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Thin Bonded Overlay Evaluation

Final Report
June 2001

Sponsored by the
Iowa Department of Transportation
Project Development Division,
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the Iowa Highway Research Board

Iowa Department of Transportation

Iowa DOT Project HR-559

REPORT

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FHWA Work Order No. DTFH71-94-TBL-IH-37

Iowa State University of Science and Technology
Department of Civil and Construction Engineering

DISCLAIMER

"The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Project Development Division of the Iowa Department of Transportation nor the United States Department of Transportation, Federal Highway Administration."

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This work was done under the support of the U.S. Department of Transportation, Federal Highway Administration (FHWA) Work Order Number DTFH71-94-TBL-IH-37 through the Iowa Department of Transportation (Iowa DOT), and the Iowa Highway Research Board (IHRB) as Project HR-559.

Project design and data collection were the result of the efforts of many persons at the Iowa DOT Central Materials, Design and Resident Construction Office in Cedar Rapids, Civil and Construction Engineering Department (CCE) at Iowa State University (ISU), the Statistics Department at Iowa State University, ERES Consultants and the Manatts Inc. concrete paving company. It would not have been possible without the assistance of John Hart of the Iowa Department of Transportation (Iowa DOT), and Tom Ciha of ISU. It has provided a learning experience for other students involved in the construction and monitoring including Marcia McCarthy, Tom Powers, and Adnan Ali. The project resulted in moving 2 students into the pavement area of transportation for a career. It also assisted approximately 12 other undergraduates in a better understanding of concrete pavement construction and into considering pavements for their area of interest prior to graduation.

This project is a great example of the research that is made available by the cooperation between the Iowa DOT, the Iowa Concrete Paving Association, and the department of Civil and Construction Engineering at ISU. Each party had faith in the abilities of the others and worked to extend the knowledge gained in the area of ultrathin overlays by the American Concrete Paving Association in Kentucky. It is another example of how Iowa is striving to lead in the area of portland cement concrete pavement research and development.

ABSTRACT

In 1994 the Iowa Department of Transportation constructed a 7.2-mile Portland Cement Concrete overlay project in Iowa County on Iowa Highway 21. The research work was conducted in cooperation with the Department of Civil Engineering and the Federal Highway Administration under the Iowa Highway Research Board project HR-559. The project was constructed to evaluate the performance of an ultrathin concrete overlay during a 5-year period.

The experiment included variables of base surface preparation, overlay depth, joint spacing, fiber reinforcement, and the sealed or non-sealed joints. The project was instrumented to measure overlay/base interface temperatures and strains. Visual distress surveys and deflection testing were also used to monitor performance. Coring and direct shear testing was accomplished 3 times during the research period.

Results of the testing and monitoring are identified in the report. The experiment was very successful and the results provide an insight into construction and design needs to be considered in tailoring a portland cement concrete overlay to a performance need. The results also indicate a method to monitor bond with nondestructive methods.

Key Words: PCC overlay, ultrathin overlay, whitetopping

1. INTRODUCTION

1.1 Background

Portland cement concrete (PCC) whitetopping has been an effective method of pavement rehabilitation for many years. Whitetopping has been shown to provide improved structural capacity, increased life, and reduced maintenance, with lower total costs compared to asphalt cement concrete (ACC) pavement resurfacing. In addition, whitetopping improves safety by eliminating rutting and providing an excellent skid resistant surface and light reflectance. Environmental benefits are also realized through the use of whitetopping.

In recent years, ultra-thin whitetopping (UTW) has emerged as an alternative to traditional whitetopping. UTW is a process that involves placing a thin layer (2 to 4 inches) of PCC over an existing ACC pavement (so as not to confuse with unbonded overlays). Reduced PCC thickness and closer joint spacings distinguish UTW from traditional whitetopping.[1]

Initial UTW projects have enabled researchers to identify key elements responsible for the successful performance of UTW. These key elements include foundation support, interface bonding condition, PCC thickness, synthetic fiber reinforcement usage, and joint spacing.[2] The interface bonding condition is the most important of these elements because it enables the pavement to act as a composite structure, thus reducing tensile stress and allowing an ultra-thin PCC overlay to perform adequately.[3] Although the key elements affecting UTW performance have been identified in previous research, neither the impact that external variables have on the elements nor the element interaction, have been thoroughly investigated.

1.2 Objective of Research

The objective of this research was to investigate the interface bonding condition between an ultra-thin PCC overlay and an ACC base over time, considering the variables of ACC surface preparation, PCC thickness, synthetic fiber reinforcement usage, and joint spacing.

1.3 Research Approach

Laboratory testing and full-scale field testing were used to accomplish the research objective. Laboratory testing involved monitoring interface strains in fabricated PCC/ACC composite beams subjected to either static or dynamic flexural loading.

Field variables investigated included ACC surface preparation, PCC thickness, and synthetic fiber reinforcement usage. Field testing involved monitoring interface strains and temperatures, falling weight deflectometer (FWD) deflection responses, direct shear strengths, and distresses on a 7.2-mile Iowa DOT UTW project. Variables investigated included ACC surface preparation, PCC thickness, synthetic fiber reinforcement usage, and joint spacing.

2. TESTING PROGRAM

2.1 Laboratory Testing

Laboratory testing involved monitoring interface strains in fabricated PCC/ACC composite beams subjected to either static or dynamic flexural loading. Variables investigated included ACC surface preparation (milled or not milled), PCC thickness (2 or 4 inches), and synthetic fiber reinforcement usage (fiber or no fiber). Joint spacing was not evaluated in the laboratory testing. A total of 64 PCC/ACC composite beams were constructed. Half of the beams were used for static testing and half were used for dynamic testing. The static and dynamic test groups consisted of 8 sets of 4 beam groupings. The groupings were representative of the different variable combinations. Figure 2.1 illustrates the static and dynamic test groups and their beam groupings.

2.1.1 Beam Fabrication

Beam fabrication took place in Spangler Geotechnical Laboratory at Iowa State University. Fabrication of the beams involved designing the ACC and PCC mixes, mixing and placing the ACC, making and installing the deflectometers, and mixing and placing the PCC. Standard beam molds that were 6 inches wide by 6 inches deep by 36 inches long were used when fabricating beams with 2 inches of PCC. When beams with 4 inches of PCC were fabricated, standard beam molds were used with 2-inch wood extensions for added depth.

The materials and mix designs selected were similar to those used in the field testing. Mixing and placement of the ACC was accomplished by hand. The ACC was placed in 4 lifts, resulting in a thickness of approximately 3.75 inches. Deflectometers were fabricated

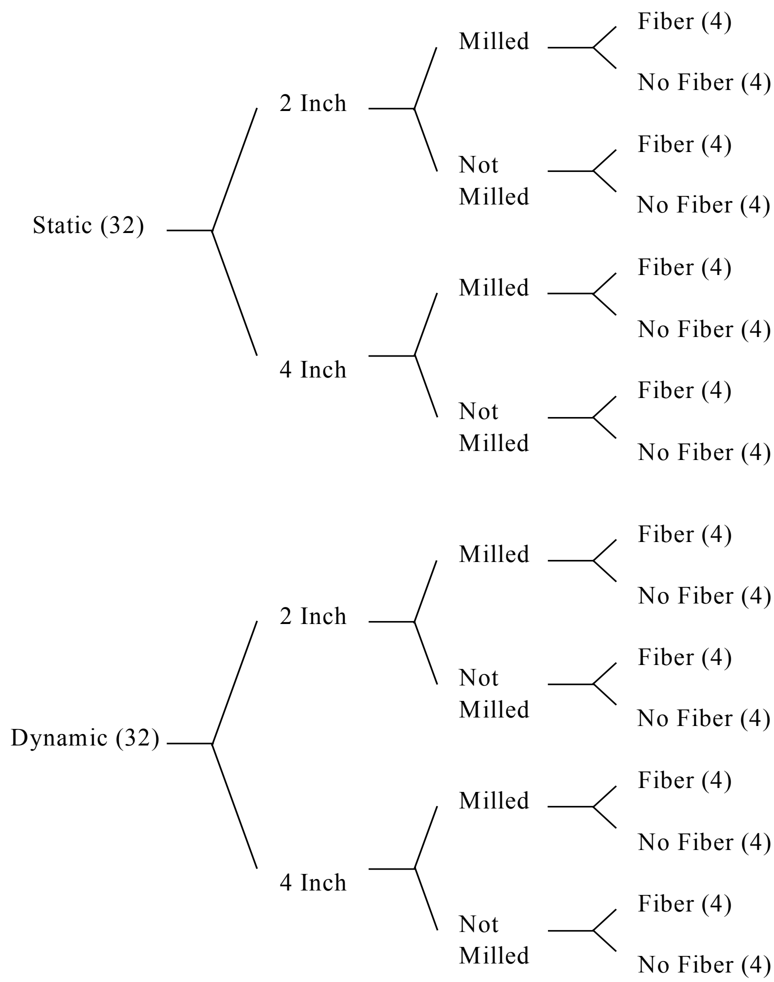


Figure 2.1 Static and Dynamic Test Groups and Their Beam Groupings

devices used to measure strains. Each deflectometer consisted of a 4 inch long by 0.5 inch wide piece of 26 gage steel, 2 Micro-Measurement type CEA-06-125-UN-120 strain gages, two 10-foot segments of AT&T shielded telephone wire, a 1 inch cube of aluminum tubing, a 1.5 inch long piece of 0.125 inch diameter thread-all, and four 0.125 inch diameter nuts. Figure 2.2 details the dimensions of the steel piece and location of the strain gages. Figure 2.3 shows an assembled deflectometer. Two deflectometers were installed in each beam.

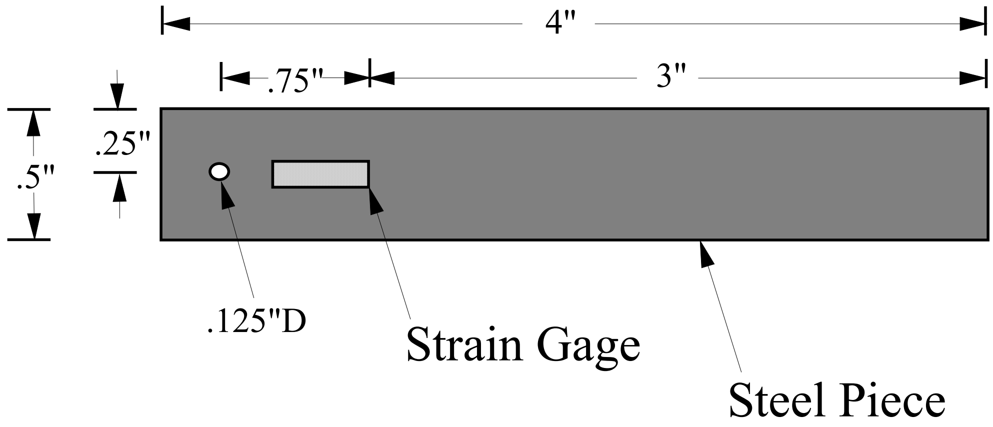


Figure 2.2 Location of Strain Gages on a Steel Piece

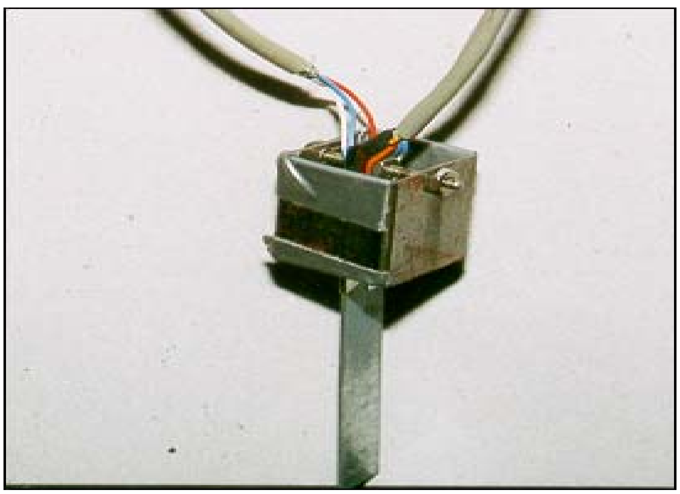


Figure 2.3 Assembled Deflectometer

The deflectometers were placed vertically in epoxy filled holes with the faces of the steel piece parallel to the ends of the beam. The holes were 3 inches deep, 0.75 inches in diameter, 6 inches on center from the ends of the beam, and centered across the width of the beam. Figure 2.4 provides a schematic of an installed deflectometer prior to PCC placement. Figure 2.5 shows the installed deflectometers prior to PCC placement. Mixing of the PCC was

