64+00.	9.67	9.64	9.65		-1.0	-0.5	-0.4	-1.0
	64+06.	9.68	9.76	9.71		-0.8	0.4	0.2	-1.0
	64+12.	10.09	10.11	10.11		-0.3	-0.8	-1.2	-1.0
	64+18.	9.91	9.93	9.86		0.5	-0.3	0.1	0.0
	64+24.	9.60	9.65	9.59		0.5	0.3	-1.3	0.0
	64+30.	10.07	10.07	10.04		0.0	0.6	0.0	-1.0
	64+36.	10.21	10.19	10.17		0.4	1.1	0.4	-1.0
	64+42.	10.01	10.03	10.02		0.2	0.8	-1.0	0.0
	64+48.	9.92	9.92	9.90		0.9	0.6	1.2	0.0
	64+54.	10.03	10.14	10.12		0.5	-0.3	0.4	0.0
15	69+00.	9.97	9.98	9.96		-0.6	0.7	-0.5	0.0
	69+06.	9.06	9.08	9.06		-1.0	0.9	-1.8	0.0
	69+12.	8.93	8.92	8.91		0.3	-0.8	0.0	0.0
	69+18.	9.26	9.33	9.25		1.0	-0.7	0.7	0.0
	69+24.	9.16	9.21	9.16		1.0	0.4	-0.3	-1.0
	69+30.	8.84	8.85	8.85		1.1	-0.6	0.7	0.0
	69+36.	8.79	8.87	8.81		-0.3	0.7	0.5	0.0
	69+42.	9.07	9.08	9.00		-0.6	0.3	1.0	0.0
	69+48.	9.57	9.59	9.61		-1.3	0.7	-0.6	-1.0
	69+54.	8.95	9.00	8.93		-0.5	-0.7	-1.0	-1.0
17	74+00.	9.89	9.95	9.90		0.2	1.0	0.9	0.0
	74+06.	9.81	9.86	9.79		0.0	-0.3	0.3	0.0
	74+12.	9.84	9.90	9.85		0.9	0.5	-1.0	0.0

	74+18.	10.06	10.06	9.96		0.9	0.0	-1.3	-1.0
	74+24.	10.36	10.36	10.27		0.4	0.0	-1.3	-1.0
	74+30.	9.89	9.90	9.91		-0.7	-0.1	0.1	0.0
	74+36.	9.97	10.00	9.96		0.9	0.5	0.7	-1.0
	74+42.	9.91	9.94	9.94		0.5	-0.3	0.5	-1.0
	74+48.	10.02	10.01	10.07		0.5	-1.0	-1.1	-1.0
	74+54.	10.02	10.05	10.03		0.4	-0.3	-0.7	-1.0
19	79+00.	10.01	10.02	9.99		-1.3	-0.3	-0.7	0.0
	79+06.	9.99	10.00	9.98		0.0	-0.3	0.2	0.0
	79+12.	10.21	10.21	10.18		1.1	0.0	0.4	-1.0
	79+18.	9.93	9.90	9.94		0.2	-0.2	-0.4	-1.0
	79+24.	9.53	9.60	9.57		0.1	0.6	-0.3	-1.0
	79+30.	9.68	9.72	9.82		0.7	-0.5	0.0	-1.0
	79+36.	10.05	10.06	10.05		1.4	-0.9	-0.5	0.0
	79+42.	10.08	10.06	10.04		0.1	-0.8	-1.0	0.0
	79+48.	10.04	10.04	10.03		-1.3	-1.3	-0.8	0.0
	79+54.	10.07	10.10	10.11		1.3	0.2	-1.5	-1.0
21	84+00.	10.06	10.11	10.07		0.3	-0.7	-0.6	0.0
	84+06.	10.02	9.98	9.98		0.3	0.8	0.1	-3.0
	84+12.	9.99	9.62	9.96		-0.8	1.0	0.5	-1.0
	84+18.	10.04	10.07	10.10		1.0	2.2	0.9	-1.0
	84+24.	10.23	10.24	10.27		-0.4	0.7	-1.0	0.0
	84+30.	9.96	10.00	9.97		-0.3	-0.3	0.0	-1.0
	84+36.	9.64	9.69	9.66		0.6	-0.8	0.2	-2.0
	84+42.	9.92	9.95	9.92		0.0	-0.3	-0.4	-1.0
	84+48.	10.08	10.11	10.09		-1.3	-1.0	0.5	-1.0
	84+54.	10.19	10.23	10.19		0.3	1.2	0.7	0.0
23	89+00.	9.85		9.81		0.1	-0.5	0.0	0.0
	89+04.5	10.16		10.21		-0.3	-0.3	0.5	0.0
	89+09.	9.92		10.00		0.2	-0.4	-0.2	0.0
	89+13.5	9.98		10.00		0.6	-0.3	-1.2	-1.0
	89+18.	10.23		10.24		0.8	0.2	-0.5	-1.0
	89+22.5	10.34		10.32		0.4	0.2	-0.8	0.0
	89+27.	10.19		10.27		0.2	0.0	1.2	0.0
	89+31.5	9.91		9.95		1.0	0.5	-0.4	-1.0
	89+36.	9.85		9.86		0.4	1.8	-0.8	-1.0
	89+40.5	10.47		10.50		0.2	0.3	0.2	0.0
25	94+00.					-0.4	0.4	0.0	0.0
	94+04.5					0.5	-1.0	0.6	0.0
	94+09.					0.0	0.4	1.0	-1.0
	94+13.5					0.1	-0.3	0.4	0.0
	94+18.					0.5	0.8	0.8	0.0
	94+22.5					1.3	-0.2	1.0	0.0
	94+27.					-0.9	0.4	-0.4	0.0
	94+31.5					-0.5	1.5	0.0	-1.0
	94+36.					0.9	1.5	-0.3	0.0
	94+40.5					-0.7	1.3	0.2	-1.0
27	99+00.					1.0	-0.4	1.1	0.0

	99+06.					-0.6	-0.3	0.1	0.0
	99+12.					-0.9	-1.5	-0.9	-1.0
	99+18.					-1.0	0.2	-0.8	0.0
	99+24.					0.0	-0.5	0.1	-1.0
	99+30.					0.8	-0.2	0.5	0.0
	99+36.					0.8	-0.3	0.0	0.0
	99+42.					-0.3	0.1	-1.0	-1.0
	99+48.					0.5	-0.2	-1.0	0.0
	99+54.					0.2	0.0	-0.5	-1.0
29	104+00.	9.59	9.65	9.66		0.6	0.1	-0.6	-1.0
	104+06.	9.27	9.28	9.93		0.1	0.2	-0.2	0.0
	104+12.	10.00	10.01	9.99		-1.0	-0.5	0.0	0.0
	104+18.	9.49	9.50	9.55		0.4	1.0	0.0	0.0
	104+24.	9.52	9.55	9.53		-1.5	0.2	-0.6	-1.0
	104+30.	9.74	9.76	9.72		-0.6	0.5	-1.1	0.0
	104+36.	9.58	9.55	9.56		-0.3	0.1	-1.0	-1.0
	104+42.	9.83	9.86	9.83		0.0	-1.0	-0.7	-1.0
	104+48.	9.46	9.50	9.46		0.6	1.1	-2.9	1.0
	104+54.	9.77	9.81	9.79		0.0	-0.2	-1.3	0.0
31	110+00.	9.49	9.44	9.42		1.5	-1.3	0.3	0.0
	110+06.	9.72	9.75	9.65		0.0	0.0	-0.8	-1.0
	110+12.	9.49	9.47	9.47		0.1	-0.6	-0.7	0.0
	110+18.	11.38	11.37	11.35		-0.3	-1.0	-0.4	0.0
	110+24.	11.28	11.24	11.27		-0.5	-0.9	-0.6	0.0
	110+30.	9.10	9.09	9.09		0.8	-0.3	0.7	-1.0
	110+36.	9.65	9.67	9.69		1.0	-0.5	-0.5	0.0
	110+42.	10.07	10.09	10.11		-0.2	0.0	-1.1	-1.0
	110+48.	9.53	9.62	9.52		0.8	0.0	-0.5	0.0
	110+54.	9.67	9.66	9.64		-0.9	0.3	-0.9	-1.0
33	116+50.	9.47	9.51	9.50		-1.3	-1.0	-0.5	0.0
	116+54.5	9.11	9.09	9.73		-0.6	-0.7	0.6	0.0
	116+59.	8.94	8.95	8.95		-0.5	-0.8	-0.5	0.0
	116+63.5	9.11	9.11	9.10		-0.2	0.6	-1.0	-1.0
	116+68.	9.23	9.21	9.23		0.0	0.1	0.8	0.0
	116+72.5	9.42	9.45	9.44		0.5	0.2	0.7	0.0
	116+77.	9.44	9.44	9.44		0.2	-1.3	-0.4	-1.0
	116+81.5	9.62	9.64	9.67		0.2	-0.3	0.1	-1.0
	116+86.	9.21	9.20	9.27		0.1	-0.4	-0.4	-1.0
	116+90.5	9.54	9.62	9.56		2.0	-0.3	-0.8	-1.0
	116+95.	9.91	9.91	9.92		-0.8	-0.8		
34	122+00.	9.34	9.42	9.36		-0.9	-0.2	0.0	0.0
	122+04.5	9.51	9.55	9.52		-0.3	-0.9	0.7	0.0
	122+09.	9.09	9.06	9.06		0.4	-0.4	-2.3	0.0
	122+13.5	9.71	9.73	9.72		-0.1	-0.2	0.1	0.0
	122+18.	9.42	9.45	9.44		0.3	-0.1	-0.7	-1.0
	122+22.5	10.12	10.10	10.09		-1.2	-0.4	-0.2	0.0
	122+27.	8.94	8.97	8.93		0.8	-0.7	0.2	-1.0
	122+31.5	9.81	9.83	9.80		0.8	-0.8	0.4	0.0

	122+36.	9.94	10.00	9.97		-0.2	0.3	0.3	0.0
	122+40.5	9.58	9.61	9.56		0.1	0.4	-0.8	0.0
36	126+00.					-0.3	1.5	-0.3	-1.0
	126+04.5					0.1	0.2	0.2	-1.0
	126+09.					-0.4	0.3	-0.3	0.0
	126+13.5					0.5	0.7	-0.9	0.0
	126+18.					-0.2	-0.3	-0.6	-1.0
	126+22.5					-0.2	0.3	-1.0	0.0
	126+27.					0.7	0.6	-0.5	0.0
	126+31.5					0.2	1.1	0.6	0.0
	126+36.					0.4	0.4	0.1	-1.0
	126+40.5					-0.3	-0.3	-0.7	1.0
38	132+00.	9.26	9.28	9.23		-0.3	0.5	0.6	-1.0
	132+06.	9.71	9.83	9.76		-0.5	-0.5	-0.6	0.0
	132+12.	8.90	8.95	8.90		0.0	0.2	-0.5	0.0
	132+18.	9.09	9.14	9.11		-0.3	-0.2	-1.2	-1.0
	132+24.	9.09	9.09	9.05		-0.3	0.0	-0.2	-1.0
	132+30.	8.64	8.69	8.67		0.1	0.8	-0.7	0.0
	132+36.	9.13	9.16	9.08		-0.7	0.0	-0.5	0.0
	132+42.	9.51	9.60	9.58		0.2	-1.2	-0.8	-1.0
	132+48.	9.73	9.91	9.89		0.0	0.4	-0.8	0.0
	132+54.	8.41	8.46	8.42		-0.5	0.0	-0.5	-1.0
40	137+00.	9.24	9.28	9.33		-0.3	-0.1	0.5	0.0
	137+06.	9.34	9.49	9.46		-0.4	0.7	-0.3	0.0
	137+12.	9.01	9.01	9.01		-1.0	-0.4	-0.5	1.0
	137+18.	9.92	9.98	9.95		-0.1	-0.1	-0.4	0.0
	137+24.	9.55	9.58	9.54		-0.3	-0.5	-0.5	0.0
	137+30.	9.68	9.69	9.64		-1.1	-0.1	-0.6	0.0
	137+36.	9.59	9.60	9.56		-1.5	-0.1	-0.4	-1.0
	137+42.	9.11	9.17	9.17		0.3	0.5	-0.3	0.0
	137+48.	9.32	9.38	9.32		-0.3	-0.6	-0.7	0.0
	137+54.	9.71	9.74	9.11		0.4	0.1	-0.5	0.0
42	142+00.	10.10	10.11	10.10		-1.0	0.0	0.0	0.0
	142+04.5	9.72	9.76	9.72		0.1	0.7	-0.8	0.0
	142+09.	9.53	9.55	9.53		0.3	-0.2	0.1	0.0
	142+13.5	8.60	8.65	9.86		0.9	-0.7	0.7	-1.0
	142+18.	10.89	10.90	10.87		-0.1	0.5	0.7	0.0
	142+22.5	9.77	9.79	9.75		0.0	0.0	-0.7	-1.0
	142+27.	9.22	9.21	9.24		-0.1	-0.4	-0.8	0.0
	142+31.5	9.62	9.62	9.68		0.5	0.7	-0.5	-1.0
	142+36.	9.54	9.59	9.50		-0.1	0.2	-0.3	-1.0
	142+40.5	10.23	10.24	10.15		-0.5	0.2	-0.5	0.0
44	147+00.	9.28	9.29	9.28		0.6	0.5	-0.9	0.0
	147+04.5	9.52	9.57	9.44		0.5	-0.5	0.0	0.0
	147+09.	8.99	8.98	8.98		0.5	-0.8	-1.1	0.0
	147+13.5	9.59	9.60	8.57		-1.9	-0.3	-0.3	0.0
	147+18.	9.18	9.23	9.22		-0.4	-0.4	-0.7	0.0
	147+22.5	9.65	9.69	9.67		-1.2	0.0	-0.5	0.0

	147+27.	8.54	8.63	8.53		0.8	-0.4	-0.3	0.0
	147+31.5	10.79	10.80	10.76		0.1	0.2	-0.3	0.0
	147+36.	9.87	9.83	9.88		0.1	0.6	-0.2	0.0
	147+40.5	10.13	10.11	10.14		0.0	0.4	-0.1	0.0
46	152+00.	9.35	9.36	9.30		-0.5	0.2	-0.4	0.0
	152+06.	9.64	9.66	9.62		0.2	0.2	-0.6	0.0
	152+12.	9.20	9.25	9.25		-0.8	-0.7	-1.0	0.0
	152+18.	10.10	10.15	10.09		0.3	0.1	0.0	0.0
	152+24.	10.03	10.12	10.09		-1.2	0.0	-0.5	0.0
	152+30.	9.73	9.75	9.14		-1.5	-0.3	-0.6	0.0
	152+36.	10.52	10.59	10.55		-0.1	0.5	0.3	0.0
	152+42.	9.45	9.46	9.44		-0.7	0.2	-0.2	0.0
	152+48.	9.85	9.91	9.88		-0.3	0.1	0.0	0.0
	152+54.	10.00	10.03	9.97		-0.5	0.1	-0.2	0.0
48	157+00.	9.41	9.44	9.41		-0.8	0.0	-0.7	-1.0
	157+06.	8.99	9.05	9.02		-0.1	-1.1	-0.8	0.0
	157+12.	9.42	9.48	9.42		-0.5	-1.2	-1.2	0.0
	157+18.	9.32	9.38	9.41		-3.0	-0.9	-1.0	0.0
	157+24.	9.73	9.74	9.72		0.2	-0.4	0.4	0.0
	157+30.	9.53	9.52	9.51		-0.3	-0.3	-1.0	0.0
	157+36.	8.32	8.37	8.43		-0.1	-0.3	-0.7	0.0
	157+42.	9.72	9.72	9.72		-0.5	-1.2	-1.3	0.0
	157+48.	9.98	10.03	9.99		0.5	-0.8	-0.3	-1.0
	157+54.	8.81	8.83	9.79		1.1	0.5	-0.5	-1.0
50	162+00.	9.27	9.32	9.32		-0.4	1.4	-0.5	-1.0
	162+09.	9.63	9.71	9.65		0.5	0.0	-0.4	0.0
	162+18.	9.39	9.41	9.31		-1.8	1.3	-0.5	-1.0
	162+27.	9.84	9.89	9.86		0.0	0.8	-1.0	-1.0
	162+36.	9.80	9.91	9.91		0.2	-0.3	0.1	-1.0
	162+45.					0.0	1.2	-0.5	-1.0
	162+54.					-1.5	0.7	-0.5	0.0
	162+63.					1.0	1.2	0.0	0.0
	162+72.					1.5	0.3	0.0	0.0
	162+81.					0.5	0.7	0.1	0.0
52	167+00.					-0.3	-1.7	0.2	0.0
	167+09.					-1.7	-0.3	1.6	0.0
	167+18.					-1.0	0.7	-0.8	0.0
	167+27.					0.5	-0.2	-0.7	-1.0
	167+36.					-0.6	0.0	-0.3	0.0
	167+45.					0.3	-0.2	0.7	-2.0
	167+54.					-0.8	1.7	0.0	-1.0
	167+63.					-0.4	0.5	-0.4	-3.0
	167+72.					-0.5	0.9	-0.3	0.0
	167+81.					0.2	1.5	-1.0	-1.0
54	172+00.	9.10	9.19	9.20		0.0	1.3	-0.3	0.0
	172+09.	9.49	9.54	9.53		0.2	-0.3	-0.4	-1.0
	172+18.	9.91	9.99	9.97		0.7	0.7	-0.2	-1.0
	172+27.	9.57	9.64	9.59		0.8	0.4	-1.2	-1.0

	172+36.	9.31	9.41	9.37		0.5	-0.4	-0.6	0.0
	172+45.	10.34	10.44	10.39		-0.6	0.5	-0.5	-1.0
	172+54.	9.67	9.77	9.69		-0.3	-0.9	0.5	-1.0
	172+63.	9.48	9.56	9.56		-0.6	-0.5	-0.4	0.0
	172+72.	9.49	9.57	9.57		1.0	-0.7	-0.3	0.0
	172+81.	9.20	9.24	9.25		1.1	-0.5	0.5	-1.0
56	176+00.					-0.6	0.2	-0.90	-1.0
	176+09.					0.2	-0.3	0.00	0.0
	176+18.					0.7	0.1	-0.10	0.0
	176+27.					0.8	1.0	-0.20	0.0
	176+36.					1.0	0.4	-0.8	-1.0
	176+45.					-0.6	0.0	0.0	-1.0
	176+54.					0.2	-0.5	-0.5	-1.0
	176+63.					0.3	-0.2	-1.0	0.0
	176+72.					-0.8	-0.3	0.5	0.0
	176+81.					1.8	-0.2	-0.3	0.0
57	180+00.					-0.8	-0.6	-0.6	-1.0
	180+09.					-0.8	-1.0	0.1	-1.0
	180+18.					-1.3	0.2	-1.0	-2.0
	180+27.					-0.4	-0.5	-0.6	-1.0
	180+36.					0.2	0.3	-0.1	-1.0
	180+45.					-0.5	0.0	-0.2	0.0
	180+54.					0.0	-0.8	-0.3	-1.0
	180+63.					0.3	-1.2	-0.7	0.0
	180+72.					0.0	-0.9	0.0	0.0
	180+81.					-0.9	0.2	1.0	-2.0
59	185+00.					-0.4	0.2	0.2	0.0
	185+06.					0.5	-0.5	-0.8	-1.0
	185+12.					0.0	0.1	-0.5	-1.0
	185+18.					0.3	0.3	0.0	-1.0
	185+24.					1.1	-0.8	-1.5	-1.0
	185+30.					-1.9	0.3	-1.3	0.0
	185+36.					0.3	1.5	-0.4	-1.0
	185+42.					0.1	0.4	-0.1	-1.0
	185+48.					0.8	0.1	-0.6	-1.0
	185+54.					0.0	-1.4	-0.5	0.0
61	191+00.	9.39	9.52	9.42		-0.5	0.2	-0.5	0.0
	191+04.5	9.13	9.18	9.18		1.2	-0.8	0.0	0.0
	191+09.	9.48	9.55	9.51		0.4	-1.1	-1.3	0.0
	191+13.5	9.95	10.05	10.01		0.8	-0.1	-0.5	1.0
	191+18.	9.21	9.30	9.27		0.1	-0.4	-0.5	0.0
	191+22.5	9.26	9.36	9.33		0.3	-0.3	-0.6	0.0
	191+27.	9.40	9.51	9.44		0.6	-0.5	-0.3	-1.0
	191+31.5	9.25	9.31	9.30		0.5	0.0	-1.2	0.0
	191+36.	9.36	9.43	9.35		0.2	-0.5	-0.9	0.0
	191+40.5	9.50	9.60	9.54		-0.3	-0.2	0.0	0.0
63	196+00.		9.70	9.66		-1.9	0.2	-1.4	0.0
	196+04.5	9.00	9.08	9.05		-1.1	-0.8	-0.9	0.0

	196+09.	9.48	9.53	9.53		-0.2	-1.1	-0.5	0.0
	196+13.5	9.63	9.71	9.70		-0.8	0.9	-1.5	0.0
	196+18.	9.75	9.80	9.76		-0.5	-0.2	0.4	0.0
	196+22.5	9.49	9.53	9.51		-0.2	-0.3	-0.2	0.0
	196+27.	9.78	9.88	9.86		0.2	-0.7	-0.1	0.0
	196+31.5	10.22	10.32	9.03		0.3	0.2	-0.5	0.0
	196+36.	9.09	9.25	9.22		1.3	1.0	0.1	0.0
	196+40.5	9.03	9.08	9.05		1.0	0.3	-0.8	0.0
65	201+00.	9.15	9.22	9.23		0.7	0.2	0.0	0.0
	201+06.	9.14	9.24	9.23		-1.2	0.5	-1.3	0.0
	201+12.	9.58	9.65	9.62		0.5	-0.3	-0.3	0.0
	201+18.	9.49	9.52	9.51		-0.1	0.0	-0.5	0.0
	201+24.	9.64	9.72	9.61		1.6	0.4	0.6	-1.0
	201+30.	9.66	9.71	9.69		0.6	-3.0	0.0	0.0
	201+36.	9.88	9.92	9.88		0.5	-1.0	0.1	0.0
	201+42.	10.69	10.76	10.83		0.3	0.8	-0.5	-1.0
	201+48.	10.16	10.28	10.25		0.3	0.1	-0.4	-1.0
	201+54.	9.69	9.78	9.70		-0.9	1.0	-0.2	-1.0
67	206+00.	9.97	10.05	10.02		0.9	1.0	-0.4	0.0
	206+06.	10.00	10.09	10.07		1.0	-1.0	-1.2	0.0
	206+12.	9.20	9.26	9.26		-0.7	-0.3	-0.8	0.0
	206+18.	9.75	9.76	9.79		0.6	-1.1	-0.5	0.0
	206+24.	9.66	9.71	9.67		0.7	-0.1	-0.5	0.0
	206+30.	9.04	9.15	9.11		0.6	0.3	-1.0	0.0
	206+36.	10.46	10.55	10.49		-0.5	1.0	0.0	0.0
	206+42.	9.44	9.47	9.49		1.0	0.4	-2.2	-1.0
	206+48.	9.74	9.81	9.78		-0.5	0.8	-0.4	0.0
	206+54.	9.28	9.36	9.34		0.7	-0.2	-1.0	0.0
69	211+00.	9.69	9.77	9.78		-2.9	1.5	-0.2	0.0
	211+04.5	9.81	9.84	9.88		0.6	-0.2	-0.3	0.0
	211+09.	8.98	9.11	9.07		1.0	-0.5	-0.6	0.0
	211+13.5	9.69	9.74	9.69		-1.4	-1.7	0.3	0.0
	211+18.	9.87	9.92	9.93		-1.0	-0.1	0.1	-1.0
	211+22.5	8.92	8.96	8.95		0.5	-0.5	-0.5	0.0
	211+27.	8.72	8.80	8.78		0.2	0.5	-0.5	0.0
	211+31.5	9.01	9.10	9.06		-0.7	-0.4	0.9	0.0
	211+36.	9.82	9.87	9.87		0.6	-0.5	-2.9	0.0
	211+40.5	10.15	10.22	10.27		1.2	0.6	-0.8	0.0
71	216+00.					0.2	-0.8	-1.3	0.0
	216+04.5					-0.5	0.1	-0.7	0.0
	216+09.					0.4	-0.8	-0.5	0.0
	216+13.5					-1.1	0.5	-0.5	0.0
	216+18.					0.0	1.1	-0.3	0.0
	216+22.5					-1.6	1.8	-1.6	0.0
	216+27.					1.2	-0.5	-0.5	0.0
	216+31.5					0.2	0.5	-1.0	0.0
	216+36.					0.4	0.1	0.6	0.0
	216+40.5					-0.3	0.0	-0.2	0.0

73	221+00.	9.38	9.49	9.44		1.0	-0.7	0.7	-1.0
	221+06.	8.60	8.68	8.65		0.5	-0.9	-0.3	0.0
	221+12.	8.75	8.80	8.78		1.2	-1.6	-0.8	0.0
	221+18.	9.32	9.39	9.36		-0.9	1.3	0.0	0.0
	221+24.	9.53	9.59	9.59		1.2	-1.5	0.0	0.0
	221+30.	9.09	9.16	9.14		1.5	-0.2	0.4	0.0
	221+36.	9.87	10.00	9.95		-0.8	-0.8	-0.5	0.0
	221+42.	9.75	9.78	9.78		-1.0	0.5	0.2	-1.0
	221+48.	10.63	10.68	10.62		0.3	1.5	-0.6	0.0
	221+54.	9.92	10.00	9.97		1.4	0.5	0.8	-2.0
75	226+00.	9.77	9.83	9.84		0.7	1.7	0.1	-1.0
	226+06.	9.27	9.30	9.32		1.0	0.2	0.9	0.0
	226+12.	9.80	9.79	9.75		1.3	1.0	0.6	-1.0
	226+18.	9.69	9.68	9.69		1.2	0.0	0.0	0.2
	226+24.	9.50	9.57	9.58		1.1	0.6	0.0	0.2
	226+30.	9.39	9.44	9.38		-1.3	0.6	0.2	0.0
	226+36.	9.64	9.68	9.78		-0.3	-0.5	-0.8	-1.0
	226+42.	9.33	9.35	9.39		-1.3	-0.4	0.3	0.0
	226+48.	9.82	9.86	9.83		-1.0	1.0	-0.5	-1.0
	226+54.	10.20	10.25	10.14		-0.5	-0.9	-0.4	-1.0
77	231+00.	9.33	9.40	9.39		1.2	0.7	-0.6	0.0
	231+04.5	9.91	9.99	9.94		0.6	0.2	-1.0	0.0
	231+09.	9.49	9.58	9.55		1.5	1.5	-0.1	-1.0
	231+13.5	9.34	9.43	9.42		-0.3	-0.2	-0.9	-1.0
	231+18.	9.81	9.87	9.88		0.2	-0.5	-0.2	0.2
	231+22.5	9.88	9.91	9.94		-0.8	0.5	-0.3	0.0
	231+27.	9.34	9.43	9.42		2.0	0.3	-0.8	0.0
	231+31.5	9.90	9.97	10.00		1.4	-0.5	-0.9	-1.0
	231+36.	10.06	10.13	10.09		1.6	-0.5	-1.1	-1.0
	231+40.5	9.59	9.63	9.57		0.5	-0.4	0.2	-1.0
79	236+00.	9.33	9.36	9.36		-0.7	1.0	-1.1	-1.0
	236+04.5	9.56	9.59	9.58		0.2	1.4	0.2	-2.0
	236+09.	10.40	10.44	10.42		-0.5	-0.3	-0.3	0.0
	236+13.5	8.85	8.87	8.87		1.0	0.2	-0.7	-1.0
	236+18.	8.99	9.00	9.02		1.4	-0.8	0.0	-1.0
	236+22.5	9.82	9.87	9.82		-0.2	2.7	-0.3	-1.0
	236+27.	9.66	9.66	9.65		0.0	0.2	-0.1	0.0
	236+31.5	9.63	9.70	9.68		-0.4	-0.8	-0.1	-1.0
	236+36.	8.71	8.71	8.77		-0.5	1.5	-0.1	-1.0
	236+40.5	8.79	8.87	8.31		0.5	0.9	-0.3	-1.0
81	241+00.	9.29	9.29	9.25		0.4	0.1	-0.4	0.0
	241+06.	9.78	9.90	9.82		-0.3	1.5	-0.8	-1.0
	241+12.	9.66	9.72	9.69		-0.2	-0.5	-1.3	0.0
	241+18.	10.24	10.25	10.26		1.5	0.2	-1.3	0.0
	241+24.	9.71	9.81	9.79		0.2	-0.5	0.0	0.0
	241+30.	9.74	9.77	9.76		1.0	-2.0	-0.4	0.0
	241+36.	10.07	10.14	10.10		-0.2	-0.8	-0.6	-1.0
	241+42.	9.35	9.36	9.34		0.2	0.4	-1.4	0.0