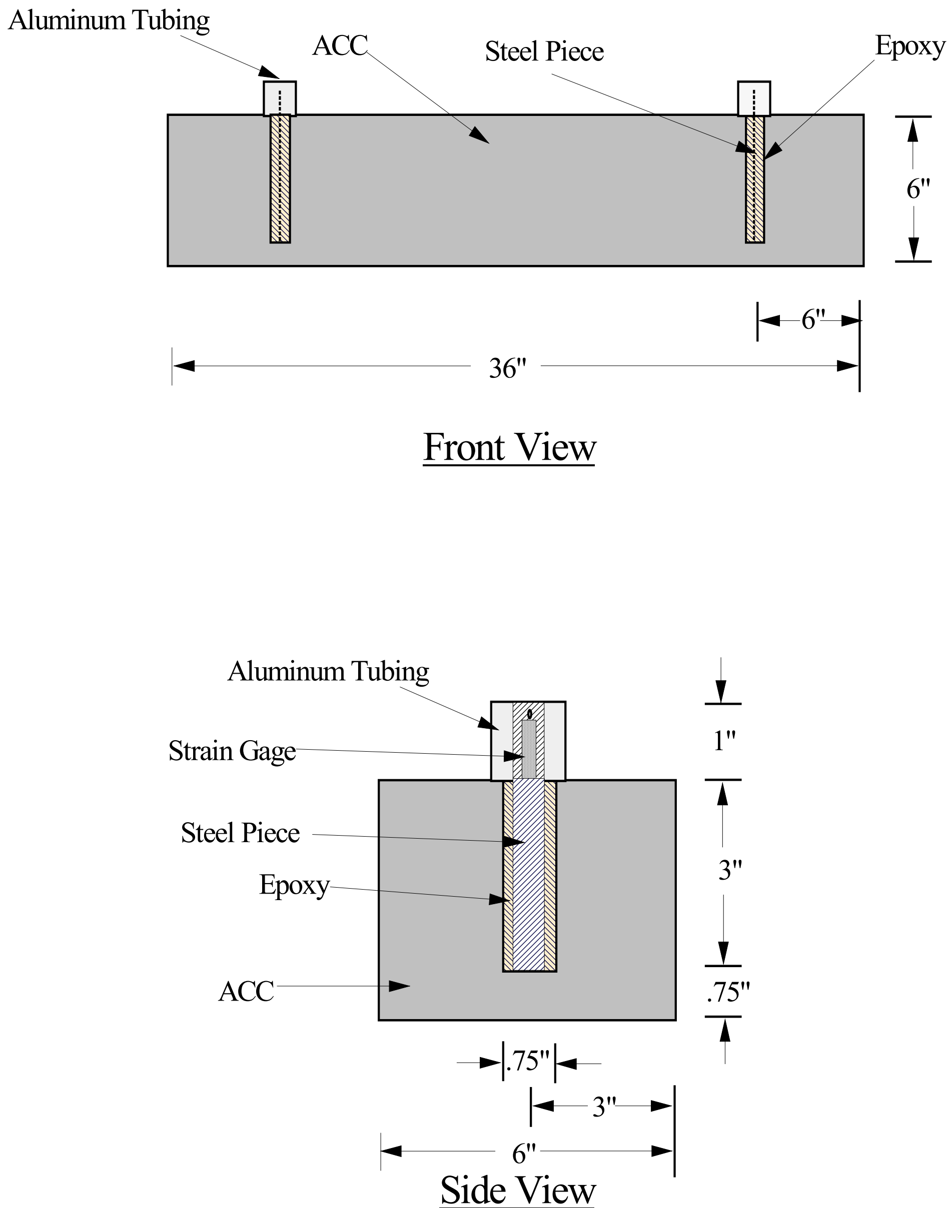


Figure 2.4 Schematic of an Installed Deflectometer Prior to PCC Placement

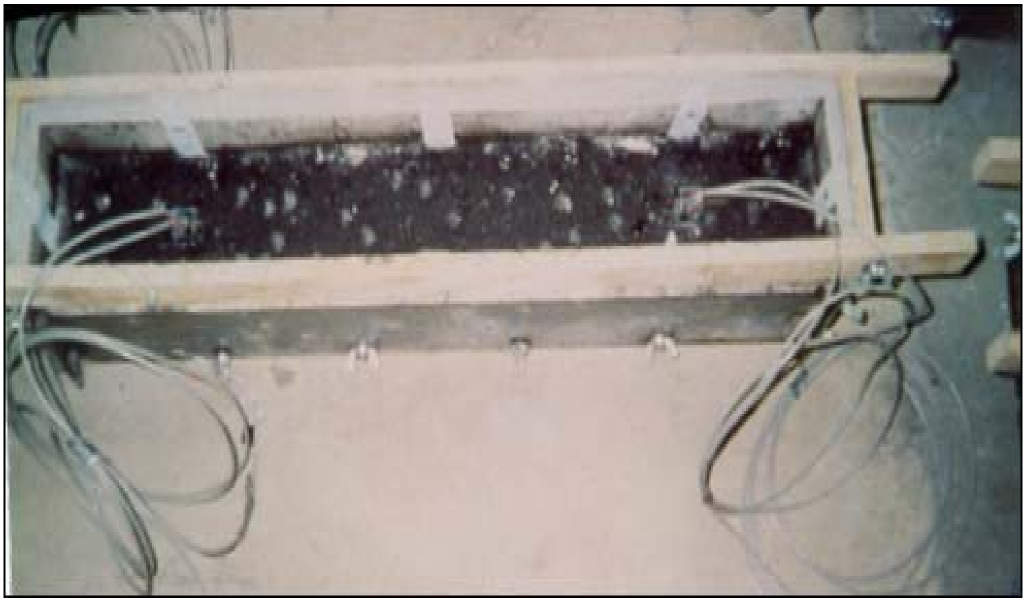


Figure 2.5 Installed Deflectometers Prior to PCC Placement

accomplished using a drum mixer. The PCC was placed by hand and consolidated with the use of a vibrating table. All PCC was placed in 1 lift, resulting in a thickness of approximately 2 or 4 inches. Beam molds were removed after at least 1 day of curing.

2.1.2 Testing Device

Testing was conducted in the ISU Aerospace Testing Laboratory using a device consisting of a 55 kip Materials Testing System (MTS) capable of static or dynamic loading, a 3-part loading frame, and a data acquisition system (DAS). The MTS and the 3-part loading frame were used to impart the load onto the beams and the DAS was used to control and monitor testing. The same testing device was used for static and dynamic testing.

The MTS had a fixed top load head and a moving bottom load head. The moving bottom load head allowed for loads to be imparted onto the beam and deflections to be measured. The 3-part loading frame consisted of 2 steel base plates and a solid steel cage.

Figure 2.6 shows the MTS and the 3-part loading frame. The DAS consisted of a personal computer, a MTS control and data recording program, and a Vishay voltage amplifier.

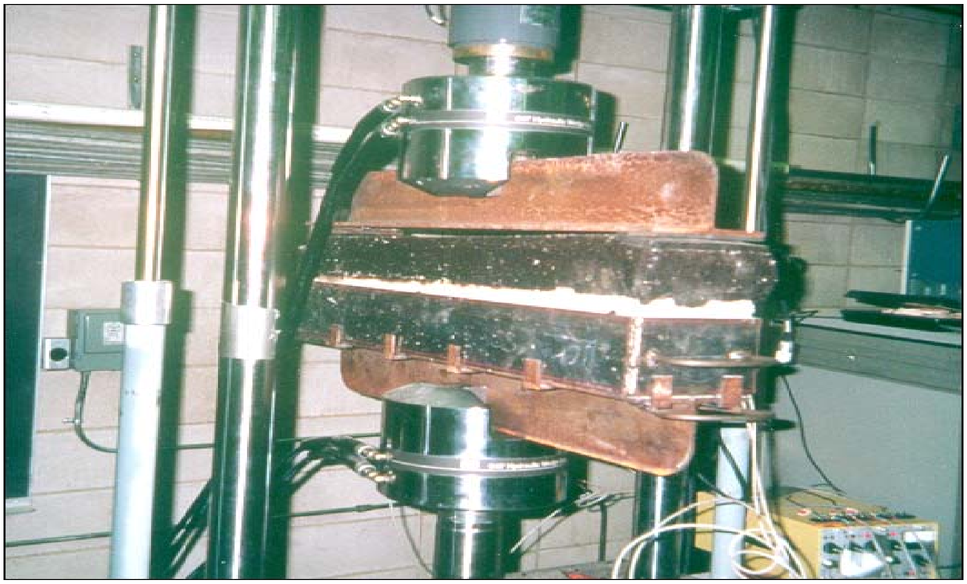


Figure 2.6 MTS and Three-Part Loading Frame

2.1.3 Static Testing

Static testing was conducted prior to dynamic testing. The primary objective of static testing was to determine the appropriate load magnitudes to be used for dynamic testing for each beam grouping. Secondary objectives of static testing included monitoring interface strains during loading and visually observing failure modes.

Static testing began by aligning the base plates and then gripping their flanges with the load head clamps. A neoprene covered roller pin was positioned on the bottom base plate. The beam was placed squarely onto the bottom base plate with the PCC in contact with the neoprene covered pins. Initial attempts to place the beams with the ACC on the bottom resulted in the ACC failing in tension while being handled. A neoprene covered roller pin was positioned on the ACC and then the bottom load head was raised until contact was initiated between the ACC and the pins of the top base plate. Strain gages were connected and balanced. The MTS control and data recording program was then used to apply a constant rate of deflection of 0.05 inches per second until failure occurred.

2.1.4 Dynamic Testing

Dynamic testing was conducted after static testing had been completed and the appropriate load magnitudes for each beam grouping had been determined. The primary objective of dynamic testing was to monitor interface strains at varying levels of load repetitions. A secondary objective of dynamic testing was to visually observe failure modes if they occurred.

The beam placement procedure used in the static testing was also used in dynamic testing with the exception that the loading cage was placed around the beam after the beam had been placed onto the bottom base plate and that a preloading of 30 to 40 pounds was applied when contact was initiated. The cage and preloading helped to prevent the beam and roller pins from shifting during loading. The MTS control and data recording program was used to apply an oscillating load. The load was applied for 0.05 seconds and then removed for 0.05 seconds. This timing was selected to simulate loading of traffic traveling over a 3-foot length of pavement at 60 mph. At increments of 10,000 applied repetitions, the MTS control and data recording program automatically stopped applying the oscillating load and initiated a ramp load. The ramp load was applied or removed at a constant rate of 20 pounds

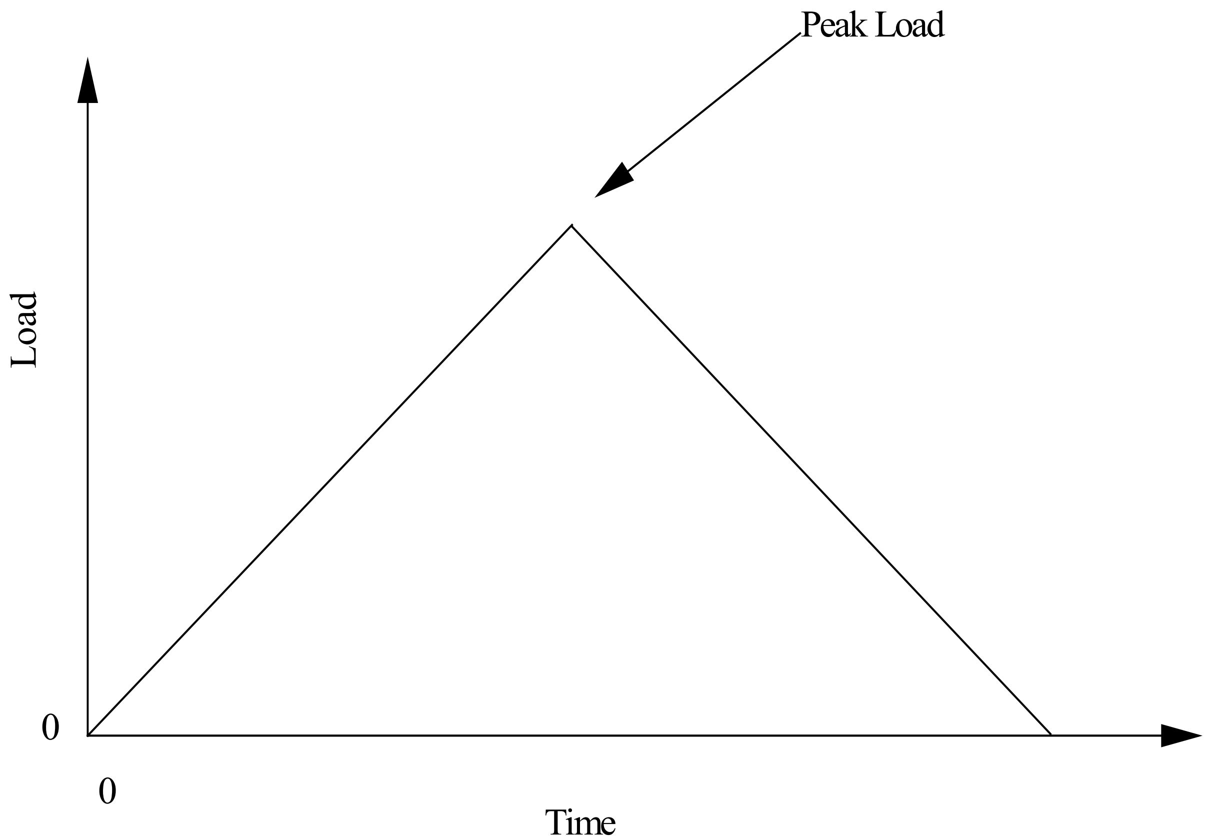


Figure 2.7 Ramp Load Application

per second. Figure 2.7 depicts the ramp load application. Table 2.1 shows the oscillating and peak ramp load magnitudes used for each beam grouping. Strains were only measured during ramp loading. This sequence was continued until failure occurred or 100,000 repetitions were applied.

Table 2.1 Oscillating and Peak Ramp Load Magnitudes for Each Beam Grouping

Beam Grouping	Oscillating Load (lbs.)	Peak Ramp Load (lbs.)
2, M, F	190	174
2, NM, F	230	231
2, NM, N	210	196
2, NM, N	-	-
4, M, F	925	385
4, M, N	950	422
4, NM, F	900	407
4, NM, N	1,100	452

2 = 2-inch PCC   NM = not milled
4 = 4-inch PCC   F = fibers
M = milled   N = no fibers

2.2 Field Testing

Field testing involved monitoring interface strains and temperatures, FWD deflection responses, direct shear strengths, and visual distresses on an UTW project. Variables investigated included ACC surface preparation (milled, patch only, or cold in place recycle (CIPR)), PCC thickness (2, 4, 6, or 8 inches), synthetic fiber reinforcement usage (fiber or no fiber), and joint spacing (2, 4, 6, or 12 foot square panels). The UTW project consisted of 65 sections, including 35 test, 27 transition, and 3 control sections. Variables remained constant in test sections and were 200 to 2700 feet in length with most sections being 700 feet long. Transition sections were located between test sections and allowed for changes in variables to occur. Control sections consisted of conventional ACC overlays. Table 2.2 shows the section locations and design properties. Table 2.3 shows a comparison of design properties for several UTW projects.

Table 2.2 Section Locations and Design Properties

Section Number	Section Type	Station	PCC Thickness (in.)	Synthetic Fiber Usage	Joint Spacing (ft. X ft.)	ACC Surface Preparation
1	Recon.	2335+64 - 2340+00	8	N	20 X 12	-
2	Trans.	2340+00 - 2342+00	8 - 6	N, F	12 X 12	Milled
3	Test	2342+00 - 2349+00	6	F	12 X 12	Milled
4	Test	2349+00 - 2356+00	6	F	6 X 6	Milled
5	Trans.	2356+00 - 2357+00	6 - 4	F	6 X 6	Milled
6	Test	2357+00 - 2364+00	4	F	6 X 6	Milled
7	Test	2364+00 - 2371+00	4	F	2 X 2	Milled
8	Test	2371+00 - 2378+00	4	F	4 X 4	Milled
9	Trans.	2378+00 - 2380+00	4 - 2	F	2 X 2	Milled
10	Test	2380+00 - 2387+00	2	F	2 X 2	Milled
11	Test	2387+00 - 2394+00	2	M	4 X 4	Milled
12	Trans.	2394+00 - 2396+00	2 - 6	M	4 X 4, 6 X 6	Milled
13	Test	2396+00 - 2403+00	6	M	6 X 6	Milled
14	Test	2403+00 - 2414+00	6	M	12 X 12	Milled
15	Trans.	2414+00 - 2415+00	6 – 4.5	F	12 X 12, 6 X 6	Milled
16	Control	2415+00 - 2425+00	4.5 (1)	-	-	Milled
17	Trans.	2425+00 - 2426+00	4.5 - 6	N	6 X 6, 12 X 12	Milled
18	Test	2426+00 - 2433+00	6	N	12 X 12	Milled
19	Test	2433+00 - 2440+00	6	N	6 X 6	Milled
20	Trans.	2440+00 - 2441+00	6 - 4	N	6 X 6, 2 X 2	Milled
21	Test	2441+00 - 2448+00	4	N	2 X 2	Milled
22	Trans.	2448+00 - 2449+00	4 - 2	N	2 X 2	Milled
23	Test	2449+00 - 2456+00	2	N	2 X 2	Milled
24	Trans.	2456+00 - 2458+00	2 - 6	N	2 X 2, 6 X 6	Milled
25	Test	2458+00 - 2460+00	6	N	6 X 6	Milled
26	Test	2460+00 - 2468+00	6	N	6 X 6	Patch Only
27	Test	2468+00 - 2479+00	6	N	12 X 12	Patch Only
28	Trans.	2479+00 - 2480+00	6 - 4	N	12 X 12, 4 X 4	Patch Only
29	Test	2480+00 - 2487+00	4	N	4 X 4	Patch Only
30	Trans.	2487+00 - 2489+00	4 - 8	N	4 X 4, 15 X 12	Patch Only
31	Test	2489+00 - 2496+00	8	N	15 X 12	Patch Only
32	Test	2496+00 - 2503+00	8	N	15 X 12 D	Patch Only
33	Trans.	2503+00 - 2505+00	8 – 4.5	N	15 X 12, 6 X 6	Patch Only
34	Control	2505+00 - 2515+00	4.5 (1)	-	-	Patch Only
35	Trans.	2515+00 - 2516+00	4.5 - 6	N	4 X 4, 6 X 6	Patch Only
36	Test	2516+00 - 2538+00	6	N	6 X 6	Patch Only
37	Trans.	2538+00 - 2540+00	6 - 2	N, F	6 X 6, 2 X 2	Patch Only
38	Test	2540+00 - 2547+00	2	F	2 X 2	Patch Only
39	Test	2547+00 - 2554+00	2	F	4 X 4	Patch Only