	241+48.	9.19	9.23	9.22		0.2	-0.7	-0.2	0.0
	241+54.	10.33	10.35	10.37		1.2	-0.8	0.2	0.0
83	246+00.	9.27	9.29	9.26		0.1	0.0	-0.3	0.0
	246+06.	10.09	10.18	10.11		0.0	0.6	-1.3	-1.0
	246+12.	8.78	8.79	8.78		-0.3	1.1	0.0	-1.0
	246+18.	9.78	9.84	8.83		-0.9	-0.1	-0.1	0.0
	246+24.	9.22	9.24	9.23		0.7	1.0	-0.8	0.0
	246+30.	9.32	9.39	9.35		0.0	0.5	0.2	0.0
	246+36.	8.96	9.01	8.98		-0.1	0.5	-0.3	-1.0
	246+42.	9.76	9.82	9.78		0.2	0.2	0.1	-1.0
	246+48.	9.42	9.48	9.46		-0.4	0.0	-1.4	0.0
	246+54.	9.97	10.01	9.98		0.5	-0.2	-0.2	0.0
85	251+00.	9.53	9.59	9.54		1.8	0.7	-0.5	-1.0
	251+09.	9.66	9.71	9.67		0.0	0.2	-0.2	-1.0
	251+18.	9.81	9.88	9.83		1.5	1.2	1.8	-2.0
	251+27.	9.51	9.62	9.55		0.0	0.0	0.7	-1.0
	251+36.	9.46	9.50	9.48		1.9	0.2	0.5	-1.0
	251+45.	9.09	9.13	9.76		1.4	-0.5	-0.8	0.0
	251+54.	9.33	9.37	9.38		1.4	1.0	-0.5	0.0
	251+63.	9.17	9.23	9.78		1.4	-0.3	0.1	0.0
	251+72.	9.61	9.64	9.66		-0.8	0.2	-0.9	-1.0
	251+81.					0.2	0.6	0.2	0.0
87	256+00.	9.87	9.92	9.92		0.5	-0.4	-0.7	-1.0
	256+09.	9.68	9.73	9.67		0.8	1.3	-0.7	0.0
	256+18.	8.77	8.84	9.82		1.5	0.6	-0.5	0.0
	256+27.	9.78	9.86	9.87		0.0	0.6	-0.7	-1.0
	256+36.	10.04	10.11	10.06		1.0	0.5	-0.6	-1.0
	256+45.	9.89	9.97	9.93		0.5	0.0	-1.0	-1.0
	256+54.	9.99	10.02	10.03		-1.4	0.1	0.0	0.0
	256+63.	10.78	10.82	10.81		0.3	-0.5	-0.3	-1.0
	256+72.	9.25	9.33	9.30		0.1	-1.3	-1.1	0.0
	256+81.	9.36	9.35	9.38		0.4	-0.9	0.0	-2.0
89	261+00.					1.3	0.5	-1.0	0.0
	261+04.5					0.5	1.0	-0.4	-1.0
	261+09.					0.7	-0.5	0.0	0.0
	261+13.5					1.6	-1.8	0.6	-1.0
	261+18.					-1.6	0.7	-0.6	-1.0
	261+22.5					0.3	0.7	-0.3	-1.0
	261+27.					-0.7	0.5	-0.5	-1.0
	261+31.5					-0.5	1.6	-0.6	-1.0
	261+36.					0.5	0.5	-1.0	0.0
	261+40.5					-0.6	-1.2	-0.2	0.0
91	267+00.	9.65	9.69	9.64		1.5	-1.1	-0.3	0.0
	267+09.	9.96	9.97	9.96		1.2	0.4	-0.3	0.0
	267+18.	10.07	10.13	10.09		0.0	-0.3	-0.9	-1.0
	267+27.	9.20	9.26	9.21		0.7	1.3	0.4	-1.0
	267+36.	9.71	9.79	9.76		1.2	0.6	-0.2	0.0
	267+45.	9.38	9.44	9.43		1.2	1.2	-1.5	0.0

	267+54.	8.53	8.56	8.56		-0.1	-0.3	0.5	-1.0
	267+63.	10.26	10.31	10.30		-1.8	0.0	-1.3	-1.0
	267+72.	8.83	8.93	8.89		0.9	1.2	-0.3	0.0
	267+81.	8.91	8.92	8.97		0.0	-1.1	0.3	0.0
93	272+00.	9.10	9.17	9.09		0.7	-0.5	-0.8	-1.0
	272+09.	10.51	10.57	10.56		1.1	0.9	-0.3	-1.0
	272+18.	8.93	9.04	9.02		-1.4	0.7	-1.3	-1.0
	272+27.	9.49	9.56	9.52		2.5	0.6	0.0	-1.0
	272+36.	9.20	9.25	9.17		2.0	1.0	0.0	-1.0
	272+45.	9.64	9.69	9.68		-0.3	0.8	0.0	0.0
	272+54.	9.05	9.13	9.06		1.9	0.3	0.0	-2.0
	272+63.	10.08	10.08	10.19		0.1	0.6	0.0	0.0
	272+72.	8.85	8.87	8.86		0.8	2.0	0.0	0.0
	272+81.	9.47	9.51	9.48		0.7	-0.8	0.0	0.0
95	277+00.	9.24	9.29	9.28		1.0	1.1	0.0	-1.0
	277+04.5	8.73	8.74	8.78		0.0	0.9	0.0	-1.0
	277+09.	10.45	10.47	10.49		-0.2	0.0	0.0	0.0
	277+13.5	9.05	9.05	9.07		1.0	0.0	-1.0	0.0
	277+18.	8.59	8.63	8.63		0.1	1.2	0.0	0.0
	277+22.5	9.57	9.65	9.63		0.6	-1.0	0.0	0.0
	277+27.	9.62	9.68	9.65		-0.8	-0.7	-1.0	-1.0
	277+31.5	9.83	9.84	9.84		-0.5	1.0	0.0	-1.0
	277+36.	9.83	9.83	9.91		0.3	-0.2	0.0	-1.0
	277+40.5	9.17	9.22	9.29		0.4	0.2	0.0	0.0
98	282+00.	9.70	9.77	9.79		1.1	0.3	-0.2	0.0
	282+04.5	9.30	9.35	9.37		-0.5	-0.4	-1.0	0.0
	282+09.	9.33	9.33	9.34		0.4	0.7	-0.5	0.0
	282+13.5	8.83	8.89	8.89		-1.2	-0.5	-0.5	-1.0
	282+18.	9.89	9.95	9.88		0.2	0.0	-0.3	0.0
	282+22.5	9.59	9.57	9.56		0.2	0.2	-0.1	0.0
	282+27.	10.16	10.19	9.90		1.4	-0.5	0.4	0.0
	282+31.5	10.31	10.33	10.34		0.4	0.3	-1.1	0.0
	282+36.	10.40	10.46	10.44		1.0	0.2	-1.4	0.0
	282+40.5	9.91	9.91	9.98		0.1	-0.5	-0.5	0.0
100	287+00.	8.85	8.84	8.88		-0.9	-0.4	-0.9	-1.0
	287+06.	9.91	9.91	10.00		0.1	0.6	-0.3	-1.0
	287+12.	9.90	9.92	9.94		1.2	0.6	-0.5	0.0
	287+18.	8.89	8.90	8.93		-0.5	0.5	-0.3	0.0
	287+24.	9.10	9.12	9.11		0.7	0.1	-1.0	-1.0
	287+30.	9.58	9.68	9.67		0.0	0.4	-0.7	-1.0
	287+36.	9.59	9.62	9.62		0.5	0.0	-0.8	0.0
	287+42.	9.50	9.53	9.52		0.9	0.8	-1.0	-1.0
	287+48.	9.27	9.24	9.32		-0.7	0.3	-0.4	-1.0
	287+54.	9.40	9.40	9.44		-0.9	0.3	-1.0	0.0
102	292+00.	9.30	9.34	9.34		-0.5	-0.2	-0.5	0.0
	292+06.	10.43	10.44	10.44		0.0	1.5	-0.6	0.0
	292+12.	9.95	9.96	10.00		-0.2	0.2	-0.9	0.0
	292+18.	10.71	10.83	10.14		0.1	0.3	-0.9	-1.0

	292+24.	9.39	9.39	9.43		-0.3	0.4	-0.7	0.0
	292+30.	9.48	9.47	9.46		0.3	0.0	-0.4	0.0
	292+36.	9.36	10.36	10.37		0.2	-0.3	-0.4	0.0
	292+42.	8.93	8.98	8.99		-0.3	-0.5	-0.8	0.0
	292+48.	10.15	10.16	10.18		-0.1	0.6	-0.5	-1.0
	292+54.	8.85	8.91	8.94		2.8	-1.0	0.6	-1.0
104	297+00.	9.59	9.61	9.61		-0.5	-0.1	-0.7	0.0
	297+04.5	9.62	9.63	9.60		0.4	0.4	-0.1	0.0
	297+09.	9.96	10.00	10.00		0.0	-0.8	0.2	0.0
	297+13.5	10.62	10.65	10.67		-1.0	0.1	-1.5	0.0
	297+18.	10.38	10.42	10.47		-0.7	-0.2	-0.5	-1.0
	297+22.5	10.14	10.15	10.18		0.5	-0.2	-1.0	0.0
	297+27.	8.74	8.78	8.83		-0.1	0.5	-0.5	-1.0
	297+31.5	9.95	9.97	10.00		0.3	0.7	-0.6	0.0
	297+36.	9.46	9.57	9.54		2.1	-0.1	-0.8	0.0
	297+40.5	9.50	9.53	9.51		-0.4	-0.6	0.0	1.0
106	302+00.	8.79	8.81	8.78		0.5	-0.3	-1.6	0.0
	302+04.5	8.97	9.03	9.08		1.0	-1.2	-1.1	0.0
	302+09.	8.51	8.52	8.57		0.7	0.3	-1.2	0.0
	302+13.5	9.90	9.95	9.87		1.4	-0.5	-0.5	-1.0
	302+18.	8.90	8.94	8.96		0.7	-0.2	-0.3	0.0
	302+22.5	9.39	9.50	9.46		0.8	0.3	-0.1	-1.0
	302+27.	9.37	9.40	9.40		0.5	-0.2	-1.1	-1.0
	302+31.5	9.48	9.55	9.53		0.0	0.7	-0.7	0.0
	302+36.	10.04	10.15	10.13		-1.5	0.0	0.2	0.0
	302+40.5	10.14	10.20	10.16		0.4	0.2	-0.3	0.0
108	307+00.	9.58	9.64	9.58		-0.2	-1.3	0.2	0.0
	307+06.	9.47	9.48	9.50		-0.2	-0.2	-0.3	0.0
	307+12.	9.77	9.78	9.81		-0.4	-0.2	-0.1	-1.0
	307+18.	9.30	9.33	9.30		-0.3	0.8	-0.4	-1.0
	307+24.	10.11	10.17	10.16		0.7	0.4	-0.9	0.0
	307+30.	8.94	8.96	8.97		0.2	0.5	-0.5	0.0
	307+36.	9.82	9.92	9.81		0.5	0.7	-2.3	-1.0
	307+42.	9.33	9.35	9.35		-0.5	0.2	-0.5	0.0
	307+48.	10.71	10.74	10.14		0.0	0.2	-1.1	0.0
	307+54.	10.12	10.17	10.04		-0.9	0.5	-0.8	0.0
110	312+00.	9.60	9.61	9.63		-0.5	0.2	-0.4	0.0
	312+06.	9.89	9.91	10.17		-1.0	0.4	0.1	-1.0
	312+12.	9.82	9.89	9.90		-0.1	0.1	-0.6	-1.0
	312+18.	8.83	8.85	8.81		0.2	-1.0	-0.3	0.0
	312+24.	9.78	9.85	9.86		1.7	0.1	-0.8	-1.0
	312+30.	10.25	10.31	10.32		-0.2	0.2	0.0	0.0
	312+36.	9.30	9.38	9.40		0.1	-0.2	0.7	-1.0
	312+42.	9.29	9.38	9.38		0.6	0.1	0.1	0.0
	312+48.	8.61	8.61	8.77		1.2	0.7	-0.5	-1.0
	312+54.	8.30	8.30	8.33		0.3	-0.1	-0.7	-1.0
112	317+00.	9.18	9.22	9.29		-0.7	0.3	-1.1	-1.0
	317+04.5	9.23	9.26	9.28		0.9	0.5	-0.3	0.0

	317+09.	9.40	9.42	9.40		-0.1	-0.2	-1.3	0.0
	317+13.5	8.91	8.95	8.96		0.2	-1.2	0.4	0.0
	317+18.	9.33	9.40	9.40		0.6	0.3	0.5	0.0
	317+22.5	9.98	10.02	10.06		0.6	-0.8	-0.9	0.0
	317+27.	9.38	9.44	9.48		0.5	-0.5	-1.2	-1.0
	317+31.5	9.81	9.84	9.75		-0.5	-0.6	-0.9	0.0
	317+36.	9.20	9.27	9.78		0.5	0.0	0.0	0.0
	317+40.5	9.29	9.34	9.28		-0.4	0.5	-0.7	0.0
114	322+00.					-0.5	-0.5	0.5	-1.0
	322+04.5					0.3	1.0	1.0	0.0
	322+09.					0.7	0.2	0.3	-1.0
	322+13.5					1.2	0.5	0.8	0.0
	322+18.					0.1	0.0	0.0	-1.0
	322+22.5					0.2	0.7	-0.5	0.0
	322+27.					-0.5	0.4	-1.2	0.0
	322+31.5					0.2	-1.0	-0.3	0.0
	322+36.					0.1	-1.4	0.6	0.0
	322+40.5					-0.6	-0.9	0.3	0.0
116	327+00.	9.51	9.61	9.55		0.6	-1.8	0.8	0.0
	327+06.	9.49	9.53	9.50		0.2	-0.1	-1.0	0.0
	327+12.	9.40	9.50	9.47		-1.2	-0.2	-0.6	0.0
	327+18.	8.62	8.64	8.69		0.7	-0.1	-0.6	-1.0
	327+24.	10.18	10.33	10.29		0.1	-0.7	-0.5	-1.0
	327+30.	8.79	8.82	886.00		-0.4	0.6	-0.1	0.0
	327+36.	9.42	9.55	9.54		-1.1	-0.4	-1.3	-1.0
	327+42.	9.69	9.71	9.72		-0.9	0.8	-0.7	0.0
	327+48.	9.85	9.94	9.92		1.4	0.5	0.0	0.0
	327+54.	8.71	8.82	8.81		-0.3	1.0	-3.0	-1.0
118	332+00.	9.38	9.49	9.46		-0.2	-0.3	-1.1	-1.0
	332+06.	9.38	9.45	9.44		0.4	0.0	-0.8	-1.0
	332+12.	9.27	9.32	9.27		-0.2	0.2	0.0	0.0
	332+18.	9.41	9.43	9.41		-0.5	1.0	0.3	0.0
	332+24.	9.40	9.40	9.47		0.5	0.4	-0.5	0.0
	332+30.	9.57	9.66	9.64		0.1	0.2	-0.6	0.0
	332+36.	10.10	10.15	10.18		-0.5	0.0	-1.0	-1.0
	332+42.	9.45	9.48	9.46		-0.3	1.2	-0.4	-1.0
	332+48.	9.57	9.62	9.63		0.7	0.2	-0.8	0.0
	332+54.	9.50	9.57	9.52		-0.3	0.7	-1.1	0.0
120	337+00.	9.27	9.37	9.35		1.0	-0.7	-0.5	0.0
	337+09.	9.78	9.82	9.81		0.5	-1.5	-0.5	0.0
	337+18.	8.47	8.52	8.54		0.5	0.3	-0.7	0.0
	337+27.	9.94	10.03	9.99		-0.9	0.2	0.2	0.2
	337+36.	9.73	9.77	9.77		0.9	0.3	0.2	0.0
	337+45.	8.96	9.08	9.04		0.4	0.5	-1.3	0.0
	337+54.	8.91	8.98	8.99		0.8	-1.4	0.6	0.0
	337+63.	9.56	9.66	9.61		1.4	0.8	-0.8	0.0
	337+72.	8.89	8.95	8.91		0.7	0.7	-2.2	-1.0
	337+81.	9.62	9.66	9.67		-1.2	-0.2	-0.7	-1.0

122	342+00.	9.91	10.01	10.00		-0.6	0.4	-0.5	0.0
	342+09.	10.01	10.06	10.08		-0.4	0.5	0.4	0.0
	342+18.	8.91	8.95	9.20		-0.6	1.0	0.7	0.0
	342+27.	9.55	9.53	9.57		0.7	0.2	-1.0	0.0
	342+36.	9.82	9.88	9.19		-0.3	-0.2	2.0	0.0
	342+45.	8.94	9.03	9.01		0.3	0.7	-1.5	0.0
	342+54.	9.79	9.86	9.90		0.9	0.0	-8.0	0.0
	342+63.	8.67	8.65	8.75		0.0	0.2	0.1	-1.0
	342+72.	9.55	9.62	9.43		0.5	1.8	-1.7	-1.0
	342+81.	9.56	9.61	9.60		-0.3	0.0	-1.6	0.0
124	347+00.	8.93	8.99	8.96		-1.2	-1.3	-0.9	-1.0
	347+09.	8.85	8.92	8.96		0.0	2.2	0.2	-1.0
	347+18.	9.25	9.31	9.32		0.7	0.7	0.5	0.0
	347+27.	9.20	9.28	9.25		1.0	0.3	-0.6	0.0
	347+36.	9.65	9.73	9.70		0.6	1.5	-0.9	0.0
	347+45.	9.12	9.25	9.27		0.7	0.5	-0.3	0.0
	347+54.	9.66	9.73	9.75		-0.6	-1.2	-0.7	0.0
	347+63.	9.48	9.59	9.58		0.2	0.0	0.0	0.0
	347+72.	9.03	9.02	9.06		-0.1	0.0	-1.0	-1.0
	347+81.	9.42	9.48	9.48		0.5	-0.2	-0.8	-1.0
126	352+00.	9.24	9.23	9.19		-1.4	-0.5	-0.9	0.0
	352+09.	9.07	9.12	9.06		-0.4	0.5	-2.1	-1.0
	352+18.	10.51	10.54	10.57		0.7	1.2	0.1	0.0
	352+27.	9.29	9.38	9.39		-0.2	0.9	-0.7	0.0
	352+36.	9.21	9.25	9.12		-0.5	-0.4	1.0	0.0
	352+45.	9.21	9.23	9.25		1.2	-0.2	-1.3	0.0
	352+54.	9.51	9.61	9.56		1.0	-0.1	-0.6	0.0
	352+63.	8.90	8.92	9.01		-0.4	-0.8	-1.7	0.0
	352+72.	9.74	9.90	9.76		1.0	-0.5	-1.3	0.0
	352+81.	10.75	10.80	10.79		-0.6	-0.3	-0.6	0.0
128	356+00.					-0.1	0.2	-0.8	0.0
	356+04.5					-0.1	0.4	-0.4	1.0
	356+09.					-0.1	0.8	-1.5	0.0
	356+13.5					0.1	0.9	-0.2	0.0
	356+18.					-0.4	-1.0	-1.0	-1.0
	356+22.5					0.5	-0.7	-1.4	0.0
	356+27.					1.0	0.2	0.3	0.0
	356+31.5					0.5	-0.8	0.5	1.0
	356+36.					1.4	-0.3	0.4	0.0
	356+40.5					0.2	0.2	-1.0	0.0
130	362+00.	9.57	9.61	9.58		0.7	-0.8	0.3	0.0
	362+04.5	9.03	9.05	9.07		0.5	-0.3	-0.8	0.0
	362+09.	9.81	9.72	9.83		-1.0	-1.5	-0.4	0.0
	362+13.5	8.96	9.02	8.95		0.8	1.5	-0.3	0.0
	362+18.	9.05	9.09	9.13		0.8	0.0	1.4	0.0
	362+22.5	9.00	9.00	9.01		-0.9	0.8	0.7	0.0
	362+27.	9.76	9.80	9.76		-0.9	1.0	-0.6	0.0
	362+31.5	9.46	9.44	9.42		0.0	-1.1	-0.3	0.0

	362+36.	9.52	9.56	9.51		-1.2	0.5	-0.6	0.0
	362+40.5	10.31	10.29	10.34		1.1	-0.8	0.2	0.0
132	367+00.	9.38	9.41	9.41		-0.4	0.2	-1.1	0.0
	367+06.	9.59	9.56	9.61		0.1	0.5	0.4	0.0
	367+12.	8.95	8.92	9.07		0.7	0.8	-0.8	0.0
	367+18.	8.63	8.63	8.68		-0.7	-1.2	-1.3	0.0
	367+24.	9.87	9.73	8.88		-0.1	0.3	-0.5	0.0
	367+30.	9.18	9.17	9.17		0.7	-1.0	-1.1	0.0
	367+36.	9.18	9.16	9.19		0.1	-0.4	1.0	0.0
	367+42.	9.65	9.70	9.65		0.0	1.2	0.7	0.0
	367+48.	8.80	8.82	8.87		0.9	-0.4	-0.6	-1.0
	367+54.	9.73	9.75	9.69		-0.4	0.2	0.3	0.0
134	372+00.	8.51	8.50	8.52		0.2	-0.3	0.3	0.0
	372+06.	9.10	9.17	9.18		0.5	-0.7	-0.3	0.0
	372+12.	8.88	8.84	8.84		0.1	-0.1	-0.3	0.0
	372+18.	9.49	9.54	9.58		0.3	0.6	-0.7	0.0
	372+24.	9.31	9.32	9.29		-0.3	-1.0	-1.0	0.0
	372+30.	10.07	10.07	10.01		1.4	-0.1	-1.0	0.0
	372+36.	9.41	9.39	9.43		1.5	0.0	0.5	0.0
	372+42.	9.69	9.71	9.67		-1.3	1.0	-0.8	0.0
	372+48.	9.85	9.85	9.85		1.6	-0.5	-0.3	0.0
	372+54.	9.41	9.49	9.52		-0.7	0.0	0.2	0.0
136	377+00.	9.30	9.29	9.34		0.1	-1.0	-0.4	0.0
	377+04.5	9.51	9.56	9.62		0.2	1.2	-1.6	0.0
	377+09.	9.20	9.21	9.30		0.3	1.0	0.4	0.0
	377+13.5	9.38	9.38	9.40		-0.9	0.0	-1.3	0.0
	377+18.	9.13	9.17	9.16		-0.9	0.2	-1.0	-1.0
	377+22.5	9.23	9.27	9.35		0.1	1.0	-0.9	0.0
	377+27.	9.24	9.22	9.22		1.5	0.4	-0.7	0.0
	377+31.5	8.50	8.51	8.67		-1.1	-0.6	-1.0	-1.0
	377+36.	10.44	10.46	10.50		0.2	0.5	-1.2	0.0
	377+40.5	9.20	9.27	9.29		0.2	1.1	-0.7	0.0
138	382+00.	9.83	9.78	9.88		-0.2	0.5	-1.0	0.0
	382+04.5	9.57	9.57	9.63		1.8	0.7	-0.3	0.0
	382+09.	9.09	9.04	9.14		-0.5	0.3	0.3	0.0
	382+13.5	9.05	9.05	9.13		1.3	-1.1	0.2	0.0
	382+18.	9.45	9.47	9.35		-0.5	0.0	-0.2	0.0
	382+22.5	10.50	10.55	10.49		0.7	-0.3	1.3	-1.0
	382+27.	9.56	9.50	9.47		-0.7	-0.2	-0.7	0.0
	382+31.5	9.15	9.16	9.01		0.9	1.6	-1.4	-1.0
	382+36.	9.84	9.83	9.76		0.2	0.5	1.1	0.0
	382+40.5	9.55	9.62	9.66		0.7	0.9	-0.5	0.0
140	387+00.	9.25	9.25	9.25		0.2	0.5	0.6	0.0
	387+06.	8.97	9.05	9.06		0.0	1.0	-0.3	0.0
	387+12.	9.48	9.47	9.47		0.5	0.0	-0.7	-1.0
	387+18.	10.07	10.10	10.10		1.9	0.0	-1.5	-2.0
	387+24.	8.87	8.86	8.50		-1.0	1.1	-0.3	-1.0
	387+30.	10.91	10.94	10.93		1.0	-0.4	1.2	0.0

	387+36.	9.33	9.32	9.32		-1.2	0.3	-0.5	0.0
	387+42.	9.33	9.36	9.43		-0.7	-0.3	0.3	0.0
	387+48.	8.53	8.59	8.53		0.0	-1.5	0.0	0.0
	387+54.	9.17	9.12	9.13		1.2	0.8	0.3	0.7
142	392+00.	9.26	9.24	9.25		1.9	-0.5	-0.5	0.0
	392+06.	9.41	9.34	9.39		-0.2	-0.8	0.1	0.0
	392+12.	8.91	8.91	8.95		0.4	0.1	-1.1	0.0
	392+18.	9.62	9.63	9.65		-0.2	0.8	-2.9	0.0
	392+24.	9.38	9.36	9.46		0.2	0.0	1.2	-1.0
	392+30.	8.86	8.82	8.87		-0.8	-1.1	-1.2	0.0
	392+36.	10.11	10.17	10.76		1.5	0.2	-1.1	-1.0
	392+42.	8.95	8.97	9.01		0.2	0.1	0.1	0.0
	392+48.	9.35	9.35	9.41		2.0	1.2	-2.2	-1.0
	392+54.	9.42	9.45	9.52		0.5	0.5	1.0	-1.0
144	397+00.	10.29	10.29	10.24		0.7	-0.4	1.2	0.0
	397+04.5	9.85	9.74	9.88		0.1	0.3	-1.3	0.0
	397+09.	9.30	9.27	9.37		-1.6	0.4	-0.8	0.0
	397+13.5	8.63	8.60	8.72		0.9	0.6	-0.8	-1.0
	397+18.	8.92	8.92	8.97		1.7	-0.2	-1.1	0.0
	397+22.5	9.49	9.55	9.45		-1.1	1.3	-0.9	0.0
	397+27.	9.00	9.04	9.07		1.0	1.5	0.2	0.0
	397+31.5	10.33	10.34	10.02		-0.8	-0.5	-0.8	-1.0
	397+36.	9.05	9.09	9.07		0.2	1.5	-1.7	0.0
	397+40.5	8.73	8.73	8.67		-0.5	2.6	-0.4	-1.0
146	402+00.	8.80	8.85	8.83		-0.5	0.3	-1.5	0.0
	402+04.5	9.63	9.58	9.58		1.7	0.1	-0.8	-1.0
	402+09.	9.53	9.55	9.56		1.0	-0.4	0.2	0.0
	402+13.5	9.15	9.19	9.16		-0.3	0.1	-0.5	0.0
	402+18.	9.18	9.17	9.24		0.2	-0.3	0.8	0.0
	402+22.5	10.03	10.00	10.05		0.2	1.4	-2.4	0.0
	402+27.	9.68	9.69	9.71		0.5	-1.3	-2.3	-1.0
	402+31.5	9.96	9.92	10.07		0.5	0.2	-1.6	-1.0
	402+36.	9.53	9.45	9.47		0.7	-1.1	0.5	0.0
	402+40.5	9.80	9.83	9.86		0.3	1.2	-0.3	0.0
148	407+00.	9.18	9.13	9.14		0.3	0.2	-0.7	0.0
	407+06.	9.25	9.23	9.33		1.3	0.7	-0.3	0.0
	407+12.	9.51	9.57	9.54		1.2	-0.6	0.4	0.0
	407+18.	9.55	9.58	9.54		-0.1	1.1	-1.1	0.0
	407+24.	9.32	9.32	9.33		-0.1	-1.5	-1.3	0.0
	407+30.	10.17	10.14	10.01		0.6	-0.5	-0.3	0.0
	407+36.	9.13	9.19	9.14		0.5	0.2	0.2	0.0
	407+42.	9.85	9.86	9.87		1.1	1.6	-1.0	-1.0
	407+48.	8.88	8.89	8.98		-0.8	1.0	-0.8	0.0
	407+54.	8.98	9.01	9.01		0.5	-0.8	-0.1	0.0
150	412+00.	10.16	10.13	10.18		-0.2	1.1	0.9	-1.0
	412+06.	8.46	8.45	8.51		0.3	1.1	-0.3	0.0
	412+12.	9.91	9.95	9.91		-0.2	-0.8	-1.7	0.0
	412+18.	10.39	10.42	10.41		1.1	-1.4	-1.2	0.0