Table 2.2 Section Locations and Design Properties (continued)

Section Number	Section Type	Station	PCC Thickness (in.)	Synthetic Fiber Usage	Joint Spacing (ft. X ft.)	ACC Surface Preparation
40	Trans.	2554+00 - 2555+00	2 - 4	F	4 X 4	Patch Only
41	Trans.	2555+00 - 2562+00	4	F	4 X 4	Patch Only
42	Test	2562+00 - 2569+00	4	F	2 X 2	Patch Only
43	Test	2569+00 - 2576+00	4	F	6 X 6	Patch Only
44	Trans.	2576+00 - 2577+00	4 - 6	F	6 X 6, 12 X 12	Patch Only
45	Test	2577+00 - 2585+00	6	F	12 X 12	Patch Only
46	Test	2585+00 - 2593+00	6	F	6 X 6	CIPR
47	Trans.	2593+00 - 2594+00	6 - 4	F	6 X 6	CIPR
48	Test	2594+00 - 2601+00	4	F	6 X 6	CIPR
49	Test	2601+00 - 2608+00	4	F	2 X 2	CIPR
50	Test	2608+00 - 2615+00	4	F	4 X 4	CIPR
51	Trans.	2615+00 - 2616+00	4 - 2	F	4 X 4, 2 X 2	CIPR
52	Test	2616+00 - 2624+00	2	F	2 X 2	CIPR
53	Test	2624+00 - 2631+00	2	F	4 X 4	CIPR
54	Trans.	2631+00 - 2633+00	2 - 6	F	4 X 4, 6 X 6	CIPR
55	Test	2633+00 - 2640+00	6	N	6 X 6	CIPR
56	Test	2640+00 - 2653+00	6	N	12 X 12	CIPR
57	Trans.	2653+00 - 2654+00	6 - 4	N	12 X 12, 6 X 6	CIPR
58	Test	2654+00 - 2661+00	4	N	6 X 6	CIPR
59	Trans.	2661+00 - 2662+00	4 - 6	N	6 X 6, 12 X 12	CIPR
60	Test	2662+00 - 2689+00	6	N	12 X 12	CIPR
61	Trans.	2689+00 - 2691+00	6 - 2	N	12 X 12, 4 X 4	CIPR
62	Test	2691+00 - 2698+00	2	N	4 X 4	CIPR
63	Trans.	2698+00 - 2700+00	2 - 6	N	4 X 4, 12 X12	CIPR
64	Trans.	2700+00 - 2704+00	6 – 4.5	N	12 X 12, 4 X 4	CIPR
65	Control	2704+00 - 2714+08	4.5 (1)	-	-	CIPR

Recon. = reconstruction
Trans. = transition
Control = ACC control
N = no fibers

F = fibrillated fibers
M = monofilament fibers
D = dowels
(1) ACC thickness

Table 2.3 Comparison of Design Properties for Several UTW Projects

Project	Belle Plaine, Iowa; Iowa Highway 21	Louisville, Kentucky; Disposal Facility Entrance Road	St. Louis, Missouri; Spirit of Saint Louis Airport	Leawood, Kansas; 119th Street	Denver, Colorado; Santa Fe Drive Frontage Road
Year Built	1994	1991	1994	1995	1996
PCC Thickness (in.)	2, 4, 6, 8	2, 3.5	3.5	2	4, 5
Joint Spacing (ft. X ft.)	2 X 2 4 X 4 6 X 6 12 X 12	2 X 2 6 X 6	4.2 X 4.2	3 X 3 4 X 4	4 X 4 5 X 5 5.5 X 5.5
ACC Surface Preparation	Milled Patch Only CIPR	Milled	Milled	Milled	Milled Patch Only
Synthetic Fiber Usage (pcy)	3, 0	3	3	3, 0	0

2.2.1 Location and History

The project was located south of the City of Belle Plaine, Iowa, in Iowa County on a 7.2 mile stretch of Iowa Highway 21 from US 6 to Iowa Highway 212. Figure 2.8 illustrates the project location. This portion of Iowa Highway 21 is a 2-lane roadway 24 feet in width with 9-foot granular shoulders and ditch drainage. The existing alignment was graded in 1958. A granular driving surface was used until 1961, at which time improvements were made. The improvements included replacing the original subgrade with select soil material 24 inches in depth and 24 feet wide on center, covering the select soil material with 6 inches of granular material beneath 7 inches of cement treated sand (CTS) beneath 0.75 inches of chip seal all 24 feet wide on center, and constructing 9-foot granular shoulders. The chip seal was used as the driving surface until 1964, when 3 inches of Type B ACC was placed on top

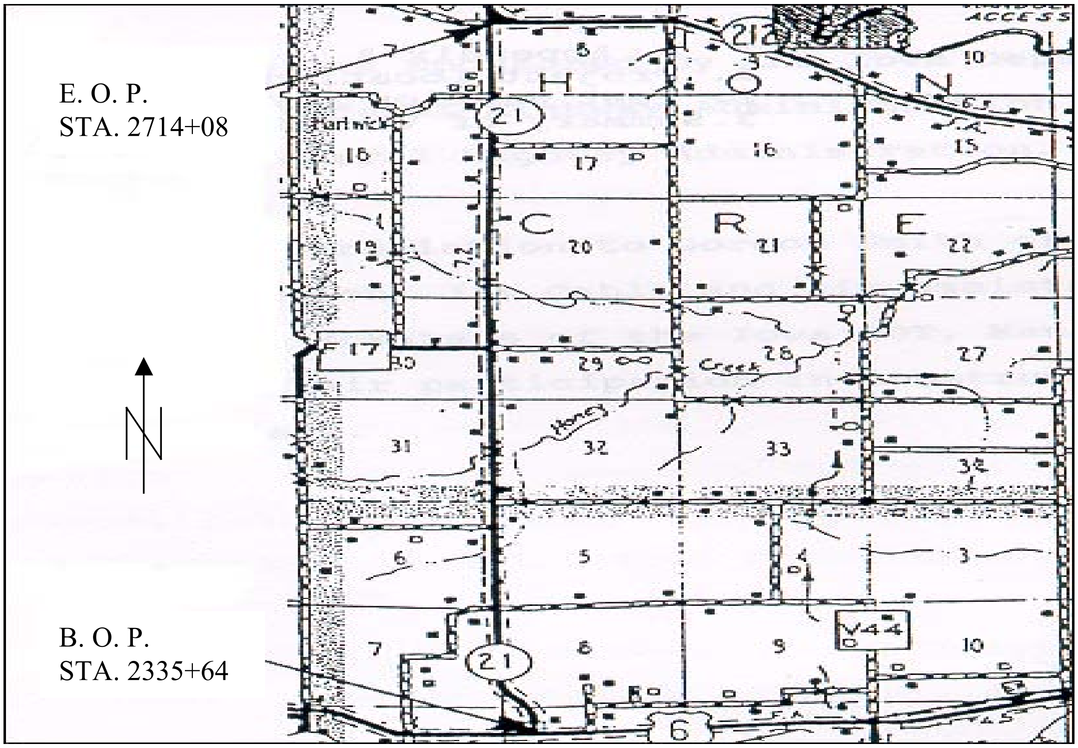


Figure 2.8 Project Location

of it. In 1987, a seal coat of negligible thickness was applied to the ACC surface. Construction of the UTW project occurred in 1994. All pavement layers were designed and placed according to effective Iowa State Highway Commission (ISHC) or Iowa DOT specifications at the time of contract letting. Figure 2.9 shows the pavement layers and the years of their construction.

2.2.2 Soil Conditions

According to the Iowa County Soil Survey Report, Fayett-Downs, Tama-Downs, and Colo-Bremer-Nevin-Nodaway soil associations occur along the project.[4] Fayett-Downs and Tama-Downs are the primary associations along the project. These associations were formed from loess, are generally well drained, and have moderate to high shrink/swell potential.

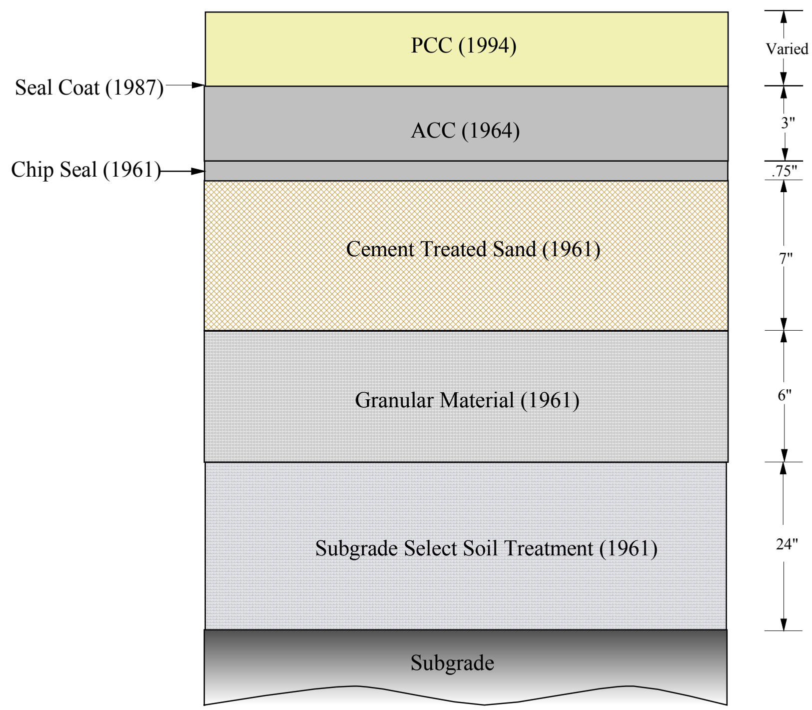


Figure 2.9 Pavement Layers and Their Construction Years

They are fair subgrade soils. The Colo-Bremer-Nevin-Nodaway association is along a small portion of the project. This association was formed from alluvium, is generally poorly to moderately drained, and has moderate to high shrink/swell potential. It is an unsuitable subgrade soil.

More detailed soil information was obtained from a soil survey conducted by the ISHC prior to the 1958 grading operations. Soil borings were taken approximately every 100 feet in cut areas. The soils found were primarily fine grained and had American Association of State Highway and Transportation Officials (AASHTO) classifications ranging from A-6 (6) to A-7-6 (20). Soils with these classifications are fair to poor subgrade soils and have moderate to high shrink/swell and frost heave potential. Some very limited pockets of A-1-b, A-2-4, A-3, and A-4 soils were found. Based on the survey findings, select soil treatment for the entire project was specified in the 1961 improvements. Table 2.4 details the class names and AASHTO classifications of project soils.

Table 2.4 Class Names and AASHTO Classifications of Project Soils

Station	Class Names	AASHTO Classifications
2341+00 - 2408+00	Silty Clay	A-7-6 (11, 12, 13)
	Clay	A-6 (9, 11)
2408+00 - 2456+00	Silty Clay	A-7-6 (14, 15, 17)
	Clay	A-6 (8, 9, 10, 11, 12)
		A-7-5 (20)
2456+00 - 2502+00	Silty Clay Loam	A-6 (10)
		A-7-6 (12)
	Silty Clay	A-6 (9, 10, 11)
		A-7-6 (11, 12, 13, 15)
	Clay Loam	A-6 (6)
	Gravel Clay Loam	A-6 (4)
	Gravel Sand	A-1-b (0)
	Clay	A-6 (8, 9, 10)
		A-7-6 (19)
2502+00 - 2561+00	Gravel Clay Loam	A-6 (10)
	Clay Loam	A-6 (3, 5, 6, 7)
	Silty Clay	A-6 (7, 8, 10, 11)
		A-7-6 (12, 15, 17)
	Sandy Loam	A-2-4 (0)
	Clay	A-6 (8)
		A-7-6 (19)
2561+00 - 2615+00	Silty Clay Loam	A-6 (8, 10)
	Silty Clay	A-6 (10)
		A-7-6 (10, 12, 13, 14, 15, 18)
	Clay Loam	A-6 (5)
	Sandy Loam	A-2-4 (0)
	Gravel Sand	A-3 (0)
	Clay	A-7-6 (20)
	Sand	A-2-4 (0)

Table 2.4 Class Names and AASHTO Classifications of Project Soils (continued)

Station	Class Names	AASHTO Classifications
2621+00 - 2676+00	Silty Clay Loam	A-6 (10)
	Silty Clay	A-6 (9, 11, 12)
		A-6-7 (10, 14, 18)
	Clay Loam	A-4 (5)
		A-6 (6, 7)
	Clay	A-7-6 (19)
2676+00 - 2706+00	Silty Clay Loam	A-4 (8)
		A-6 (9, 12)
	Silty Clay	A-6 (10, 12)
		A-7-6 (10, 12)
	Clay Loam	A-4 (4)

2.2.3 Climate Conditions

The climate in Iowa County is subhumid with seasonal variations in temperature and moisture.[4] Rapid changes in weather are frequently experienced throughout the year due to the convergence of 2 major storm tracks. Typically, the winters are cold and the summers are hot. Prolonged periods of extreme temperatures are rare. January is typically the coldest and driest month with an average temperature of 19.9°F and an average precipitation of 1.28 inches.[5] July is normally the hottest month with an average temperature of 75.0°F. The average yearly precipitation is 30.70 inches. Two-thirds of the precipitation occurs from April to June with the seasonal peak in June. Frost penetration in the area is approximately 60 inches.

2.2.4 Traffic Loading

The project is located along a portion of Iowa Highway 21 that serves primarily as a farm to market road and as an access route for US 6. Private residences and a few intersections with lightly traveled county roads exist along the project. No commercial or industrial sites are present to create large fluxes in traffic or uneven directional usage. Historic Iowa DOT average daily traffic (ADT), average daily truck traffic (ADTT), classification counts, and typical vehicle axle configurations and weights were used to estimate traffic loading using the same methods used to supply annual traffic information to the Federal Highway Administration (FHWA). In 1994, the average ADT was 1,090 and the average ADTT was 142. Figure 2.10 shows the ADT and ADTT observations and growth trends for Iowa Highway 21. Figure 2.11 shows the percent of traffic for each IDOT vehicle classification.