	412+24.	8.12	8.11	8.41		-0.8	-0.5	-0.3	0.0
	412+30.	10.20	10.21	10.22		1.7	1.0	-0.8	0.0
	412+36.	9.57	9.58	9.58		0.2	-1.0	-0.5	0.0
	412+42.	10.10	10.11	10.16		0.1	-0.5	-1.4	-1.0
	412+48.	9.91	9.91	9.85		1.1	-1.8	0.0	0.0
	412+54.	9.01	9.01	8.99		0.1	1.0	-0.5	1.0
152	416+00.					0.4	0.4	-0.3	0.0
	416+06.					-0.2	-0.5	-0.5	-1.0
	416+12.					-0.8	1.2	0.6	-2.0
	416+18.					0.2	1.6	-1.5	0.0
	416+24.					-1.2	0.4	-0.7	0.0
	416+30.					1.5	-0.3	-1.2	-1.0
	416+36.					-0.3	1.1	0.8	0.0
	416+42.					0.5	-0.2	-0.5	0.0
	416+48.					1.5	1.3	-0.4	0.0
	416+54.					-0.6	1.0	0.5	0.0
154	422+00.	9.37	9.23	9.32		-0.4	1.2	-1.5	0.0
	422+06.	9.19	9.13	9.15		0.5	0.5	-0.9	0.0
	422+12.	10.19	10.20	10.31		0.4	0.1	-2.0	0.0
	422+18.	8.74	8.75	8.79		0.1	1.0	-1.0	0.0
	422+24.	8.93	8.92	8.78		0.5	1.2	-0.7	-1.0
	422+30.	9.57	9.58	9.58		0.6	1.0	-1.0	-1.0
	422+36.	9.29	9.08	9.34		0.4	-0.6	-0.7	0.0
	422+42.	10.16	10.24	10.27		0.8	-0.5	-0.8	0.0
	422+48.	9.26	9.27	9.42		0.5	-0.5	-0.5	0.0
	422+54.	9.46	9.49	9.50		-1.3	-0.5	-1.0	0.0
156	427+00.	9.17	9.20	9.13		0.1	2.7	-0.2	0.0
	427+06.	9.92	9.94	9.93		-1.0	0.5	-1.0	0.0
	427+12.	9.68	9.63	9.52		-0.7	0.9	-1.5	0.0
	427+18.	9.91	9.95	9.94		0.1	0.9	-1.5	-1.0
	427+24.	9.12	9.14	9.21		0.1	0.2	-1.0	0.0
	427+30.	9.02	9.09	9.07		-1.2	0.7	-0.4	-1.0
	427+36.	9.22	9.25	9.23		0.3	-0.5	0.0	0.0
	427+42.	9.69	9.70	9.70		0.0	1.4	-0.4	-1.0
	427+48.	9.10	9.07	9.72		1.3	0.0	1.5	0.0
	427+54.	8.88	8.97	8.97		1.0	1.8	0.2	0.0
158	432+00.	9.18	9.26	9.22		1.3	0.7	-1.3	0.0
	432+06.	9.18	9.88	9.88		1.3	0.3	-0.5	-1.0
	432+12.	8.72	8.78	9.73		0.5	1.9	-0.7	0.0
	432+18.	8.93	8.96	8.95		0.2	0.7	0.2	0.0
	432+24.	9.34	9.37	9.33		0.2	-0.1	-0.8	0.0
	432+30.	8.80	8.79	8.73		-0.2	-0.3	-0.7	0.0
	432+36.	9.35	9.40	9.28		0.7	1.4	0.0	0.0
	432+42.	9.40	9.39	9.42		-0.5	-0.7	0.1	0.0
	432+48.	8.24	8.31	8.28		1.2	0.5	-0.4	0.0
	432+54.	9.11	9.14	9.15		0.1	-1.1	-0.8	0.4
160	437+00.	9.37		9.27		-0.6	-0.7	0.2	0.0
	437+04.5	9.22		9.33		-1.0	-0.6	-0.8	0.0

	437+09.	9.45		9.45		0.0	-0.9	0.4	-1.0
	437+13.5	9.04		9.10		-0.3	-1.3	-0.5	-1.0
	437+18.	9.18		9.12		0.2	0.3	-1.6	0.0
	437+22.5	9.74		9.86		0.1	-0.3	0.2	0.0
	437+27.	8.69		8.67		0.5	-0.5	-0.3	-1.0
	437+31.5	9.36		9.38		1.0	0.0	-1.0	-1.0
	437+36.	9.48		9.50		0.6	-1.3	-0.2	0.0
	437+40.5	9.94		9.67		-0.3	-0.1	-0.5	-1.0
162	442+00.	9.19	9.12	9.13		1.5	0.6	0.4	0.0
	442+04.5	9.61	9.61	9.49		0.4	0.0	-0.4	0.0
	442+09.	9.23	9.21	9.19		1.1	-0.1	-0.8	0.0
	442+13.5	9.44	9.52	9.38		1.3	-1.5	-0.4	-1.0
	442+18.	8.45	8.44	8.48		1.2	-0.8	0.0	0.0
	442+22.5	9.13	9.15	9.15		-0.6	-0.2	0.0	0.0
	442+27.	9.41	9.45	9.36		0.2	0.1	0.0	0.0
	442+31.5	9.53	9.46	9.44		1.3	-0.4	-0.7	0.0
	442+36.	9.95	9.89	9.74		-0.3	0.6	-0.8	0.0
	442+40.5	9.36	9.43	9.32		0.5	0.6	-0.5	0.0
164	447+00.	9.32	9.40	9.35		0.7	-0.3	-1.3	0.0
	447+06.	10.08	10.15	9.97		-0.3	-2.2	-1.3	0.0
	447+12.	9.75	9.81	9.82		-1.3	0.2	-1.7	0.0
	447+18.	10.07	10.02	10.05		-1.0	-1.3	-1.0	0.0
	447+24.	8.63	8.61	8.61		0.3	-0.2	0.2	0.0
	447+30.	9.46	9.46	9.57		-0.5	0.7	-0.5	0.0
	447+36.	9.57	9.54	9.54		-0.5	1.1	-0.3	0.0
	447+42.	8.13	8.16	8.23		0.9	1.0	-2.0	0.0
	447+48.	9.91	9.91	9.95		1.3	-0.7	-0.3	-1.0
	447+54.	10.06	10.06	10.08		-0.2	0.0	-1.1	-1.0
166	452+00.	9.22	9.20	9.16		0.5	-0.4	0.0	0.0
	452+06.	8.96	8.96	9.05		-0.7	-0.4	-0.5	0.0
	452+12.	9.97	10.00	10.04		-0.1	-0.6	-1.5	-1.0
	452+18.	9.11	9.07	9.20		-0.4	-0.9	-0.4	0.0
	452+24.	9.07	8.94	9.06		0.0	0.7	-0.6	0.0
	452+30.	8.39	8.35	8.41		-2.9	-0.8	-1.3	0.0
	452+36.	8.54	8.52	8.52		0.2	0.7	0.2	0.0
	452+42.	8.03	8.01	8.09		0.2	1.0	0.5	-1.0
	452+48.	9.06	9.09	9.13		0.9	-0.2	0.3	1.0
	452+54.	9.66	9.66	9.57		1.7	1.5	-0.3	-1.0
170	461+50.	9.72	9.64	9.69		0.7	-1.3	0.0	0.0
	461+54.5	9.14	9.05	9.08		0.4	-0.5	-2.7	0.0
	461+59.	10.24	10.16	10.02		-0.4	-0.2	-0.3	0.0
	461+63.5	9.94	9.98	10.05		1.1	0.2	0.2	0.0
	461+68.	10.28	10.21	10.15		0.6	0.5	0.7	-1.0
	461+72.5	9.16	9.15	9.29		0.5	0.0	-1.1	0.0
	461+77.	8.93	8.92	9.05		-0.6	0.4	-0.2	-1.0
	461+81.5	9.33	9.37	9.36		-0.3	0.8	-0.2	-1.0
	461+86	8.90	8.90	8.75		0.4	-0.6	-1.7	0.0
	461+90.5	10.11	10.13	9.98		-0.3	1.8	0.5	0.0

172	466+00.	9.92	9.91	9.84		-1.0	1.2	0.2	0.0
	466+06.	10.30	10.29	10.28		0.0	0.4	-0.9	0.0
	466+12.	10.04	10.07	10.11		-0.4	-0.8	0.4	0.0
	466+18.	8.58	8.54	8.57		-0.2	-1.1	-0.3	0.0
	466+24.	10.19	10.20	10.27		0.2	-0.2	-0.3	0.0
	466+30.	9.21	9.18	9.17		1.2	-2.3	-0.5	-2.0
	466+36.	9.74	9.74	9.61		-0.6	-0.5	-1.1	0.0
	466+42.	9.07	9.02	9.13		-0.2	-0.3	-0.3	0.0
	466+48.	9.15	9.11	8.97		0.7	-0.5	0.1	0.0
	466+54.	9.81	9.80	9.81		-1.2	-1.5	-1.4	-1.0
174	470+50.	9.64	9.59	9.49		0.0	0.4	-0.6	0.0
	470+56.	8.63	8.63	8.64		0.3	-0.3	-1.3	0.0
	470+62.	10.06	10.04	10.04		0.6	0.0	-1.4	0.0
	470+68.	9.00	8.98	9.03		0.7	-0.5	-0.8	0.0
	470+74.	8.91	8.86	8.88		-0.8	-0.4	-0.7	0.0
	470+80.	9.95	9.93	9.95		0.8	-0.3	-1.0	0.0
	470+86	8.99	8.97	8.95		-1.1	0.3	-2.0	0.0
	470+92.	9.87	9.72	9.87		-0.5	0.6	-0.3	0.0
	470+98.	9.58	9.53	9.48		-0.1	0.5	-0.7	0.0
	471+04.	9.45	9.50	9.32		1.2	-0.6	-1.5	0.0
176	475+00.	9.65	9.59	9.65		-0.8	-1.6	-0.8	0.0
	475+04.5	9.83	9.86	9.92		1.6	-1.0	0.0	0.0
	475+09.	9.26	9.22	9.23		0.1	-0.2	-0.5	-1.0
	475+13.5	9.14	9.18	9.22		-0.3	0.2	-0.9	0.0
	475+18.	8.87	8.75	8.79		0.3	-0.3	-0.8	0.0
	475+22.5	9.35	9.32	9.37		0.4	-0.3	-0.9	-1.0
	475+27.	8.33	8.37	8.26		0.8	-0.1	0.0	0.0
	475+31.5	-	-	-		0.7	0.1	0.0	0.0
	475+36.	9.14	9.19	9.73		-0.6	0.2	-1.8	0.0
	475+40.5	9.66	9.62	9.43		0.0	-0.5	0.7	0.0
178	479+50.	9.57	9.58	9.69		0.3	-0.3	0.5	0.0
	479+54.5	9.47	9.53	9.55		-0.4	-0.4	-0.7	0.0
	479+59.	8.67	8.62	8.62		-0.2	0.0	-0.5	-1.0
	479+63.5	9.26	9.26	9.28		0.6	1.2	-0.2	0.0
	479+68.	9.85	9.80	9.77		0.0	0.2	-1.8	0.0
	479+72.5	9.87	9.92	9.95		-1.4	-0.4	-0.6	0.0
	479+77.	11.15	11.13	11.02		-1.0	23.0	-0.3	0.0
	479+81.5	9.20	9.23	9.19		-0.3	0.0	-0.9	0.0
	479+86.	8.82	8.79	8.72		-0.8	-2.0	-0.6	0.0
	479+90.5	9.30	9.29	9.30		-0.3	-0.3	-0.2	0.0
180	484+00.	8.93	8.88	8.99		-0.5	0.5	0.4	0.0
	484+06.	9.08	9.06	8.82		1.4	2.0	-1.0	0.0
	484+12.	9.81	9.80	9.76		-0.5	0.8	-0.1	0.0
	484+18.	9.69	9.69	9.69		0.7	1.3	-1.2	0.0
	484+24.	9.71	9.69	9.54		0.9	0.1	-0.8	0.0
	484+30.	9.87	9.77	9.98		1.8	0.2	-1.0	0.0
	484+36.	8.88	8.88	8.74		0.0	-0.5	-0.5	0.0
	484+42.	9.57	9.53	9.42		-1.3	0.8	-1.1	-1.0

	484+48.	9.34	9.37	9.38		-0.7	0.4	-1.8	0.0
	484+54.	9.65	9.66	9.44		-0.5	1.0	-1.0	0.0
182	488+50.	9.34	9.40	9.34		0.4	0.1	-1.6	0.0
	488+56.	8.49	8.49	8.46		-0.3	0.2	-1.2	-1.0
	488+62.	10.43	10.48	10.14		0.2	0.2	-1.5	0.0
	488+68.	9.51	9.47	9.64		-1.9	1.0	-1.3	0.0
	488+74.	9.72	9.77	9.73		1.8	0.2	-0.8	-1.0
	488+80.	9.01	8.97	8.97		-1.8	0.5	0.5	0.0
	488+86.	9.50	9.52	9.54		-0.8	0.8	0.1	0.0
	488+92.	9.65	9.57	9.52		0.5	0.5	0.1	-1.0
	488+98.	9.40	9.33	9.35		0.1	0.2	0.3	0.0
	489+04.	9.95	10.01	9.82		0.3	0.0	-0.2	-1.0
184	493+00.	8.97	8.97	8.89		0.5	0.9	-0.5	0.0
	493+09.	8.42	8.59	8.48		0.1	0.5	-1.4	0.0
	493+18.	9.29	9.20	9.21		0.6	-0.9	-1.7	0.0
	493+27.	10.62	10.63	10.52		0.3	1.4	0.0	-1.0
	493+36.	9.38	9.45	9.41		-0.5	0.5	0.0	-1.0
	493+45.	9.67	9.66	9.56		-0.8	1.3	0.7	0.0
	493+54.	9.55	9.50	9.54		1.3	0.7	0.0	0.0
	493+63.	9.65	9.59	9.58		1.5	1.0	0.1	-2.0
	493+72.	9.05	9.10	9.12		0.3	0.4	0.2	-1.0
	493+81.	9.57	9.45	9.45		-0.1	0.7	0.2	-1.0
186	497+50.	9.06	9.11	9.00		1.0	-0.5	-0.2	-1.0
	497+59.	8.56	8.64	8.53		-0.4	-0.9	-1.0	0.0
	497+68.	8.84	8.81	8.81		0.5	1.0	-0.7	0.0
	497+77.	9.46	9.43	9.49		-0.4	0.2	-0.7	0.0
	497+86.	10.13	10.07	10.09		-0.7	0.5	0.5	0.0
	497+95.	9.58	9.50	9.56		0.1	0.6	-1.3	0.0
	498+04.	10.08	10.10	10.07		-0.5	0.5	1.0	0.0
	498+13.	9.83	9.84	9.74		-0.8	0.7	-0.1	0.0
	498+22.	10.85	10.75	10.71		0.0	1.3	-0.8	0.0
	498+31.	9.87	9.91	9.87		-1.2	0.0	-1.3	0.0
189	504+50.	9.47	9.44	9.41		0.3	-1.0	-0.3	0.0
	504+54.5	9.40	9.39	9.38		0.6	1.2	0.2	0.0
	504+59.	9.94	9.92	9.78		-0.8	-0.1	-0.8	0.0
	504+63.5	9.69	9.65	9.56		-1.6	-1.5	-0.5	0.0
	504+68.	9.87	9.79	9.86		0.0	0.0	-2.2	0.0
	504+72.5	9.01	8.97	8.88		-0.1	-0.7	0.5	0.0
	504+77.	8.86	8.92	8.89		-0.2	0.7	-0.8	0.0
	504+81.5	9.59	9.47	9.45		0.2	-0.2	0.0	-1.0
	504+86.	9.16	9.14	8.91		1.2	0.1	-1.0	-1.0
	504+90.5	9.04	9.11	9.00		0.0	1.2	-0.8	0.0
191	510+50.	9.43	9.47	9.34		0.3	0.4	-0.6	-1.0
	510+56.	9.90	9.89	9.97		-0.1	0.3	-0.5	-1.0
	510+62.	10.17	10.13	9.99		0.7	-0.2	-0.5	0.0
	510+68.	8.96	9.01	8.96		0.2	0.3	0.0	-1.0
	510+74.	9.26	9.24	9.23		0.7	0.5	-0.1	0.0
	510+80.	9.22	9.23	9.12		-0.4	-1.0	-0.6	0.0

	510+86.	9.81	9.88	9.68		-1.0	-1.1	-1.0	0.0
	510+92.	9.59	9.59	9.57		1.5	-0.3	-0.8	-1.0
	510+98.	8.70	8.65	8.54		-1.8	0.1	-0.3	0.0
	511+04.	9.20	9.17	9.14		0.5	-0.5	-0.4	0.0

APPENDIX D:

CROSS SECTIONAL STRUCTURAL ANALYSIS

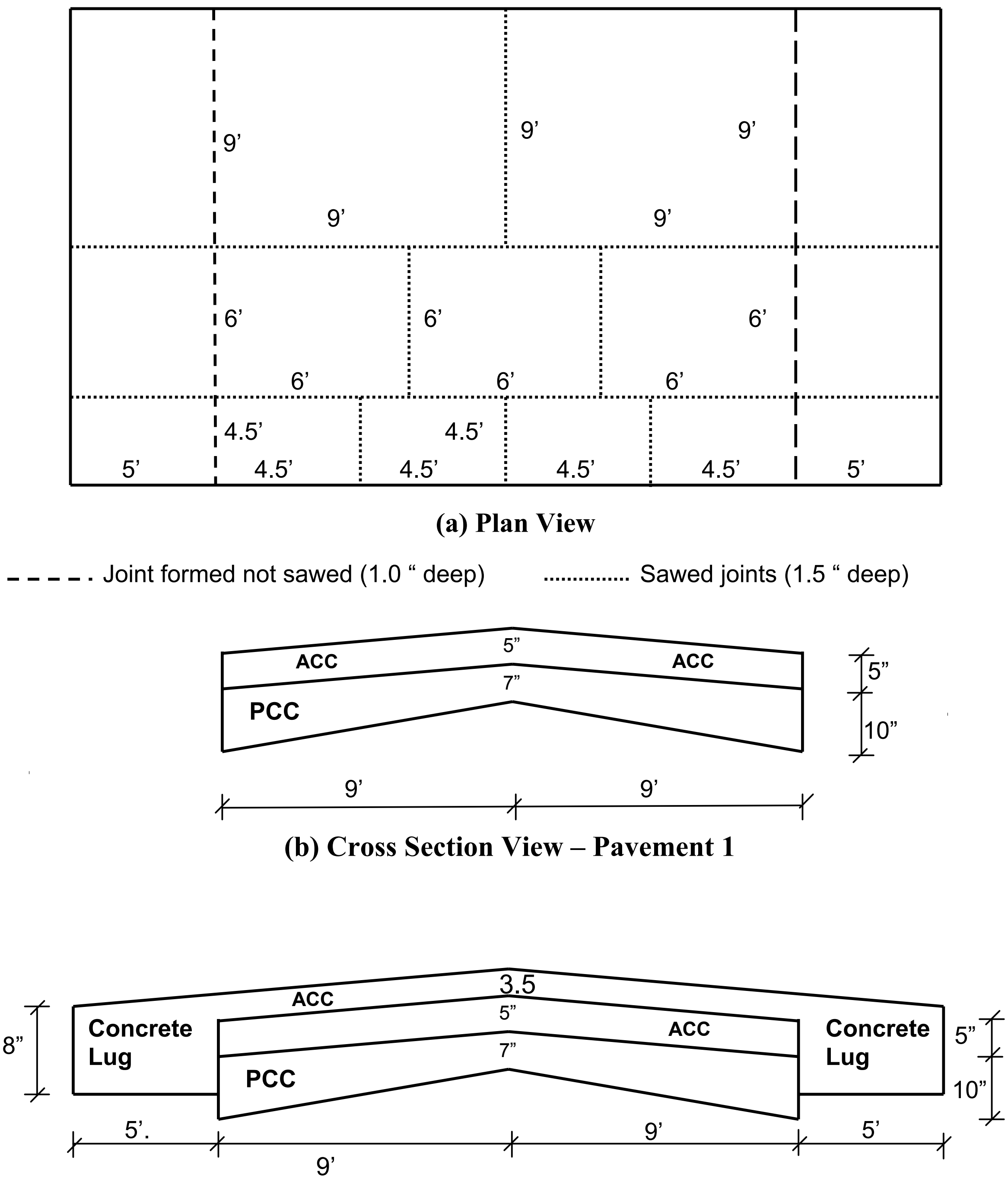
CROSS SECTIONAL STRUCTURAL ANALYSIS

DESCRIPTION OF THE COMPOSITE PAVEMENT

The cross section of the pavement on IA 13 is as shown in Figure D.1. The bottom portland cement concrete (PCC) layer consists of a thickened edge section that is 18 feet wide. This layer is 10 inches deep at each edge and 7 inches deep at the centerline and 40+ years old. Later this section was overlaid to a depth of 5 inches with asphalt cement concrete (ACC) over time during the 1970–1990s. During the summer of 2001, this overlaid and widened as shown in the figure with PCC. This consisted of 5-foot-wide by 8-inch-deep widening unit sections and an overlay of 3.5 inches of PCC in half the length of the project (9.2 miles) and 4.5 inches of PCC depth in the other half. Three different surface preparations (milling, patching, and ACC bond breaker) were used to prepare the ACC surface for the overlay and potential bonding. The PCC overlay and widening includes sections with three types of fiber reinforcement and some without reinforcement. In addition, there are three joint patterns on the PCC surface over the original pavement ACC overlay area. The 18-foot width is divided into 4.5-foot squares, 6-foot squares, or 9-foot squares. Furthermore, deformed reinforcing bars were added at the interface between the old and the concrete along the edges on some specific test sections. The pavement is provided with a two percent crown.

OBJECTIVE

The general profile of the cross section of the composite pavement shown in Figure D.1 appears to have a crown that could be considered to development of arch action. In this case, one can infer that the arch action, along with the confinement provided by the two concrete widening units along the edges of the original pavement result in reducing the loads transmitted to the original ACC and the PCC pavement sublayers. This conclusion seems to agree with basic structures behavior; however, more justification is needed to reinforce such a conclusion. The objective of this study was to develop analytical model(s) that can provide insight into the potential stress reduction in the two sublayers beneath the top PCC layer due to the arch action and the lateral confinement. In addition, a parametric study was conducted to investigate the factors that may affect, and ultimately improve the overall structural behavior of this type of composite pavement.



(a) Plan View

(b) Cross Section View – Pavement 1

(c) Cross Section View – Pavement 2

Figure D.1. Schematics of the Composite Pavement (Not to Scale)

APPROACH

The objectives of this work were attained utilizing a finite element analysis technique using the commercially available software ANSYS computer program [1]. The ANSYS software is a general-purpose finite element program that has been widely used to solve complex engineering problems.

The finite element analysis has proven to be a valuable tool in analyzing different types of structural systems. Unfortunately, due to several constraints, it was necessary that several assumptions and simplifications be made. However, it is believed that these had minimal impact on the overall accuracy and no impact on the conclusions developed. The analytical results summarized herein were based on the following modeling simplifications and assumptions:

- Elastic material properties.
- Existence of perfect bond between the different layers.
- No cracks in any of the layers exist.
- The top PCC layer is continuous.
- No dynamic load, i.e., no impact or moving loads will be considered.
- No reinforcing bars are included.
- Aggregate interlocking was neglected.

Finite Element Modeling and Calibration

The field test results of the two pavements shown in Figure D.1 were used to guide the finite element modeling to be used in analyzing the composite pavement. These results were obtained form the falling weight deflectmeter (FWD) tests performed on the composite pavements [2]. The FWD load was applied 2 feet away from the edge of the original 18 feet wide pavement and the deflections were measured at nine locations at a distance of 2 feet parallel to the pavement edge.

Modeling of the Composite Pavements

Solid “brick” elements were used to model the PCC and the ACC pavement components. The element has three translation degrees of freedom per node. In addition, the specific element utilized has an option to include extra shape functions that are needed to accurately account for the bending behavior of the pavement structure. The element size was selected to be 12 inches by 12 inches by *t* inches, where *t* is the thickness of the pavement components. Two elements through the thickness were used to model the bottom PCC pavement while the ACC and the top PCC were idealized using only one element through their thicknesses. In all cases, a 70-foot-long section of the pavement was modeled. This length was selected based on Saint Venant’s principle [3] to minimize the boundary conditions along the two ends of the selected sections. From hereafter, the pavement shown in Figure D.1a will be referred to as Pavement 1 while that shown in Figure D.1b will be referred to as Pavement 2.

In this work, a fictitious thin layer was added beneath the PCC layer resting on the soil. This was modeled with shell elements that are capable to model the behavior of plates on elastic foundation. Different soil sub-grade reactions ranging from 100 pci to 150 pci were investigated. This was considered since no FWD test results were performed on the soil at the pavement site. Similar shell elements were also added along the two sides of the 5-foot-widened section to investigate the effects of the confinement provided by soil along the side of the road.

A crack depth (joint) of one inch was considered along the two edges between the original and the widened pavement. Compression only springs were added to connect the middle part of the pavement and the 5-foot-widened sections. This type of element requires that an iterative solution be utilized until a converged solution is reached.

The finite element idealization of Pavements 1 and 2 are shown in Figures D.2 and D.3, respectively. The finite element model of Pavement 1 consisted of 6,580 elements and 9,017 nodes, while 11,482 elements and 12,283 nodes were utilized in the idealization of Pavement 2.

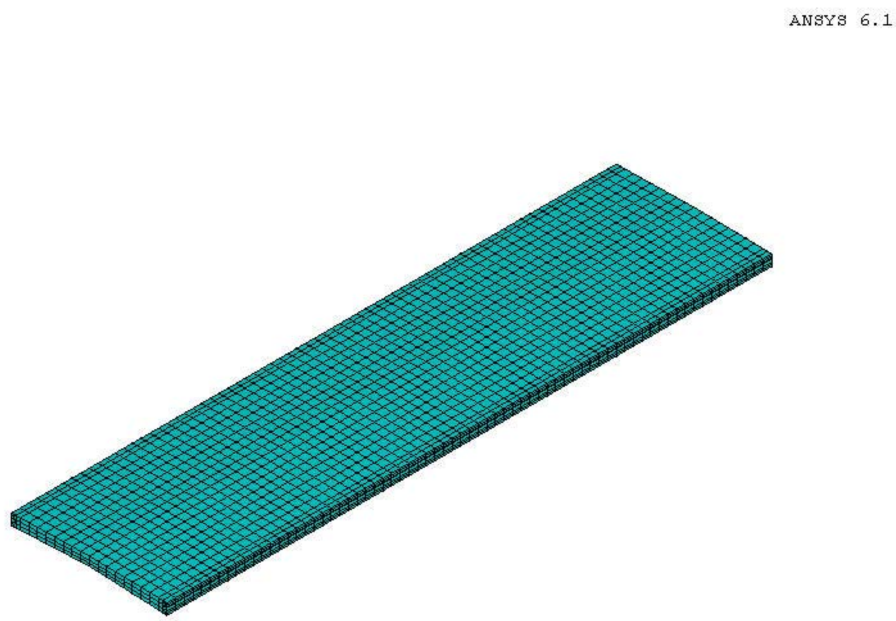


Figure D.2. Isometric View of Pavement 1 Finite Element Model

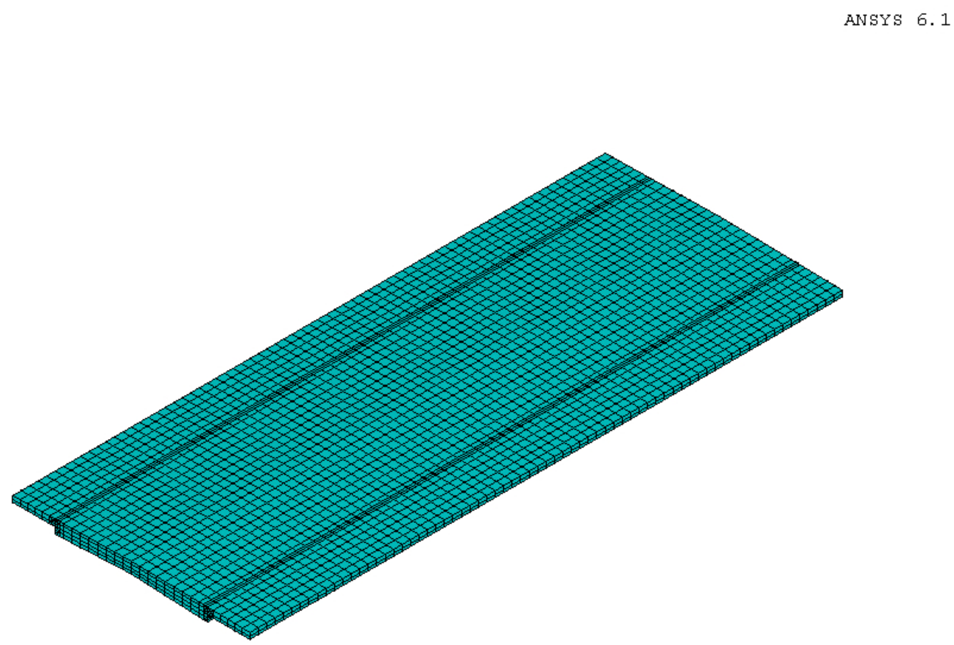


Figure D.3. Isometric View of Pavement 2

FINITE ELEMENT MODEL VS. FIELD TEST RESULTS

Figures D.4 and D.5 summarize the deflection results induced in the two pavement structures in the vicinity of the applied load considering different soil sub-grade reactions. Shown in Figure D.6 is a summary of the finite element results considering Pavement 1, Pavement 2, and without the two 5-foot-widened sections. These results were included here in to illustrate the effects of the two widening units on the deflection in Pavement 2. The solutions were carried out using different soil subgrade reactions.