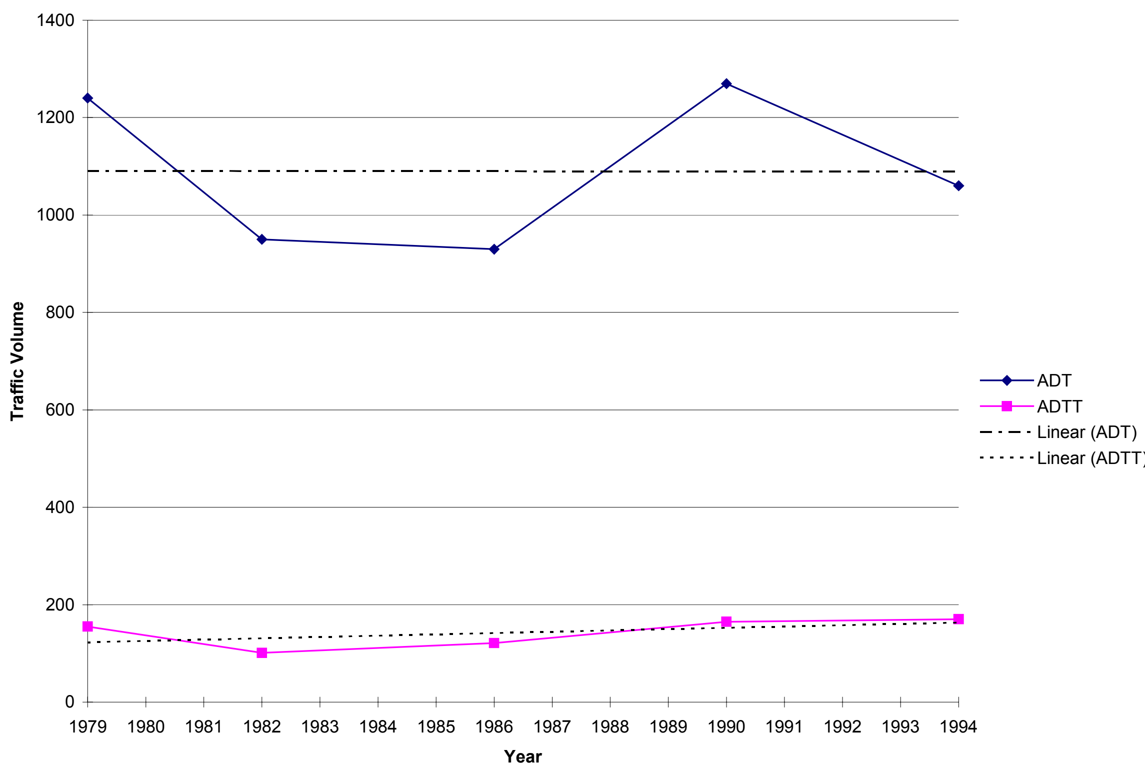


Figure 2.10 ADT and ADTT Observations and Growth Trends for Iowa Highway 21

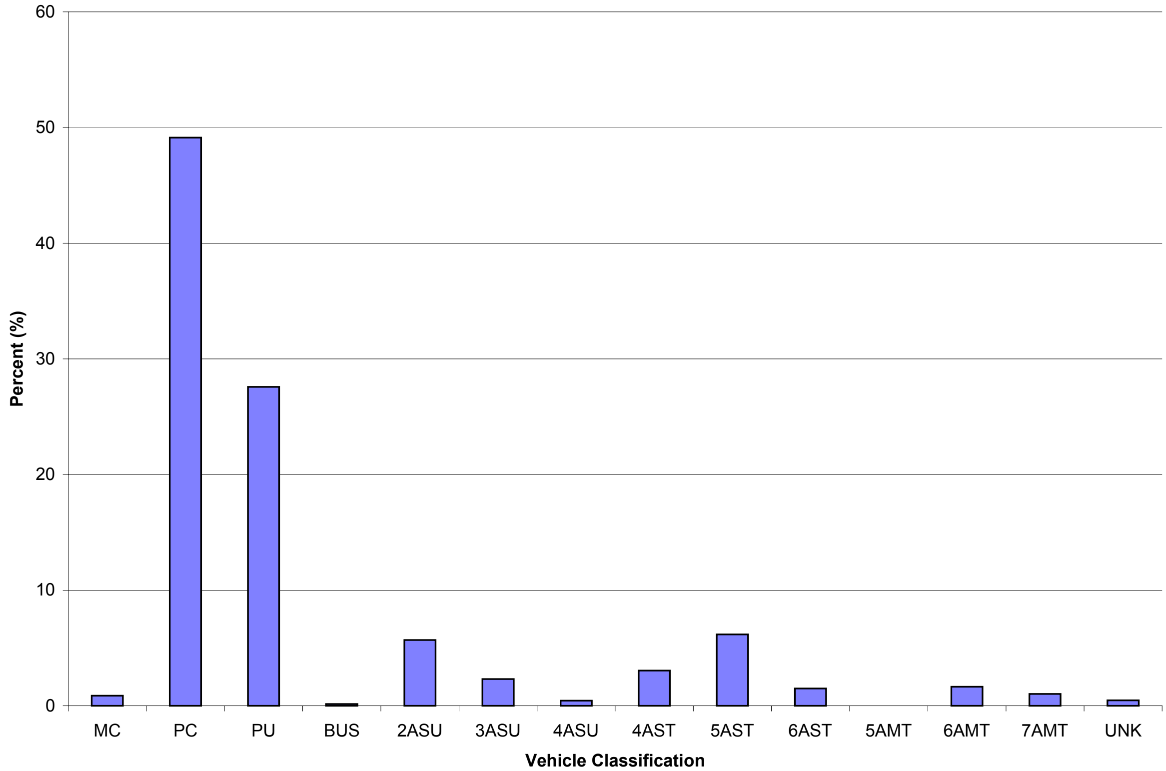


Figure 2.11 Percent of Traffic for Each IDOT Vehicle Classification

A weigh-in-motion (WIM) station was located midway through the project in each lane. Although the WIM equipment did experience some sporadic outages due to mechanical and software problems, data were obtained for the majority of each year during the research. The WIM data were used to calculate Equivalent Single Axle Loads (ESALs) based on AASHTO damage factors for 6 inch PCC. For both lanes, ESALs were found to increase each year and their totals were nearly balanced. Table 2.5 shows the ESALs by year and in total for each lane.

Table 2.5 ESALs by Year and in Total for Each Lane

Year	Northbound ESALs	Southbound ESALs
1995	2,865	9,328
1996	10,468	14,394
1997	12,337	23,394
1998	28,248	41,379
1999	57,410	42,456
Total	111,328	130,744

2.2.5 Construction

The project was constructed in the spring and summer of 1994 and conformed to Iowa DOT specifications and special provisions noted in the project contract. Conventional construction procedures and equipment were used to complete the project. Materials used underwent regular assurance testing to guarantee quality constraints were met. In addition, PCC paving operations were subjected to plant and grade inspections, ACC paving operations were subjected to plant inspections and district lab testing, and CIPR surface preparation was subjected to district lab testing. Appendix A provides a summary of pertinent inspection and testing results. Previously submitted documents should be consulted for a more detailed review of the project construction, testing, and inspection.[1,6,7]

2.2.6 Pavement Instrumentation

Pavement instrumentation was done approximately 500 feet in front of the paving operations. Test sections were instrumented for the purpose of obtaining strain and temperature measurements. No ACC control sections were instrumented. Approximately 75% of the sites were located in the northbound lanes and 25% were in the southbound lanes. Table 2.6 shows the location and as-built properties of the sites selected for instrumentation.

Table 2.6 Location and As-Built Properties of Sites Selected for Instrumentation

Section Number	Site Number	Station	PCC Design Thickness (in.)	Actual PCC Thickness (in.)	Synthetic Fiber Usage	Joint Spacing (ft. X ft.)	ACC Surface Preparation
3	1	2346+00	6	8.8	F	12 X 12	Milled
4	2	2354+00	6	5.0	F	6 X 6	Milled
6	3	2359+50	4	6.0	F	6 X 6	Milled
7	4	2370+00	4	5.0	F	2 X 2	Milled
8	5	2374+50	4	7.0	F	4 X 4	Milled
10	6	2385+50	2	3.0	F	2 X 2	Milled
11	7	2391+50	2	3.0	M	4 X 4	Milled
13	8	2399+50	6	7.3	M	6 X 6	Milled
14	9	2409+50	6	7.0	M	12 X 12	Milled
18	10	2428+25	6	7.0	N	12 X 12	Milled
19	11	2436+50	6	9.0	N	6 X 6	Milled
21	12	2445+00	4	4.0	N	2 X 2	Milled
23	13	2455+00	2	3.0	N	2 X 2	Milled
26	14	2465+00	6	7.5	N	6 X 6	Patch Only
27	15	2475+50	6	6.3	N	12 X 12	Patch Only
29	16	2485+00	4	5.3	N	4 X 4	Patch Only
31	17	2494+50	8	8.9	N	15 X 12	Patch Only
32	18	2502+00	8	9.8	N	15 X 12 D	Patch Only
36	19	2534+00	6	7.3	N	6 X 6	Patch Only
38	20	2545+50	2	2.8	F	2 X 2	Patch Only
39	21	2550+00	2	4.2	F	4 X 4	Patch Only
41	22	2560+00	4	4.6	F	4 X 4	Patch Only
42	23	2565+00	4	4.0	F	2 X 2	Patch Only
43	24	2574+00	4	4.0	F	6 X 6	Patch Only
46	25	2590+00	6	6.5	F	6 X 6	CIPR
48	26	2596+00	4	4.8	F	6 X 6	CIPR
49	27	2605+50	4	5.0	F	2 X 2	CIPR
50	28	2610+00	4	4.9	F	4 X 4	CIPR
52	29	2620+00	2	3.0	F	2 X 2	CIPR
53	30	2630+00	2	2.8	F	4 X 4	CIPR
55	31	2635+50	6	7.0	N	6 X 6	CIPR
56	32	2650+00	6	6.0	N	12 X 12	CIPR
58	33	2659+50	4	4.8	N	6 X 6	CIPR
60	34	2685+50	6	8.0	N	12 X 12	CIPR
62	35	2694+50	2	5.0	N	4 X 4	CIPR

N = no fibers M = monofilament fibers
F = fibrillated fibers D = dowels

At each site, 2 deflectometers and a thermocouple were installed. The deflectometers were identical to those used in the laboratory testing, except the length of the AT&T telephone wire was 30 feet. A description of the deflectometer fabrication process and of the deflectometers can be found on page 4. The thermocouples used were type IRAD GAGE TH-1. The thermocouples were completely assembled by the manufacturer and consisted of a thermistor covered in high impact epoxy and encapsulated in an extruded stainless steel shell. A 30 foot shielded cable with 2 copper lead wires was soldered to the thermistor sensor wires.

Pavement instrumentation began by using a tape measure to accurately locate the station of the site. Offset measurements from the located station and the edge of pavement were then made to determine the exact positioning of the deflectometers. For all sites, the positioning of the deflectometers relative to the edge of pavement and a transverse joint were identical. The deflectometers were installed using the same procedure as in the laboratory testing, except the deflectometers were oriented at right angles to each other. A description of the deflectometer installation procedure can be found on page 5. Figure 2.12 provides a schematic and the orientation of installed deflectometers prior to PCC placement. The thermocouple was placed horizontally on the ACC between the deflectometers.

After the instrumentation was installed, a shallow trench with a downward slope away from the roadway was made. The trench extended from the edge of the pavement through the foreslope. A piece of 2-inch diameter PVC pipe was cut that would extend the length of the trench and protrude slightly out of the foreslope. Wiring from the instrumentation was fed through the pipe. The pipe was sealed at the pavement end and capped with a threaded nut at

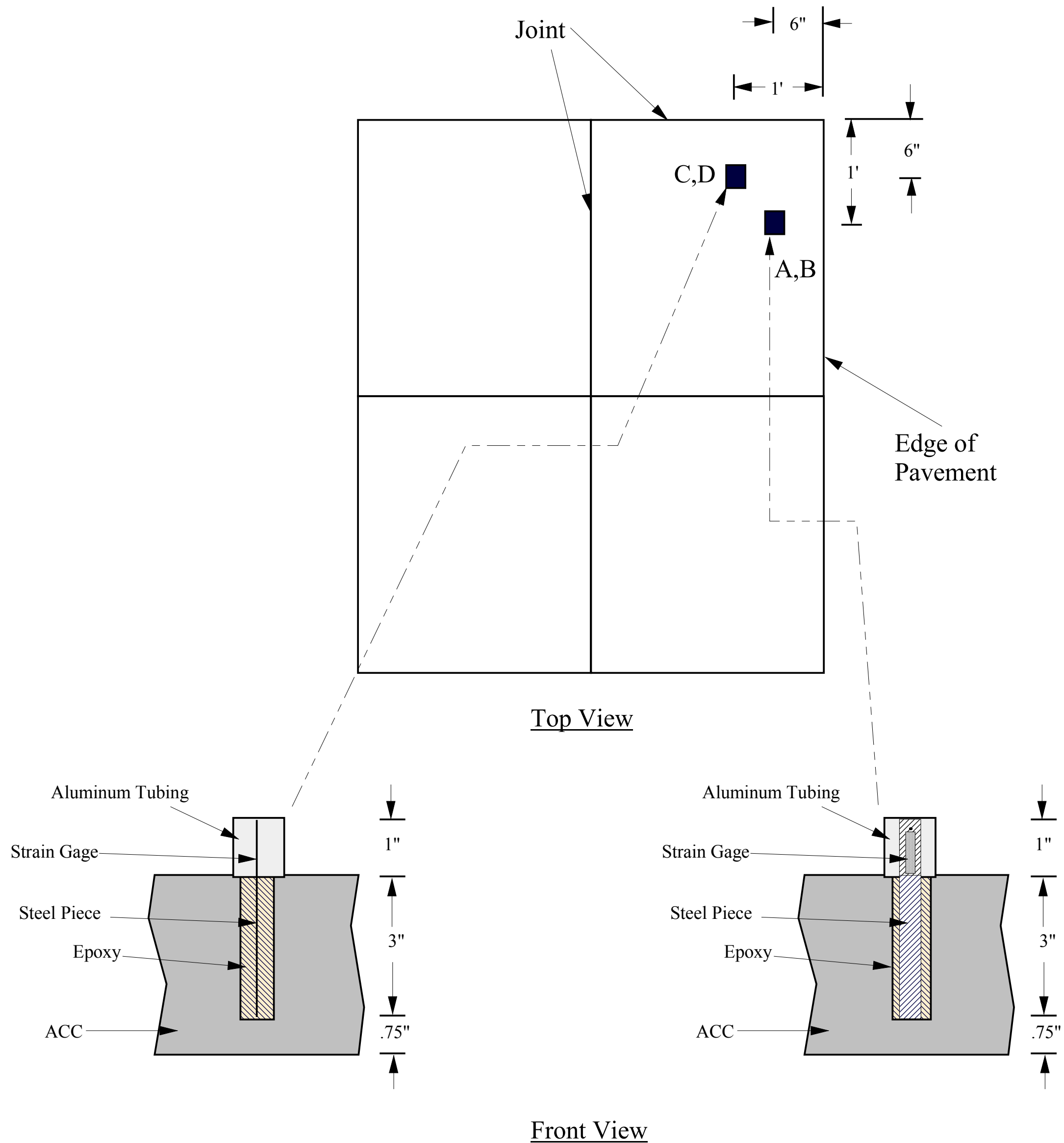


Figure 2.12 Schematic and Orientation of Installed Deflectometers Prior to PCC Placement

the foreslope end. Drain holes were drilled in the bottom of the pipe at the foreslope. Gage wires were labeled A through D according to their position. The pipe was placed in the trench and the trench was backfilled.