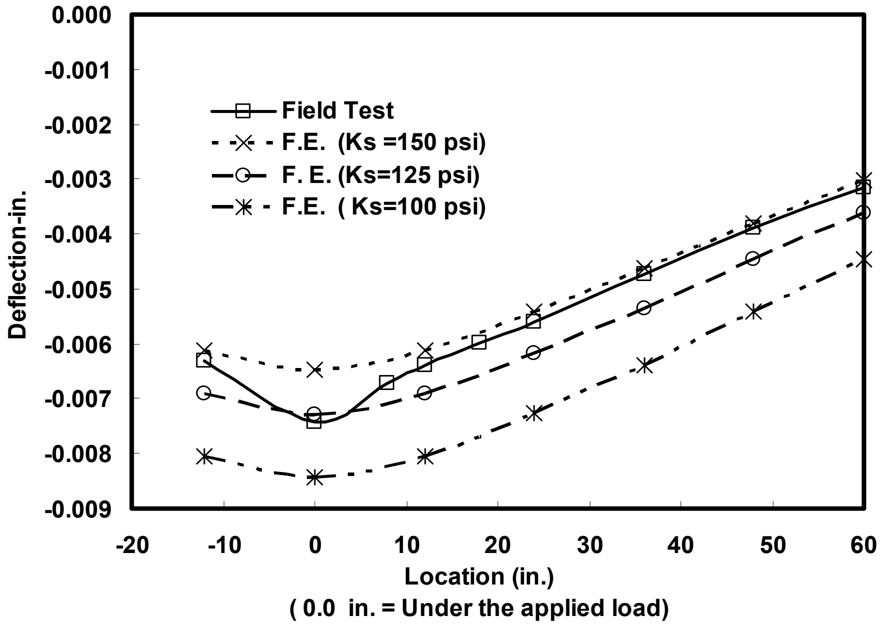


Figure D.4. Comparison between Field and Analytical Results for Pavement 1 (FWD Applied Near Edge)

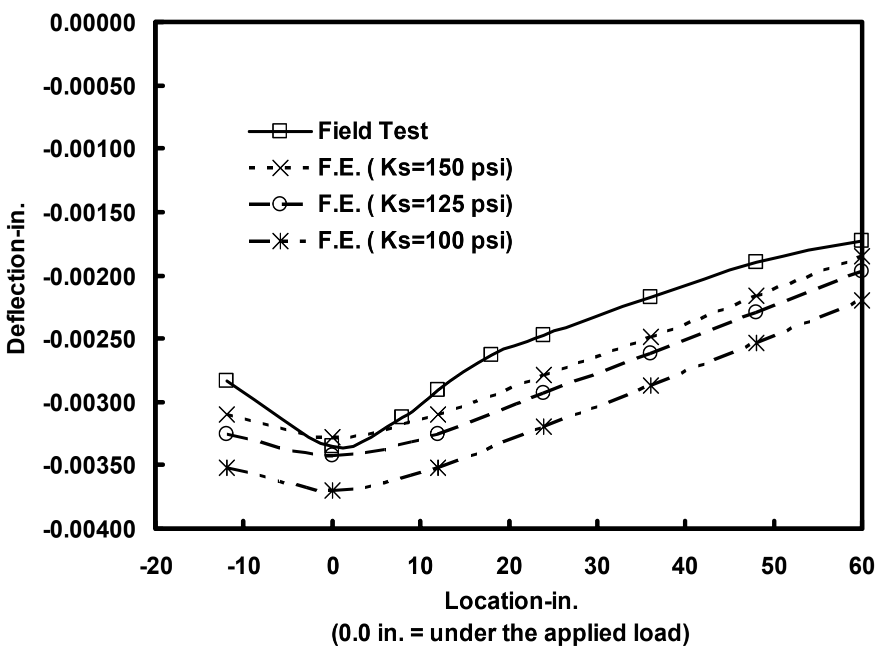


Figure D.5. Comparison between Field and Analytical Results for Pavement 2 (FWD Applied Near Edge)

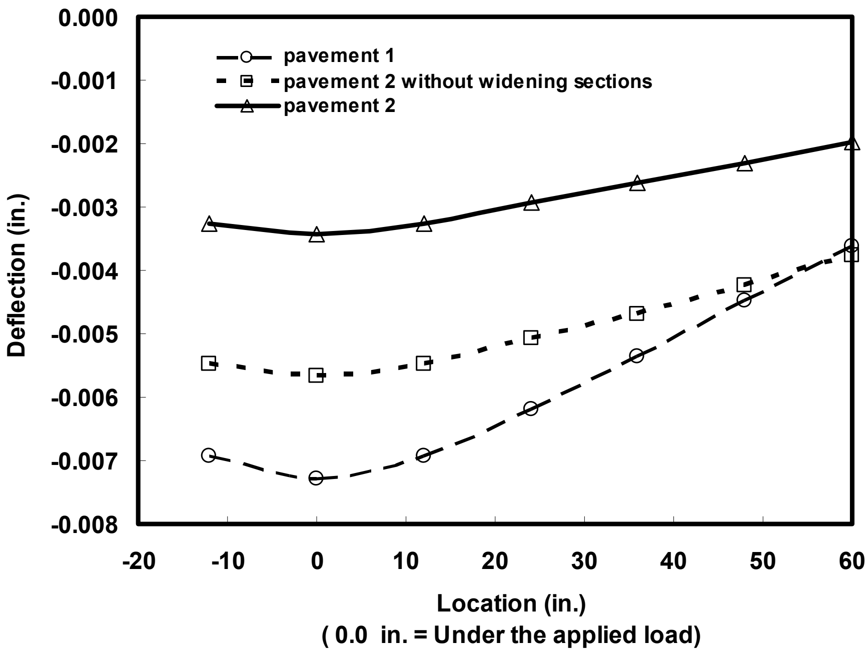


Figure D.6. Comparison between Field and Analytical Results for Pavement 2 without the Two Widening Units (FWD Applied Near the Edge)

As can be seen, the deflection distribution obtained from the finite element analyses generally follows the deflection profile of the field test. The slight discrepancy between the test and theoretical results can be attributed to the fact that the actual pavement material properties were not known, and/or not including the presence of cracks that may have existed in the pavement. However, since the differences were generally small, it was concluded that the utilized finite element models could accurately predict the deflections in the composite pavement.

Effects of the Two Widening Units

Comparing the results in Figure D.6 reveals that the addition of the two lugs reduced the deflection from 0.00765 to 0.00347 inches. On the other hand, the results summarized in Figure D.6 includes only the top PCC layer and excludes the two widening units reducing the maximum deflection from 0.00765 to 0.00492 inches. This illustrates that the two widening units provide confinement to the arch action due to the presence of the two percent crown resulting in reducing the deflection in the composite pavement.

Analysis of the Composite Pavements under Truck Loading

The two pavements illustrated in Figures D.1a and D.1b were analyzed considering the load illustrated in Figure D.7. Axel loads were applied as pressures on the elements that correspond to the tire locations. These pressures were calculated based on the load per tire and the area of element, i.e., 12 inches by 12 inches. The effects of the soil modulus, the crown, and the depth of the crack (joint) along the edges of the top PCC pavement were investigated.

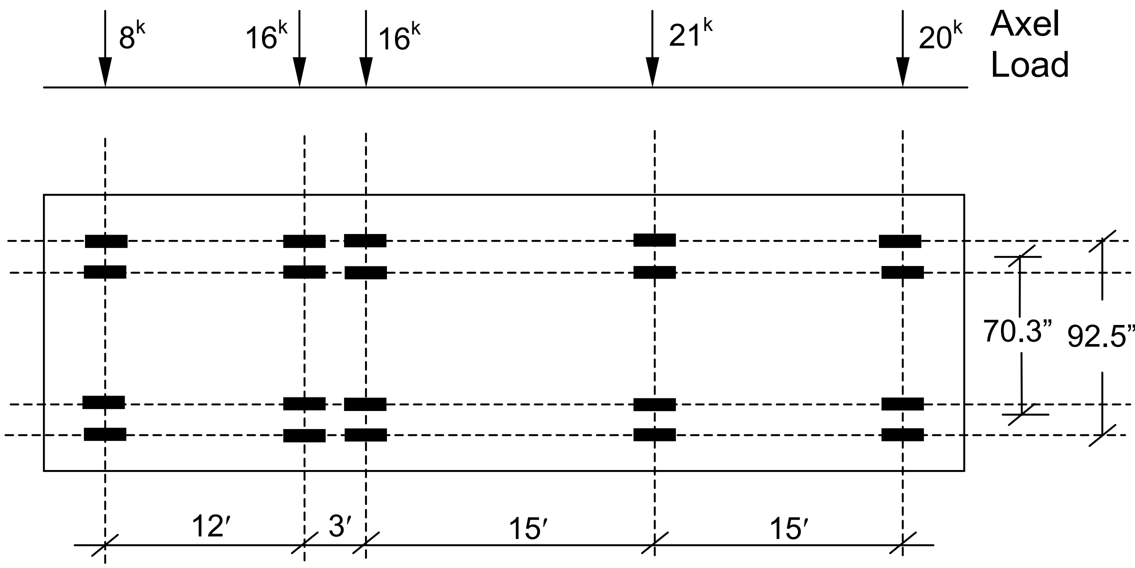
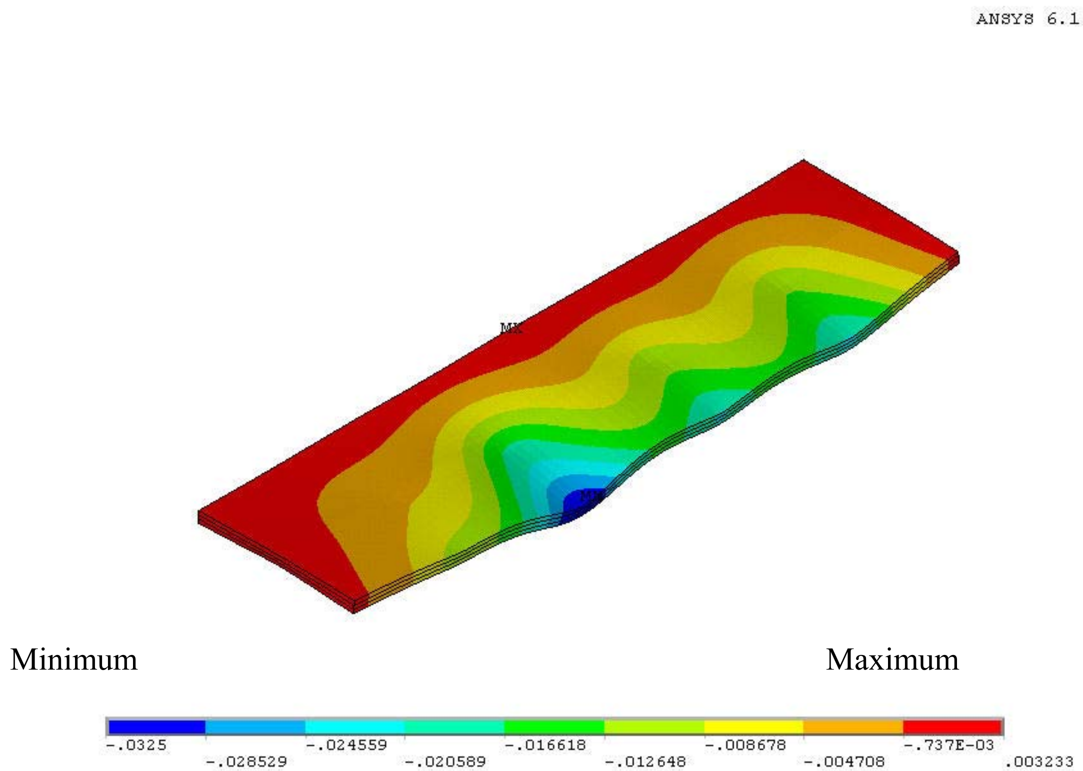


Figure D.7. Configuration of Truckload Used in Analysis

Deflection Results

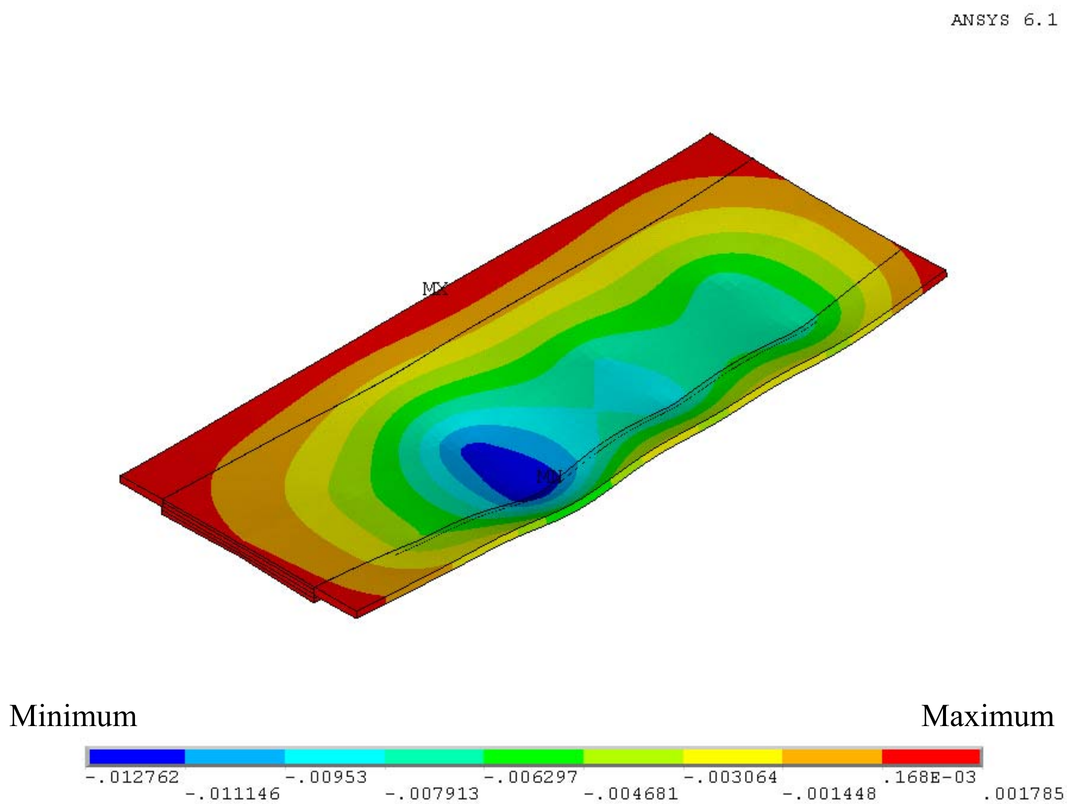
The two composite pavements were analyzed considering soil modulus of 75 and 150 pci, which were selected to represent two different seasons, i.e., spring and fall, respectively. In addition, a crack (joint) depth of one inch along the two edges of the original pavement was considered.

Table D.1 summarizes the predicted maximum deflections in Pavements 1 and 2. The different layers of the pavement are listed from top to bottom, i.e., in the following order: top PCC, ACC, and the PCC resting on the soil. The overall deflected shapes of the two pavements are shown in Figures D.8 and D.9, respectively. Notice that the maximum deflection is localized and occurs in the vicinity of the applied duel load near the pavement edge.



Note: Negative sign indicates downward deflection.

Figure D.8. Deformed Shape of Pavement 1 under Truckload Shown in Figure D.7 (Deflection Is Magnified)



Note: Negative sign indicates downward deflection.

Figure D.9. Deformed Shape of Pavement 2 under Truckload Shown in Figure D.7 (Deflection Is Magnified)

Table D.1. Maximum Deflections in the Composite Pavements

		Soil Subgrade = 75 pci		**Soil Subgrade = 150 pci**	
		Crown = 2%	**Crown = 3%**	**Crown = 2%**	**Crown = 3%**
(1)	(2)	(3)	(4)	(5)	(6)
Deflection (inches)	Pavement 1	0.0325	0.03240	0.0195	0.0194
	Pavement 2	0.0128	0.01279	0.0080	0.0078

Note: ( ) = column number.