2.2.7 Strain and Temperature Testing

Strain and temperature testing was conducted during and after the construction of the project. During construction, testing progressed with paving operations. Each instrumented site was tested twice per construction day for 2 weeks after the site had been paved and then once a week thereafter until construction was completed. Testing started at about 9:00 A.M. and then again at about 12:00 noon. After construction, testing was conducted 3 times a year. Typically, the test dates were the first Saturday in May, August, and November. Each site was tested once, and testing started at about 9:00 A.M. All testing proceeded from the south to the north. The objective of strain and temperature testing was to monitor interface strains in relation to the bonding condition over time and at various pavement temperatures.

At each site, testing began by removing the cap from the PVC pipe and exposing the instrumentation wiring. Gage wires were individually connected to a P-3500 strain indicator allowing each strain to be measured and then recorded. Thermocouple lead wires were connected to an IRAD GAGE TH-1 temperature sensor unit and the interface temperature was measured and recorded.

2.2.8 Falling Weight Deflectometer Testing

FWD testing was conducted before and after the construction of the project. Before construction, the original pavement structure was tested in the outer wheel path of the north and southbound lanes every 300 feet and at locations selected for instrumentation. Each location was tested once. After construction, the new pavement structure was tested at instrumented sites in the center of panels located in the outer wheel path of the instrumented lane. Each location was tested once a year in the last week of July, starting in the year of construction. All testing started at about 9:00 A.M. and proceeded from the south to the north. In addition to normal testing, special testing was conducted in areas where debonding was suspected or probable. The objective of FWD testing was to monitor deflection responses in relation to the bonding condition over time.

Testing was conducted by ERES Consultants Incorporated of Champaign, Illinois using a Dynatest Model 8081 FWD with a segmented 5.9-inch radius load plate and 7 seismic transducers. One transducer was located at the center of the load plate (D0) while the others were spaced at radial 12-inch intervals (D1, D2, D3, D4, D5, and D6). A van equipped with a closed circuit television (CCTV), computer, and system processor was used to pull the FWD trailer. The CCTV aided the van driver in positioning the load plate. The computer and system processor controlled testing operations and recorded maximum deflection responses measured by each transducer.

Testing began by preparing the FWD testing device and setting the computer stationing to the start point stationing. The distance the van traveled was directly linked to the stationing displayed and recorded on the computer. Tracking of the distance traveled by the van was initiated when the start point was reached. At each test location, the van driver positioned the load plate using the CCTV. The computer was then used to lower the load plate and transducers onto the pavement surface and initiate the load sequence. The load sequence consisted of a seating load followed by test loads of approximately 6, 9, and 12 kips. The different loads were obtained by varying the drop height of the weight. Figure 2.13 details the FWD loading apparatus.

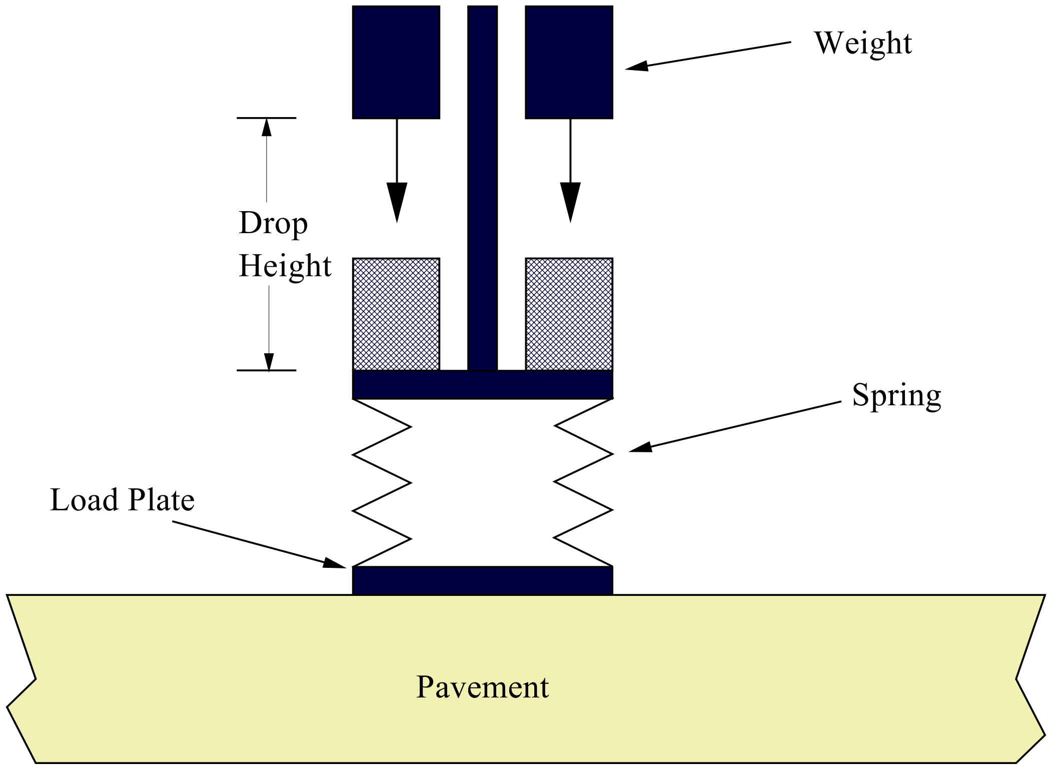


Figure 2.13 FWD Loading Apparatus

2.2.9 Direct Shear Testing

Direct shear testing was added to the initial scope of field testing and was conducted when the project was 3 and 5 years old. Future testing is scheduled when the project will be 7 years old. Sections selected for testing had 2-inch PCC design thicknesses and provided a sampling of the different variable combinations. Testing was conducted on 6 cores taken from each selected section. Coring was done on panels positioned in the outer wheel path of the northbound lane. Three cores each were obtained from the center and interior corner positions of the panels. Separate panels were used for each core. Table 2.7 details the core locations and section design properties. Special testing was conducted in areas where debonding was suspected or probable. The primary objective of direct shear testing was to quantitatively measure the interface bond over time. A secondary objective of direct shear testing was to visually observe the interface bonding condition.

Table 2.7 Core Locations and Section Design Properties

Section Number	Station	PCC Thickness (in.)	Synthetic Fiber Usage	Joint Spacing (ft. X ft.)	ACC Surface Preparation
10	2380+00	2	F	2 X 2	Milled
11	2387+00	2	M	4 X 4	Milled
23	2455+60	2	N	2 X 2	Milled
38	2546+00	2	F	2 X 2	Patch Only
39	2553+00	2	F	4 X 4	Patch Only
52	2617+00	2	F	2 X 2	CIPR
53	2624+00	2	F	4 X 4	CIPR
62	2691+00	2	F	4 X 4	CIPR

N = no fibers
F = fibrillated fibers
M = monofilament fibers

Coring was conducted using the Iowa DOT drilling rig. The rig was mounted on the back of a single unit truck, which contained a water and mortar supply. The drilling apparatus was turned by the power supply of the rig and consisted of a 4 inch diameter diamond drill bit attached to the end of a rotational shaft. The drill bit was water cooled and was supported by a rigid guide foot. An assembly of bearings allowed direct contact to be made between the guide foot and the rotating drill bit. An inverse hydraulic jack system was used to impart drilling pressure.

Coring began by locating and marking the core locations. At each core location, the drill apparatus was positioned and then the inverse hydraulic jack was lowered until it made contact with the PCC. Rotation of the drill bit and water flow was initiated and then the drill bit was lowered into contact with the PCC. A safe drilling pressure and a moderate and constant rotational speed was maintained. When drilling reached an adequate depth, the drill bit was withdrawn while still rotating. Water and rotation were terminated and the core was removed from the drill bit or the hole. The hole was filled with mortar. Cores were transported back to the Iowa DOT Central Materials Laboratory where they were photographed, measured, and tested.

Equipment used for testing included a MTS, a testing jig, and a holder clamp. The MTS had a fixed top load head and a moving bottom load head. The moving bottom load head allowed for a smooth and uniform tensile load to be applied to the testing jig. The testing jig was made of 2 separate steel plates with 4-inch diameter holes. Connected to each steel plate was a gripping shaft and a channel. The shafts were capable of being gripped by the MTS load heads and were offset to the center so that eccentric loading would not occur. The channels provided guidance for the plates and ensured that a small space existed between the steel plates. The holder clamp was attached to the channels and allowed the cores to be rigidly held in place during testing. Figure 2.14 depicts the MTS and testing jig required to perform Iowa DOT Test Method 406-C.

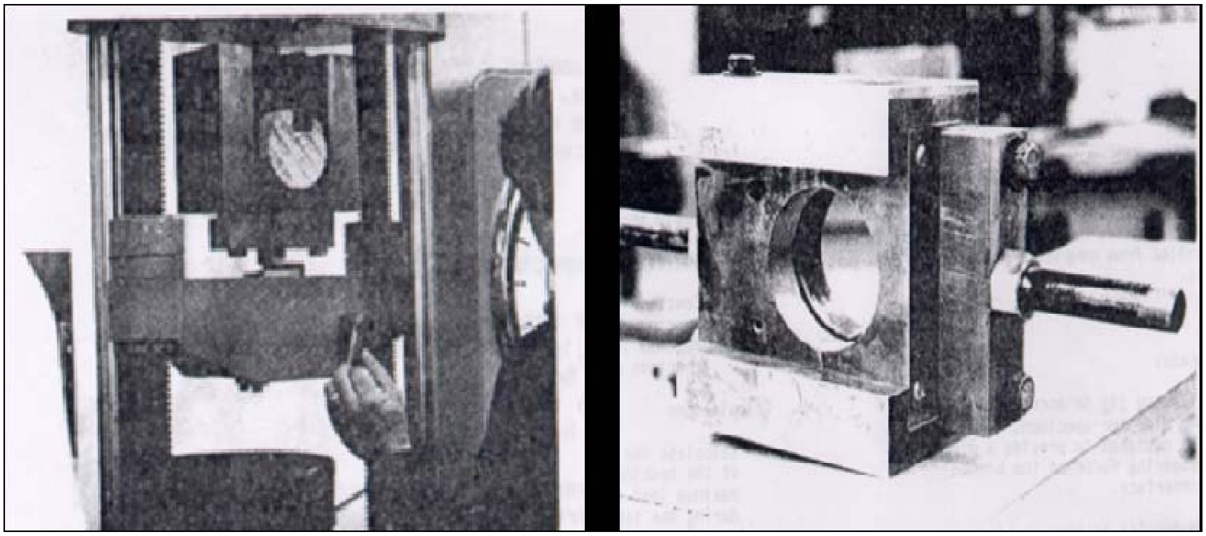


Figure 2.14 MTS and Testing Jig

Testing began by aligning the testing jig in the MTS. Care was taken to ensure the central axis of the testing jig was aligned with the central axis of the MTS. When the alignment was correct, the load heads were used to clamp the gripping shafts. This procedure was conducted at the startup of testing and was only repeated if the testing jig became misaligned. The core was placed in the testing jig with the interface positioned in the space between the steel plates. The holder clamps were then fastened to the core and a tensile load in the range of 400 to 500 psi per minute was applied until failure occurred. After the failure occurred, the failure load was recorded and the failed core was removed.

2.2.10 Visual Distress Surveys

Visual distress surveys were conducted after the construction of the project. Both lanes of every section of the project were completely surveyed. Surveys entailed a person walking on each shoulder recording the type and location of every observed distress. The types of distresses considered in the survey included transverse cracks, longitudinal cracks, corner cracks, diagonal cracks, popouts, joint spalls, and fractured panels. Surveys typically were conducted on the first Saturday in February, May, August, and November. All surveys started at about 9:00 A.M. and proceeded from the south to the north. In addition to normal surveys, driving surveys were conducted periodically by local roadway maintenance personnel. Driving surveys focused on identifying potentially hazardous fractured panels with debonded PCC. The primary objective of visual distress surveys was to monitor distresses in relation to the serviceability and bonding condition over time. Areas of high distress in which debonding had occurred, was suspected, or was probable were targeted for additional investigation with aforementioned testing.

3. ANALYSIS AND RESULTS

3.1 Introduction

Analysis of the field and lab data was focused on providing results on the interface bonding condition between an ultra-thin PCC overlay and an ACC base over time, considering the variables of ACC surface preparation, PCC thickness, synthetic fiber reinforcement usage, and joint spacing. Data preparation, statistical treatment, results, and insights have been discussed in detailed. Analysis and results of strain and temperature as well as falling weight deflectometer testing are based on the first 3 years of a scheduled 5-year program. Analysis and results of all other testing is based on 5 years of a scheduled 5-year program.

3.2 Static Testing

Static testing was conducted prior to dynamic testing. The primary objective of static testing was to determine the appropriate load magnitudes to be used for dynamic testing for each beam grouping. Secondary objectives of static testing included monitoring interface strains during loading and visually observing failure modes.

3.2.1 Data Preparation

Static data from each beam were assembled into individual Excel spreadsheets. For each beam, load and deflection versus time as well as shear strain versus time were plotted. The plots were reviewed for erroneous data resulting from reading errors or invalid deflections. Erroneous data were removed and were given no further consideration. The load and deflection versus time plot was used to determine the time of ultimate load. Shear strain and load values occurring at the time of ultimate load were referenced. All data obtained were input on a summary sheet.

Ultimate load data were used to develop a theoretical analysis of shear strain and maximum normal stresses for bonded and unbonded conditions. Calculations were done on an Excel spreadsheet. For all theoretical analyses the following assumptions were made:

1. Material properties were constant
2. PCC and ACC thicknesses were constructed as specified
3. Epcc = 3,700,000 psi
4. Eacc = 145,000 psi

Pictures of tested beams and a testing journal were used to categorize observed failure modes. Four failure modes were identified and are defined as follows:

1. Localized crack failure - complete cross-sectional break of beam
2. Localized end failure - compression of ACC in region of pins
3. Layer separation - unbonding of ACC and ACC interface
4. Interface separation - unbonding of ACC and PCC interface

3.2.2 Statistical Treatment and Results

While assembling the static data into individual Excel spreadsheets it was discovered that entire data files were overwritten or lost. In addition, gage 3 was found to be producing erroneous data for all beams while gages 1, 2, and 4 produced erroneous data intermittently. Due to premature ACC tensile failure resulting from loading the beams with the ACC on the bottom, no data existed for beams with 2-inch PCC, not milled, and no fiber. Considering the substantial amount of unusable data it was determined that a meaningful evaluation could only be made on combined thickness beam groupings of 2 and 4-inch PCC. Figure 3.1 shows the percent of strain gages producing usable data for detailed and combined thickness beam groupings. Graphical comparisons of averages were used to evaluate the data.

Average experimental ultimate loads for 2 and 4-inch PCC used to determine the appropriate load magnitudes for dynamic testing can be found in Figure 3.2. As anticipated, 2-inch PCC had lower average experimental ultimate load and shear strain than 4-inch PCC. Regardless of the PCC thickness small average experimental shear strains were produced. The magnitude of the ultimate loads combined with strain gage orientation resulted in the small shear strains. Small shear strains coupled with the inherent noise in the equipment setup made measurement and evaluation difficult. Figure 3.3 illustrates the small shear strains and equipment noise encountered.

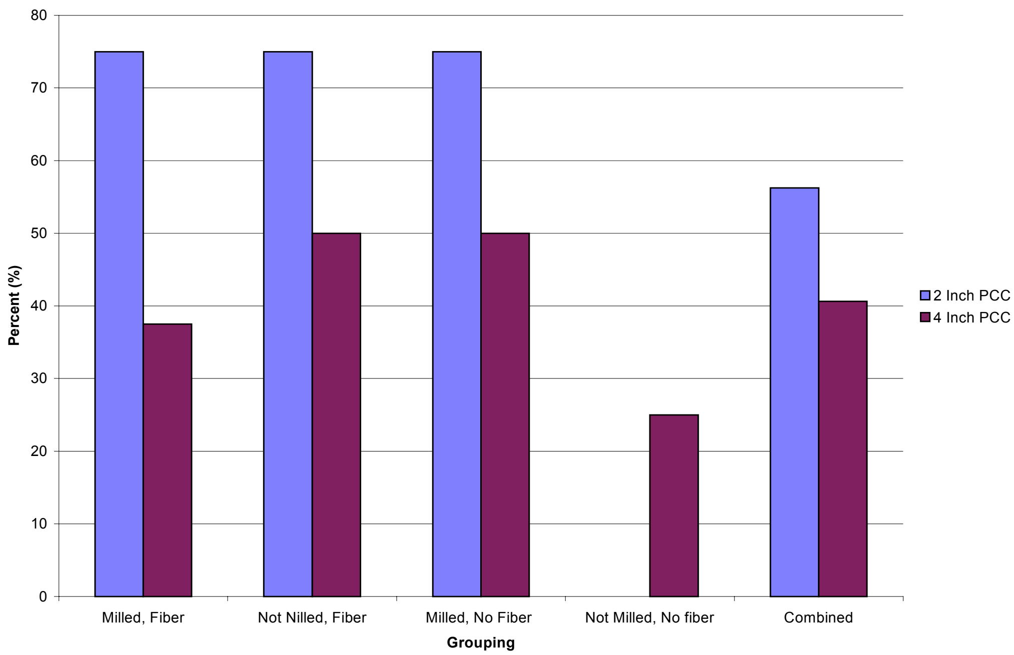


Figure 3.1 Percent of Strain Gages Producing Usable Data for Detailed and Combined Thickness Groupings of Static Beams

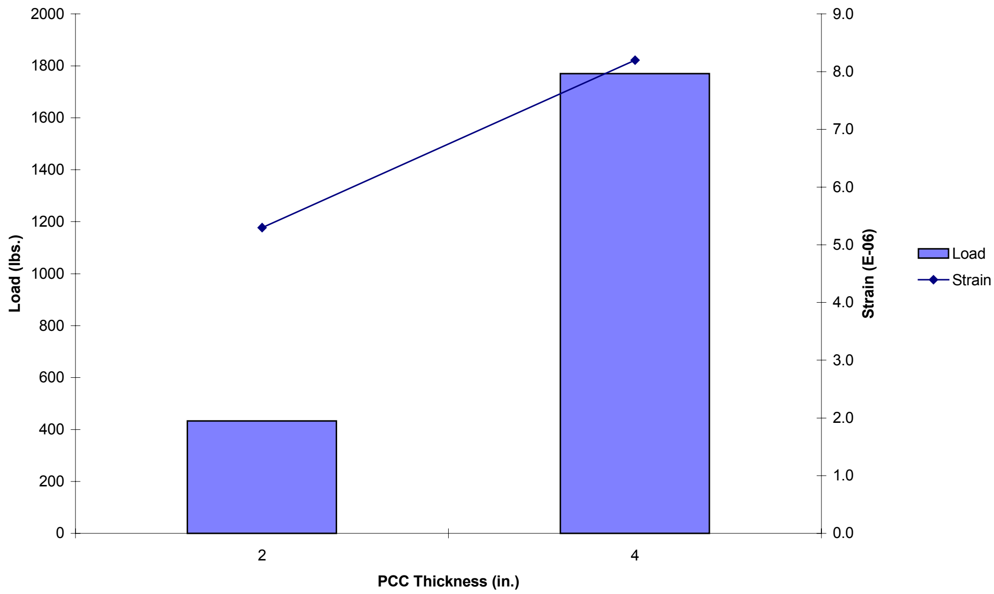


Figure 3.2 Average Experimental Ultimate Load and Shear Strain for 2 and 4-Inch PCC of Static Beams

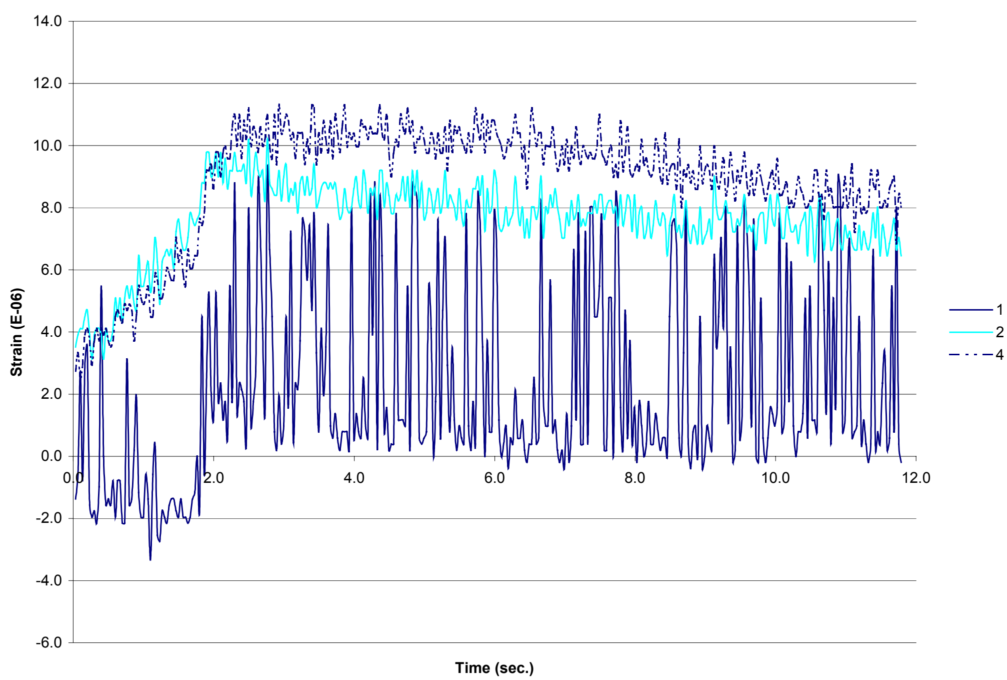


Figure 3.3 Small Shear Strains and Equipment Noise Encountered for Static Beams

Theoretical and average experimental shear strains at average ultimate load for bonded and unbonded conditions of 2 and 4-inch PCC are shown in Figure 3.4. Theoretical shear strains obtained by modeling a bonded condition closely approximated average experimental shear strains, indicating that a bonded condition was maintained through

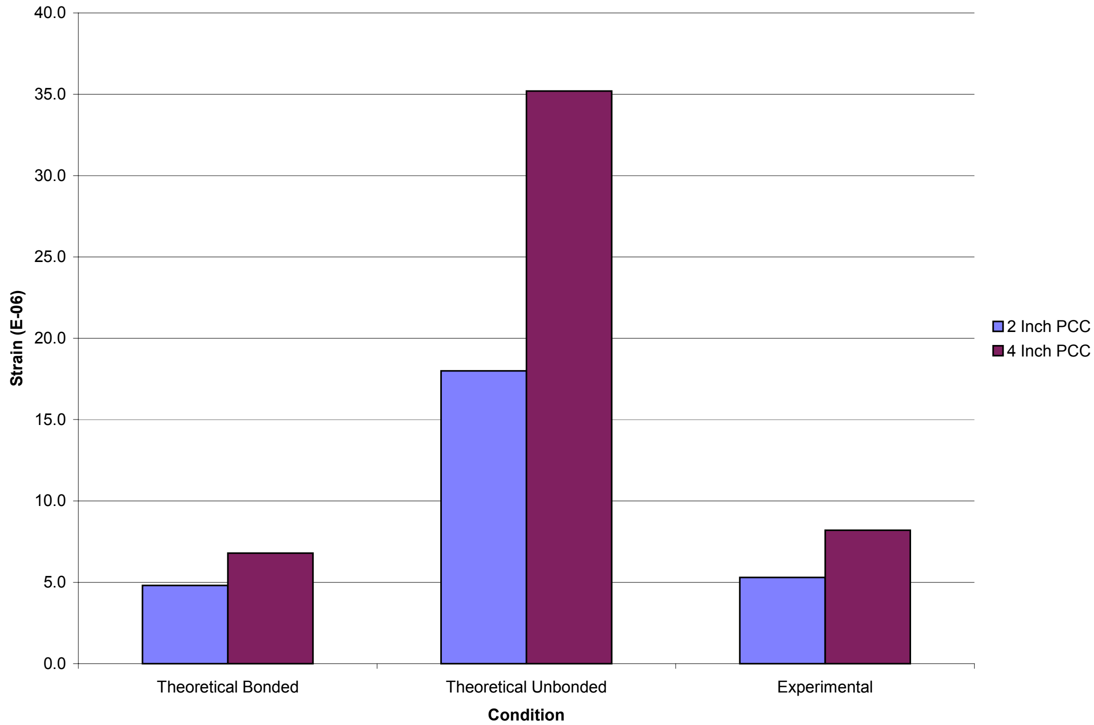


Figure 3.4 Theoretical and Average Experimental Shear Strains at Average Ultimate Load for Bonded and Unbonded Conditions of 2 and 4-Inch PCC of Static Beams

failure. Figure 3.5 details PCC and ACC maximum theoretical normal stresses at average ultimate load for bonded and unbonded conditions of 2 and 4-inch PCC. When bonded conditions exist, maximum theoretical normal stresses of the PCC are small and unequal while those of the ACC are similar and of reasonable ultimate value. These observations indicate that localized crack failure initiated in the ACC as a result of ACC tension. This assessment is further substantiated considering the maximum theoretical normal stresses of the PCC with unbonded conditions are similar and of reasonable value for PCC tensile failure.

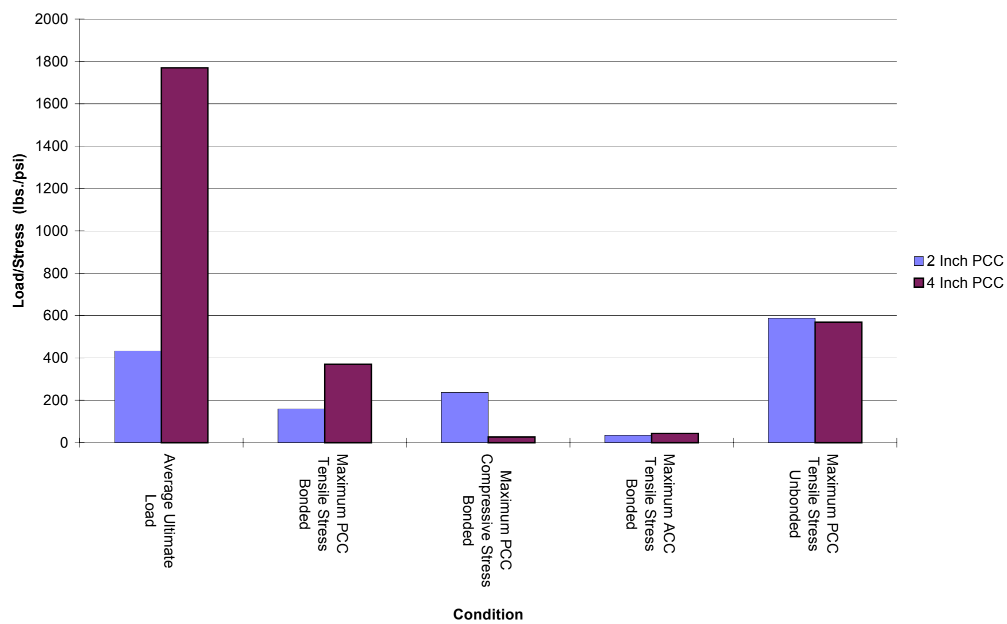


Figure 3.5 PCC and ACC Maximum Theoretical Normal Stresses at Average Ultimate Load for Bonded and Unbonded Conditions of 2 and 4-Inch PCC of Static Beams

Figure 3.6 shows the percent of observed failure modes for conditions of 2 and 4-inch PCC. All beams tested exhibited localized crack failure. Localized end failure occurred for both 2 and 4-inch PCC conditions, with 4-inch PCC having a slightly higher incidence. As a result of localized end failure, testing conditions were altered prematurely and confidence in load, deflection, and strain data was diminished. Layer separation occurred with more than twice the frequency and with more severity than interface separation. This relationship was noted for only the 2-inch PCC condition. It is not understood why it was not observed for the 4-inch PCC condition. Regardless, more frequent and severe occurrences of layer separation

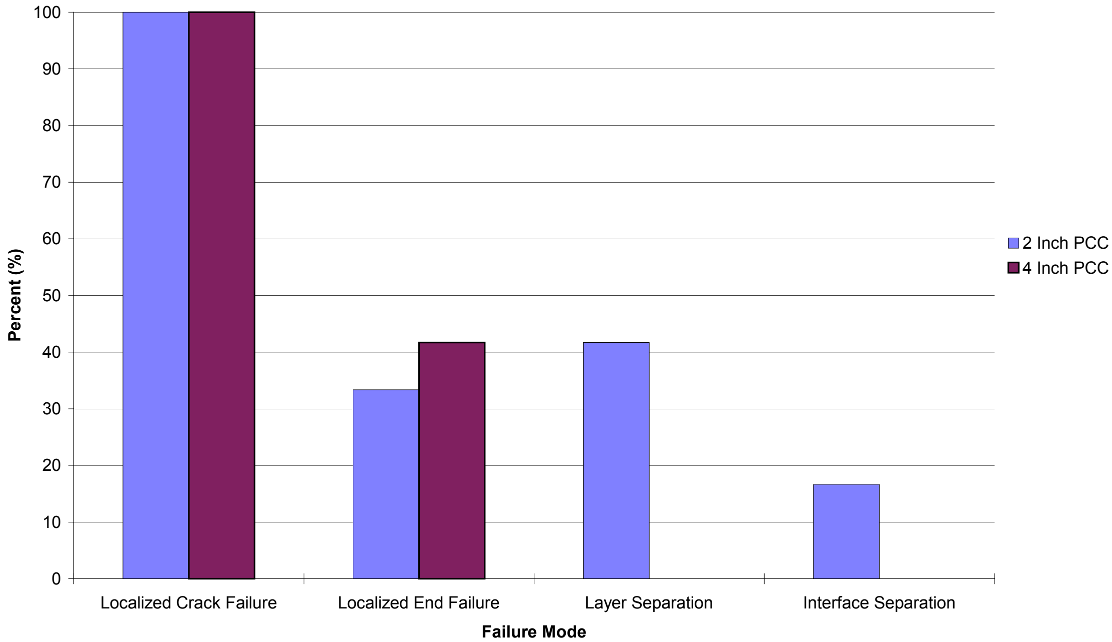


Figure 3.6 Percent of Observed Failure Modes for Conditions of 2 and 4-Inch PCC of Static Beams

indicate that conditions were more critical in the ACC than at the interface and that a bonded condition was predominant through failure.

3.3 Dynamic Testing

Dynamic testing was conducted after static testing had been completed and the appropriate load magnitudes for each beam grouping had been determined. The primary objective of dynamic testing was to monitor interface strains at varying levels of load repetitions. A secondary objective of dynamic testing was to visually observe failure modes if they occurred.