Examining the results in Table D.1 reveals that increasing the crown from two percent to three percent resulted in an insignificant reduction in the deflection (compare columns 3 and 4 or columns 5 and 6 of Table D.1). Also, comparing columns 3 and 5 or 4 and 6 of Table D.1 demonstrates that a reduction of 40 percent was reached as the soil modulus was doubled. In addition, the results in Table D.1 show that the deflection in the composite pavement was reduced by 60 percent after adding the two 5-foot-widened sections (compare columns 3, 4, 5, and 6).

Stress and Strain Results

Tables D.2 and D.3 illustrate that there is an insignificant effect of the crown on the stresses induced in the pavements. This general trend can be seen in all layers of both composite pavements.

Table D.2. Effect of Soil Modulus K_s and the Crown on the Stresses in Composite Pavement 1

Stress Type	Layer	Crown	Transverse Stress (psi)			Longitudinal Stress (psi)		
			K_s = 75 pci	K_s= 150 pci	Percent Reduction	K_s = 75 pci	K_s = 150 pci	Percent Reduction
Compression	PCC	2%	—	—	—	—	—	—
	ACC		29	27	-6.90	56	47	-16.07
	PCC		55	50	-9.09	103	88	-14.56
Tension	PCC	2%	—	—	—	—	—	—
	ACC		10	11	10.00	28	24	-14.29
	PCC		68	65	-4.41	155	129	-16.77
Compression	PCC	3%	—	—	—	—	—	—
	ACC		29	28	-3.45	55	49	-10.91
	PCC		56	52	-7.14	102	87	-14.71
Tension	PCC	3%	—	—	—	—	—	—
	ACC		9.8	11	12.24	28	24	-14.29
	PCC		66	63	-4.55	156	130	-16.67

Note:

$$\% \text{ Reduction} = \frac{\text{stress associated with } K_s = 150 \text{ pci} - \text{stress associated with } K_s = 75 \text{ pci}}{\text{stress associated with } K_s = 75 \text{ pci}} * 100$$

Table D.3. Effect of Soil Modulus K_s on the Stress in Composite Pavement 2

Stress Type	Layer	Crown	Transverse Stress (psi)			Longitudinal Stress (psi)		
			K_s = 75 pci	K_s= 150 pci	Percent Reduction	K_s = 75 pci	K_s = 150 pci	Percent Reduction
Compression	PCC	2%	103	92	-10.68	73	64	-12.33
	ACC		23	23	0.00	9.6	8.5	-11.46
	PCC		8.5	8	-5.88	51	32	-37.25
Tension	PCC	2%	15	15	0.00	65	40	-38.46
	ACC		16	14	-12.50	9	5.5	-38.89
	PCC		74	66	-10.81	78	68	-12.82
Compression	PCC	3%	101	91	-9.90	73	64	-12.33
	ACC		23	22	-4.35	9.5	8.5	-10.53
	PCC		10	9	-10.00	49	31	-36.73
Tension	PCC	3%	13	14	7.69	66	41	-37.88
	ACC		15	13.7	-8.67	9	6	-33.33
	PCC		73	66	-9.59	79	69	-12.66

Note:

$$\%\ \text{Reduction} = \frac{\text{stress associated with } K_s = 150 \text{ pci} - \text{stress associated with } K_s = 75 \text{ pci}}{\text{stress associated with } K_s = 75 \text{ pci}} * 100$$

Tables D.2 and D.3 also show that in most cases, increasing the soil subgrade modulus resulted in reducing the stress in the transverse and longitudinal directions. These tables also show that there were slight increases in (about 12 percent) the stress in the transverse direction in the ACC pavement (see the shaded cells in Tables D.2 and D.3) as the sub-grade modulus was increased from 75 pci to 150 pci. This increase is insignificant since these values were very small compared to the typical pavement material compressive strengths.

The induced strains in Pavements 1 and 2 when subject to the truckload are summarized in Tables D.4 and D.5. Notice that the maximum tabulated compressive strain value is 72 microstrains and occurred in the ACC layer of Pavement 1. Table D.4 also illustrates that the maximum induced tensile strain was 50 microstrains and occurred in the bottom layer of Pavement 1. The maximum compressive and tensile strains induced in Pavement 2 were 29 and 25 microstrains, respectively.

Table D.4. Effect of Soil Modulus K_s and the Crown on Strains in Composite Pavement 1

Stress Type	Layer	Crown	Transverse Strain (με)			Longitudinal Strain (με)		
			K_s = 75 pci	K_s= 150 pci	Percent Reduction	K_s = 75 pci	K_s = 150 pci	Percent Reduction
Compression	PCC	2%	—	—	—	—	—	—
	ACC		31	30	-3.23	72	61	-15.28
	PCC		13.5	13.4	-0.74	33	27	-18.18
Tension	PCC	2%	—	—	—	—	—	—
	ACC		18	18.8	4.44	37	32	-13.51
	PCC		16.5	16.1	-2.42	50	42	-16.00
Compression	PCC	3%	—	—	—	—	—	—
	ACC		32	30	-6.25	72	61	-15.28
	PCC		14	13.5	-3.57	32	27	-15.63
Tension	PCC	3%	—	—	—	—	—	—
	ACC		18	18	0.00	37	32	-13.51
	PCC		16	16	0.00	50	42	-16.00

Note:

$$\%\ \text{Reduction} = \frac{\text{strain associated with } K_s = 150 \text{ pci} - \text{strain associated with } K_s = 75 \text{ pci}}{\text{strain associated with } K_s = 75 \text{ pci}} * 100$$

Table D.5. Effect of Soil Modulus K_s and the Crown on Strains in Composite Pavement 2

Stress Type	Layer	Crown	Transverse Strain (με)			Longitudinal Strain (με)		
			K_s = 75 pci	K_s= 150 pci	Percent Reduction	K_s = 75 pci	K_s = 150 pci	Percent Reduction
Compression	PCC	2%	27	24	-11.11	19.7	17.	-13.71
	ACC		29	28	-3.45	10.3	9.0	-12.62
	PCC		4	3.5	-12.50	16.5	10.3	-37.58
Tension	PCC	2%	8	7.8	-2.50	21	13	-38.10
	ACC		22	19.6	-10.91	11.6	7.2	-37.93
	PCC		21.5	19.0	-11.63	25	21.9	-12.40
Compression	PCC	3%	26.5	23	-13.21	19.6	17.0	-13.27
	ACC		27.8	27	-2.88	10.3	9.0	-12.62
	PCC		4.1	3.5	-14.63	16	10	-37.50
Tension	PCC	3%	7.4	7.2	-2.70	21.4	13.3	-37.85
	ACC		21.4	19	-11.21	12.1	7.5	-38.02
	PCC		21.4	19	-11.21	25.3	22	-13.04

Note:

$$\%\ \text{Reduction} = \frac{\text{strain associated with } K_s = 150 \text{ pci} - \text{strain associated with } K_s = 75 \text{ pci}}{\text{strain associated with } K_s = 75 \text{ pci}} * 100$$

Summarized in Tables D.6 and D.7 are the stresses in Pavement 1 and 2 considering two soils with different modules of elasticity. As can be noticed, there was a significant decrease in the longitudinal stresses induced in Pavement 2 when compared to similar stresses in Pavement 1. Including the two 5 feet widening sections results in reducing these stresses in each layer of the composite pavement. Similar observations can also be noticed when comparing the compressive stresses in the transverse direction. However, one may also notice that adding the two 5-foot-widened sections results in increasing the tensile stress in the transverse direction. The shaded cells in Tables D.6 and D.7 designate these locations.

Table D.6. Comparison between the Stresses in Pavements 1 and 2 (K_s = 75 pci)

Stress Type	Layer	Crown	Transverse Stress (psi)			Longitudinal Stress (psi)		
			Pavement		Percent Difference	Pavement		Percent Difference
			(1)	(2)		(1)	(2)	
Compression	PCC	2%	—	103	N/A	—	73	N/A
	ACC		29	23	-20.69	56	9.6	-82.86
	PCC		55	8.5	-84.55	103	51	-50.49
Tension	PCC	2%	—	15	N/A	—	65	N/A
	ACC		10	16	60.00	28	9.0	-67.86
	PCC		68	74	8.82	155	78	-49.68
Compression	PCC	3%	—	101	N/A	—	73	N/A
	ACC		29	23	-20.69	55	9.5	-82.73
	PCC		56	10	-82.14	102	49	-51.96
Tension	PCC	3%	—	13	N/A	—	66	N/A
	ACC		9.8	15	53.06	28	9.0	-67.86
	PCC		66	73	10.61	156	79	-49.36

Note:

% Difference = (stress in Pavement 2 - stress in Pavement 1) / (stress in Pavement 1)

Table 7. Comparison between the Stresses in Pavements 1 and 2 (K_s = 150 pci)

Stress Type	Layer	Crown	Transverse Stresses (psi)			Longitudinal Stresses (psi)		
			Pavement		Percent Difference	Pavement		Percent Difference
			(1)	(2)		(1)	(2)	
Compression	PCC	2%	—	92	N/A	—	64	N/A
	ACC		27	23	-14.81	56	8.5	-84.82
	PCC		50	8	-84.00	103	32	-68.93
Tension	PCC	2%	—	15	N/A	—	40	N/A
	ACC		11	14	27.27	28	5.5	-80.36
	PCC		65	66	1.54	155	68	-56.13
Compression	PCC	3%	—	91	N/A	—	64	N/A
	ACC		28	22	-21.43	55	8.5	-84.55
	PCC		52	9	-82.69	102	31	-69.61
Tension	PCC	3%	—	13.7	N/A	—	41	N/A
	ACC		11	13.7	24.55	28	6	-78.57
	PCC		63	66	4.76	156	69	-55.77

Note:
% Difference = (stress in Pavement 2 - stress in Pavement 1) / (stress in Pavement 1)

The above listed observations can be attributed to the structural behavior of the widened pavement. In general, the composite pavement behaves as a shallow shell structure supported on a elastic foundation. In the longitudinal direction, the structure follows beam theory. In this case, adding the top PCC and the two widened sections increase the overall section flexural rigidity. This results in reducing the longitudinal stresses. On the other hand, the effects of adding these two components on the induced transverse stress can be explained as follows. Figure D.10 illustrates the forces acting on s cross section of the composite pavement. As can be seen, the confinement force, *F*, provides a compression force in the transverse direction as well as a moment, *M* (see Figure D.10). Utilizing the principles of mechanics of material, the combination of these two forces would result in an increase in compressive and tensile stresses in the area of the pavement above and below the neutral axis, respectively.

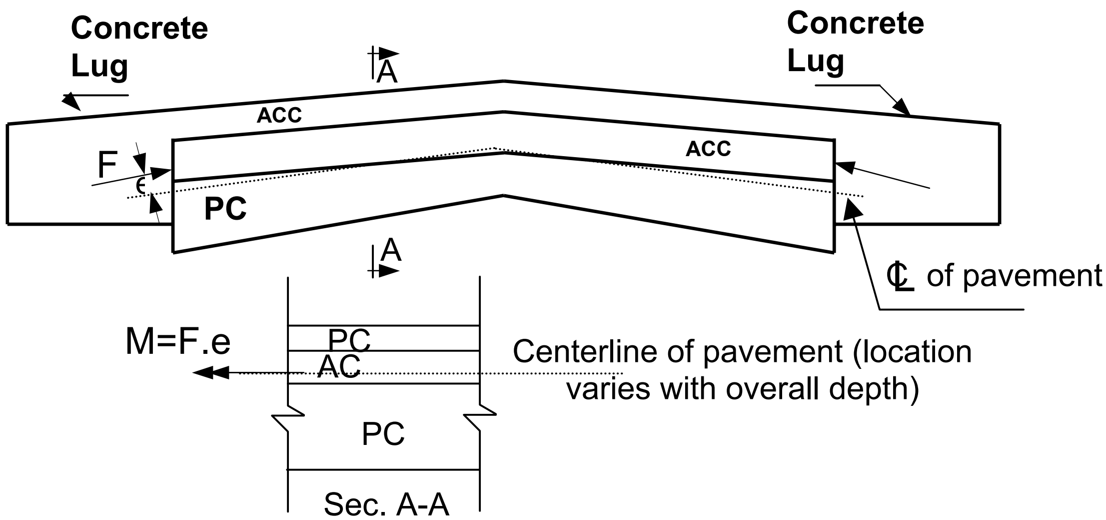


Figure D.10. Schematic Showing Forces Acting on Composite Pavement, Effect of Crack (Joint) Depth

The pavement in Figure D.1c was reanalyzed to investigate the effects of the crack depth along the edges of the top PCC pavement on the structural behavior of the composite pavement. Two different crack depths of one and two inches were considered, and the results of these analyses are summarized in Table D.8. The results demonstrated that there was an increase of 35 percent and 67 percent in the transverse and the longitudinal stresses, respectively, and in the ACC pavement when the crack depth was doubled. In addition, the compression and tension stresses induced in the top PCC layer were reduced as the crack depth was increased. This is due to the fact that this layer is acting as a free plate supported on a rigid foundation that is provided by the ACC and the Bottom PCC layers. Table D.8 also illustrates that there were insignificant changes in the stresses in the other layers of the composite pavement.

Table D.8. Effect of Crack (Joint) Depth on the Stress in Composite Pavement 2 (K_s = 75 pci and Crown = 2%)

Stress Type	Layer	Transverse Stresses (psi)			Longitudinal Stress (psi)		
		Crack Depth		Percent Change	Crack Depth		Percent Change
		1 inch	2 inches		1 inch	2 inches	
Compression	PCC	103	93	-9.71	73	71	-2.74
	ACC	23	31	34.78	9.6	16	66.67
	PCC	8.5	8.0	-5.88	51	52	1.96
Tension	PCC	15	9.1	-39.33	65	65	0.00
	ACC	16	17	6.25	9	9.5	5.56
	PCC	74	77	4.05	78	79	1.28

Note:

$$\% \text{ Change} = \frac{[\text{stress associated with a crack depth 2 in.} - \text{stress associated with a crack depth 1 in.}]}{\text{stress associated with a crack depth 1 in.}} x100$$

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Two types of composite pavements subjected to a truckload were analyzed utilizing static and elastic finite element idealizations. The analyses considered the effects of the soil subgrade reaction, the crown and other parameters on the overall structural behavior of the pavements. The results illustrated that adding two widening sections and a PCC overlay resulted in significant reduction in the deflection and the stresses in the original composite pavement. This was due to the increase in the flexural rigidity of the pavement section and the presence of the arch action along with the confinement force provided by the two widening sections.

Future work should account for the non-linear behavior of the different components of the pavement material. The effect of the cracks, bond, and aggregate interlocking should be addressed in the future since these may have dominated effects on the structural behavior of this type of pavement.

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