3.3.1 Data Preparation

Dynamic data from each beam were assembled into individual Excel spreadsheets. All data were organized in order of runs, with each run consisting of 10,000 applied oscillating loads followed by a ramp load application. For each beam, deflection and shear strain data versus number of observations of each run were plotted. The plots were reviewed for erroneous data resulting from reading errors or invalid deflections. Erroneous data were removed and were given no further consideration. Raw load data were used to determine the magnitude and time of peak ramp load for all runs. Shear strains occurring at the time of peak ramp load were referenced. All data obtained were input on a summary sheet.

Peak ramp load data were used to develop a theoretical analysis of shear strain for bonded and unbonded conditions over the application of applied oscillating loads. Calculations were done on an Excel spreadsheet. For all theoretical analyses the following assumptions were made:

1. Impact of dynamic loading could be ignored
2. Material properties were constant
3. PCC and ACC thicknesses were constructed as specified
4. Epcc = 3,700,000 psi
5. Eacc = 145,000 psi

Pictures of tested beams and a testing journal were used to categorize observed failure modes. Failure modes identified for dynamic testing are identical to those of static testing. A description of the failure modes can be found on page 33.

3.3.2 Statistical Treatment and Results

While assembling the dynamic data into individual Excel spreadsheets it was discovered that entire data files were overwritten or lost. In addition, gage 3 was found to be producing erroneous data for all beams while gages 1, 2, and 4 produced erroneous data intermittently. No data existed for beams with 2 or 4-inch PCC, not milled, and no fiber. Considering the substantial amount of unusable data it was determined that a meaningful evaluation could only be made on combined thickness beam groupings of 2 and 4-inch PCC. Figure 3.7 shows the percent of strain gages producing usable data for detailed and combined thickness beam groupings. Graphical comparisons of averages in conjunction with regression were used to evaluate the data.

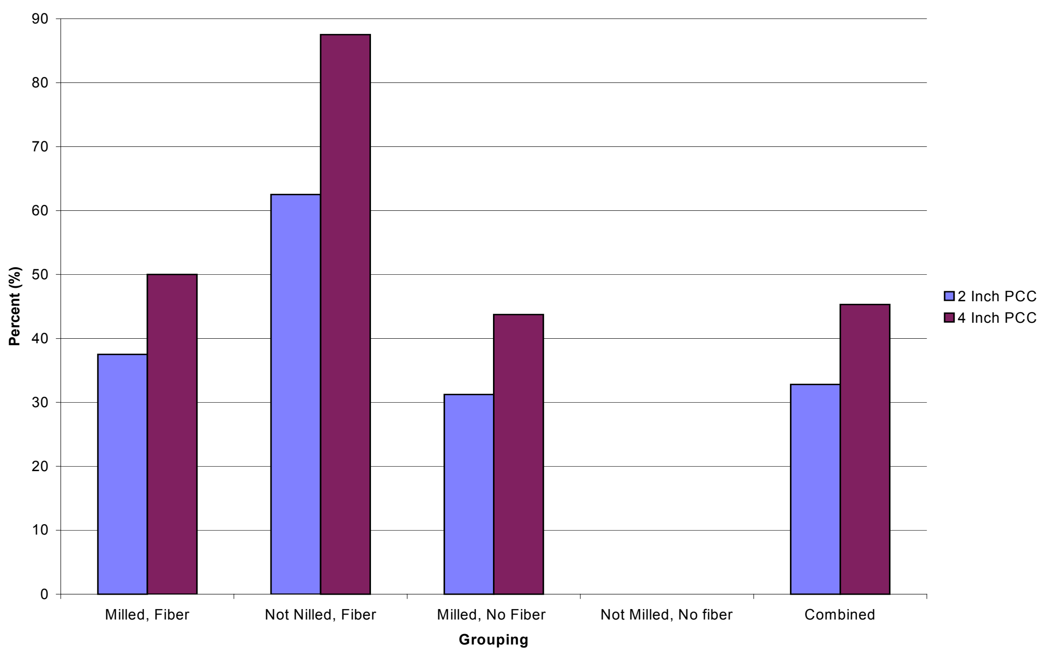


Figure 3.7 Percent of Strain Gages Producing Usable Data for Detailed and Combined Thickness Groupings of Dynamic Beams

Average applied oscillating and peak ramp loads for detailed beam groupings can be found on page 11. Average oscillating loads were approximately half of the average ultimate loads for 2 and 4-inch PCC static testing. Figure 3.8 shows average applied oscillating and peak ramp loads for conditions of 2 and 4-inch PCC. For 2-inch PCC, average oscillating and peak ramp loads were similar; however, for 4-inch PCC average peak ramp loads were

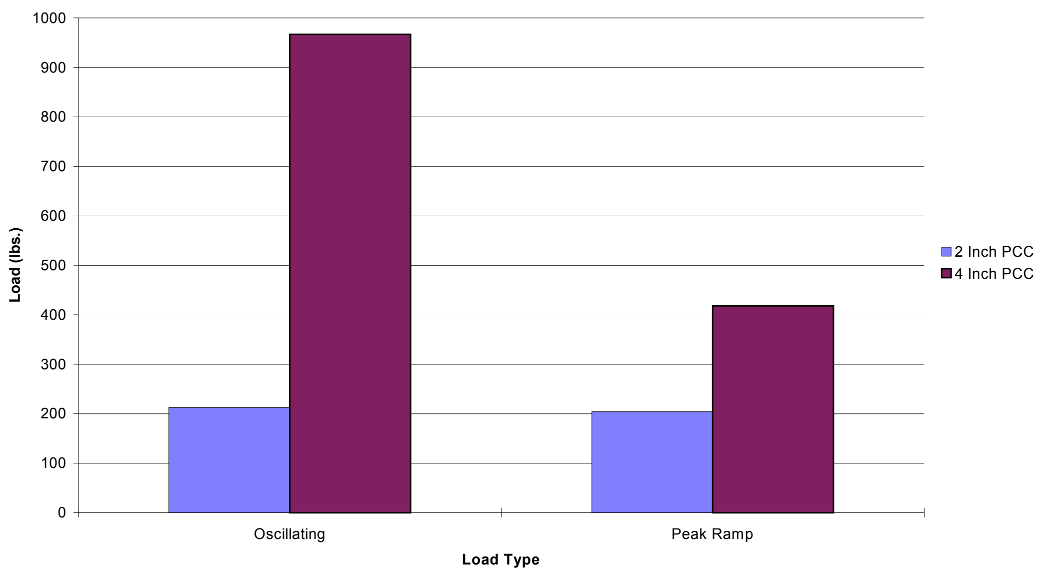


Figure 3.8 Average Applied Oscillating and Peak Ramp Loads for Conditions of 2 and 4-Inch PCC of Dynamic Beams

half the magnitude of average oscillating loads. The reason for this discrepancy was not understood. Figure 3.9 shows the average number of applied oscillating loads prior to failure for conditions of 2 and 4-inch PCC. The 2-inch PCC had a greater average number of applied oscillating loads prior to failure than the 4-inch PCC. This observation is not surprising considering that the oscillating load magnitude of the 4-inch PCC is nearly 5 times that of the 2-inch PCC. Due to the use of different oscillating and peak ramp loads, direct comparisons between 2 and 4-inch PCC was difficult.

Regardless of the PCC thickness small experimental shear strains were produced. The magnitude of the peak ramp loads combined with strain gage orientation resulted in the

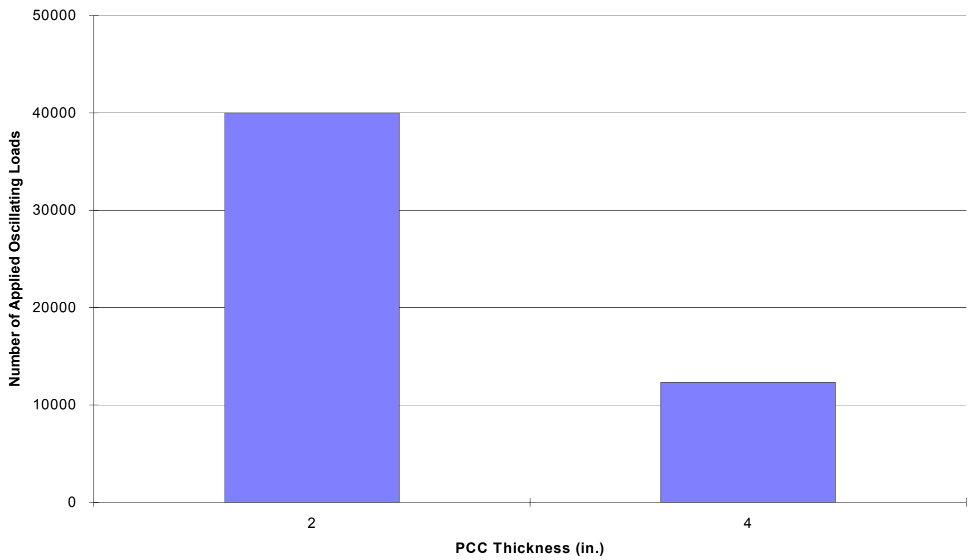


Figure 3.9 Average Number of Applied Oscillating Loads Prior to Failure for Conditions of 2 and 4-Inch PCC of Dynamic Beams

small shear strains. Small shear strains coupled with the inherent noise in the equipment setup made measurement and evaluation difficult. Figure 3.10 illustrates the small shear strains and equipment noise encountered for various runs. To limit noise and provide distinct shear strain values at the time of peak ramp load, piecewise linear regression was used. Figure 3.11 shows shear strain data after piecewise linear regression was applied.

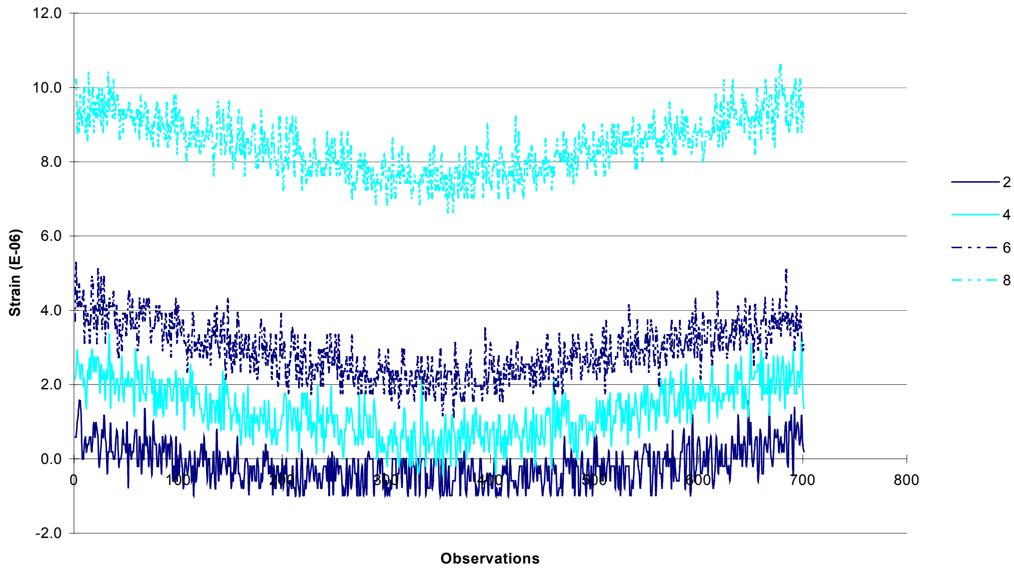


Figure 3.10 Small Shear Strains and Equipment Noise Encountered for Various Runs of Dynamic Beams

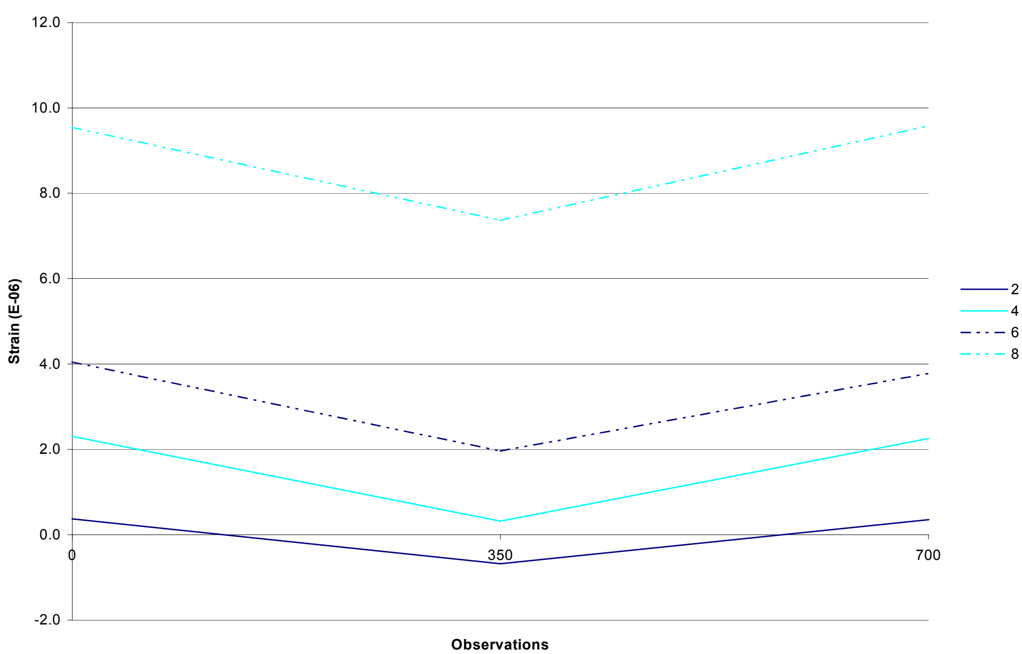


Figure 3.11 Shear Strain Data After Piecewise Linear Regression was Applied to Various Runs of Dynamic Beams

Theoretical and average experimental shear strains at peak ramp load for bonded and unbonded conditions of 2-inch and 4-inch PCC are shown in Figure 3.12 and Figure 3.13 respectively. For 2 and 4-inch PCC over the application of oscillating loads, theoretical shear strains obtained by modeling a bonded condition more closely approximated average experimental shear strains, indicating that a bonded condition was maintained. Second order polynomial regression applied to the average experimental shear strains shows an upward trend for both 2 and 4-inch PCC as the number of applied oscillating loads increase. These observations reveal that conditions became more critical as a result of fatigue. The R^2 values for the second order polynomial regression indicate the robustness of the data was adequate.

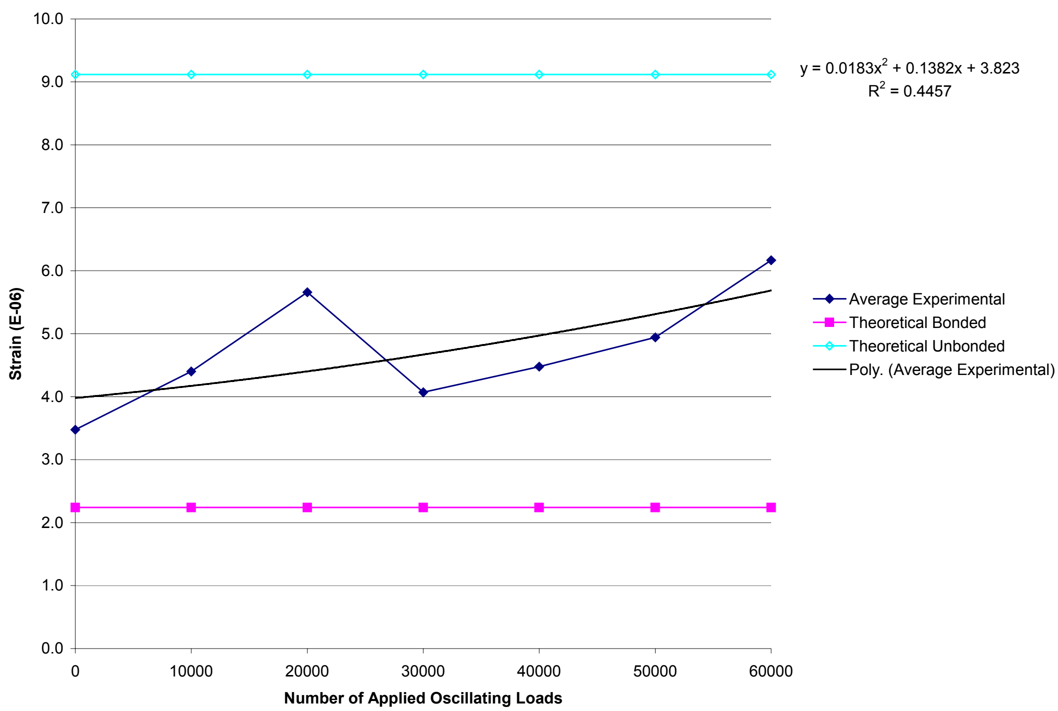


Figure 3.12 Theoretical and Average Experimental Shear Strains at Peak Ramp Load for Bonded and Unbonded Conditions of 2-Inch PCC of Dynamic Beams

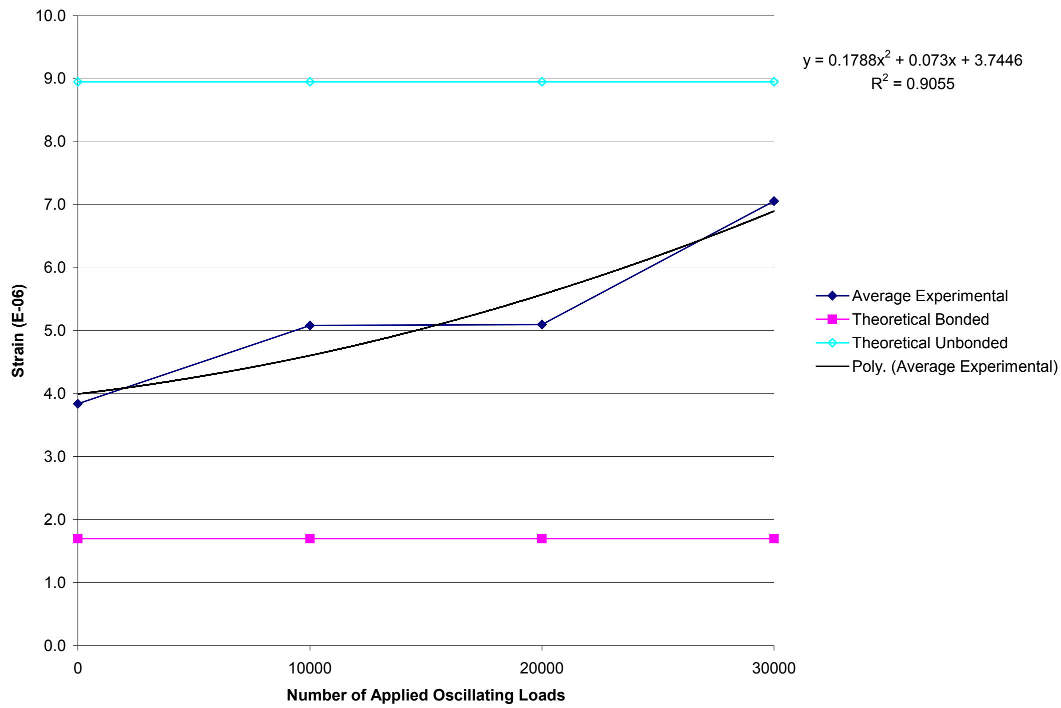


Figure 3.13 Theoretical and Average Experimental Shear Strains at Peak Ramp Load for Bonded and Unbonded Conditions of 4-Inch PCC of Dynamic Beams

To facilitate a direct comparison of shear strains between 2 and 4-inch PCC, applied oscillating loads were normalized to 4-inch PCC conditions. Previously developed second order polynomial regression equations were used to predict shear strains of 2 and 4-inch PCC with the normalized oscillating loads. Figure 3.14 details predicted shear strains for conditions of 2 and 4-inch PCC. As oscillating loads increased, predicted shear strains for 2-inch PCC increased more rapidly than for 4-inch PCC, showing that 2-inch PCC is more susceptible to fatigue. It should be noted that comparisons were only made to 30,000 oscillating loads due to a lack of data substantiating the regression equation for more oscillating loads.

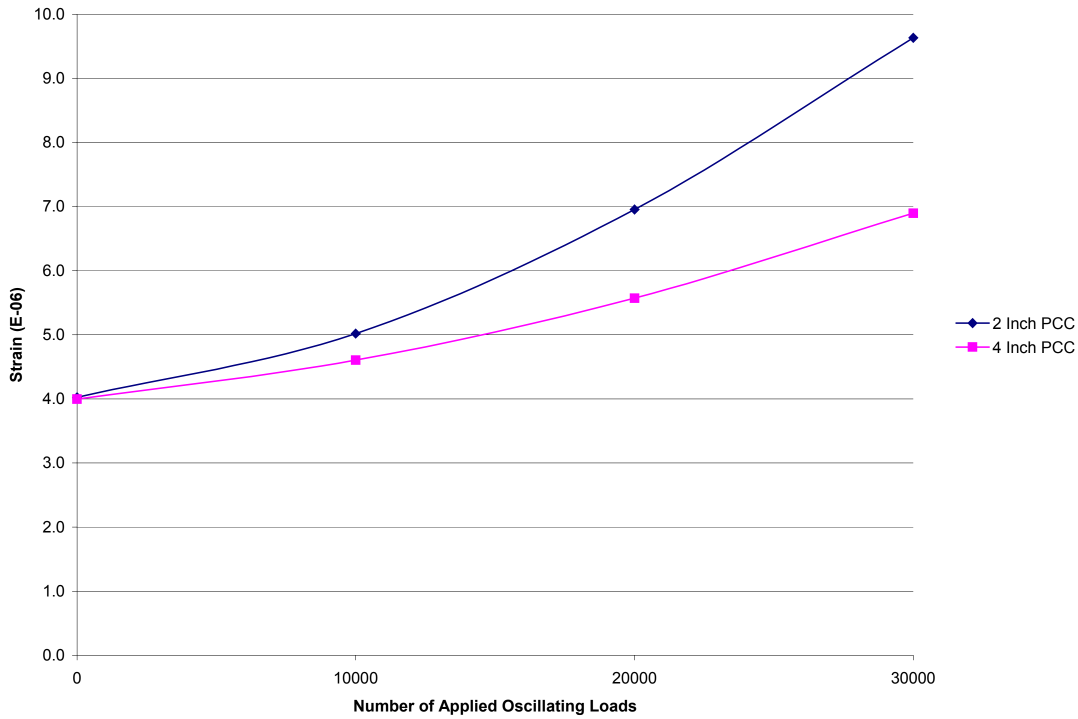


Figure 3.14 Predicted Shear Strains Using Normalized Oscillating Loads for Conditions of 2 and 4-Inch PCC of Dynamic Beams

Figure 3.15 shows the percent of observed failure modes for conditions of 2 and 4-inch PCC. Localized end failure was the only observed failure for 4-inch PCC and the average number of applied oscillating loads was extremely low. These two observations imply that 4-inch PCC loading conditions severely overstressed contact points on the ACC resulting in premature failure. Due to the premature failure, comparisons of 2 and 4-inch PCC could not be made. All types of failures were observed for 2-inch PCC and the number of average applied oscillating loads was moderate. These two observations imply that 2-inch PCC loading conditions overstressed contact points on the ACC after a substantial number of oscillating loads had been applied.

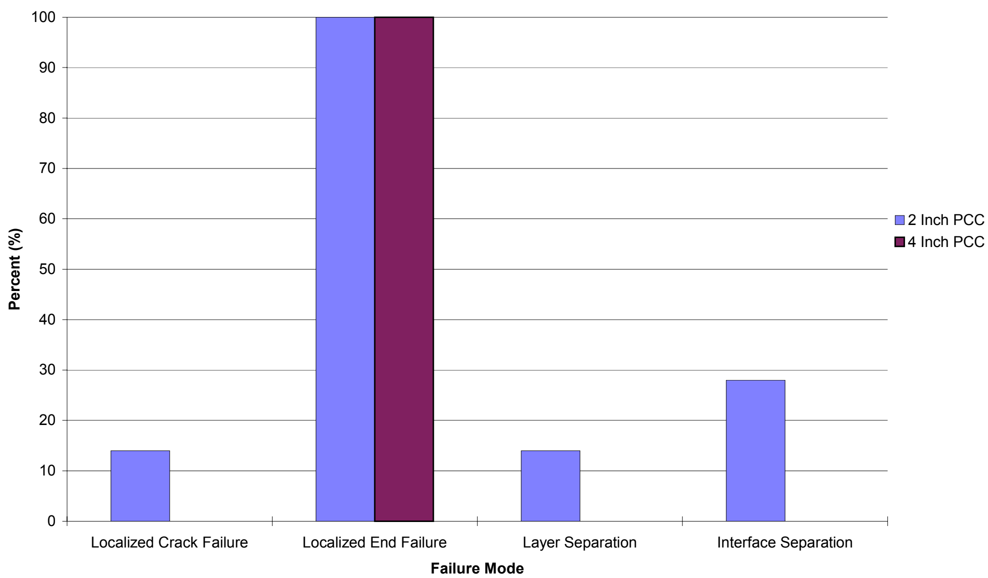


Figure 3.15 Percent of Observed Failure Modes for Conditions of 2 and 4-Inch PCC of Dynamic Beams

3.4 Strain and Temperature Testing

The objective of strain and temperature testing was to monitor interface strain in relation to the bonding condition over time and at various pavement temperatures. Due to limitations in time and expertise in complex structural modeling, efforts of this research concentrated on assembling data and identifying variables that most significantly impacted strains. This information will be helpful in focusing future modeling and evaluation efforts.

3.4.1 Data Preparation

Strain and temperature data from each site were assembled into an Excel spreadsheet. The data were reviewed for erroneous measurements resulting from reading errors or nonfunctioning gages. Erroneous measurements were removed and given no further consideration. Strain averages were calculated for gages on the same deflectometer. The final pour date and test dates were used to determine the age at testing. Data were separated into individual Excel spreadsheets based on opening time. Postopening time was considered postconstruction, while preopening time was considered construction. Postconstruction was the only data analyzed, ensuring the pavement system was stabilized. Plots of individual, average, and mean average strains versus PCC thickness, joint spacing, ACC surface preparation, synthetic fiber reinforcement usage, temperature, and age, were developed.

Data assembled on the Excel spreadsheet were copied into SPSS. Average strains were identified as the dependent variable. PCC thickness, joint spacing, ACC surface preparation, and synthetic fiber reinforcement usage were identified as factors. Levels within each factor were assigned dummy variables. Table 3.1 details how dummy variables were assigned. Temperature and age were considered covariates.

Table 3.1 Dummy Variable Assignment for Strain and Temperature Data

Factor	Level	Dummy Variable
PCC Thickness Grouping (in.)	3	0
	5	1
	7	2
Joint Spacing (ft. X ft.)	2 X 2	0
	4 X 4	1
	6 X 6	2
	12 X 12	3
ACC Surface Preparation	Milled	0
	Patch Only	1
	CIPR	2
Synthetic Fiber Usage	No Fiber	0
	Fiber	1

3.4.2 Statistical Treatment and Results

While assembling the strain and temperature data into an Excel spreadsheet it was discovered that 27% of the gages became nonfunctioning over time. In addition, 6 sites were completely destroyed by grading or maintenance mowing operations over time. Statistical analysis was difficult because of the large number of variables, lack of repetition, and incomplete matrix in the experimental design. Considering these factors as well as the loss of data over time, it was determined that an easier and more meaningful evaluation could be made by grouping data based on PCC thickness. Table 3.2 details how the PCC thicknesses were grouped.

Table 3.2 PCC Thickness Groupings for Strain and Temperature Data

PCC Thickness (in.)	PCC Thickness Grouping (in.)
$T \leq 4$	3
$4 > T \leq 6$	5
$T > 6$	7

T = PCC thickness

Strain and temperature versus age for site 1 and 29 are shown in Figure 3.16 and Figure 3.17 respectively. Site locations and as-built properties can be found on page 22. These sites were selected because their as-built properties are drastically opposite and their data were representative of the behavior of almost all of the sites. Temperature followed a regular up and down pattern clearly related to seasonal changes. Strains were constant in compression or tension until the age of approximately 480 days. At this time, a movement

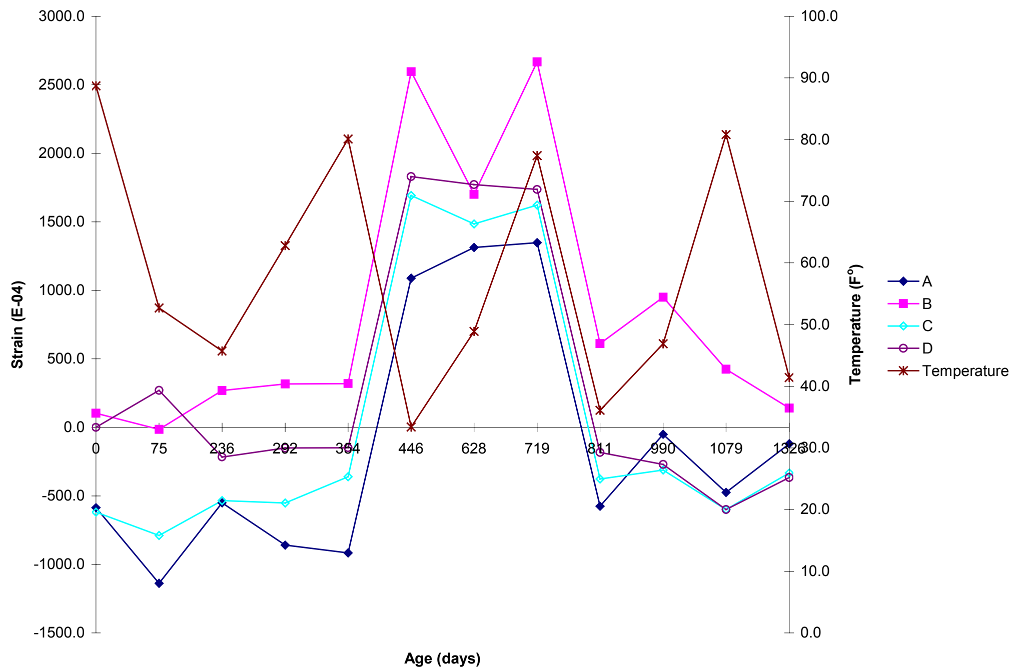


Figure 3.16 Temperature and Strain Versus Age for Site 1

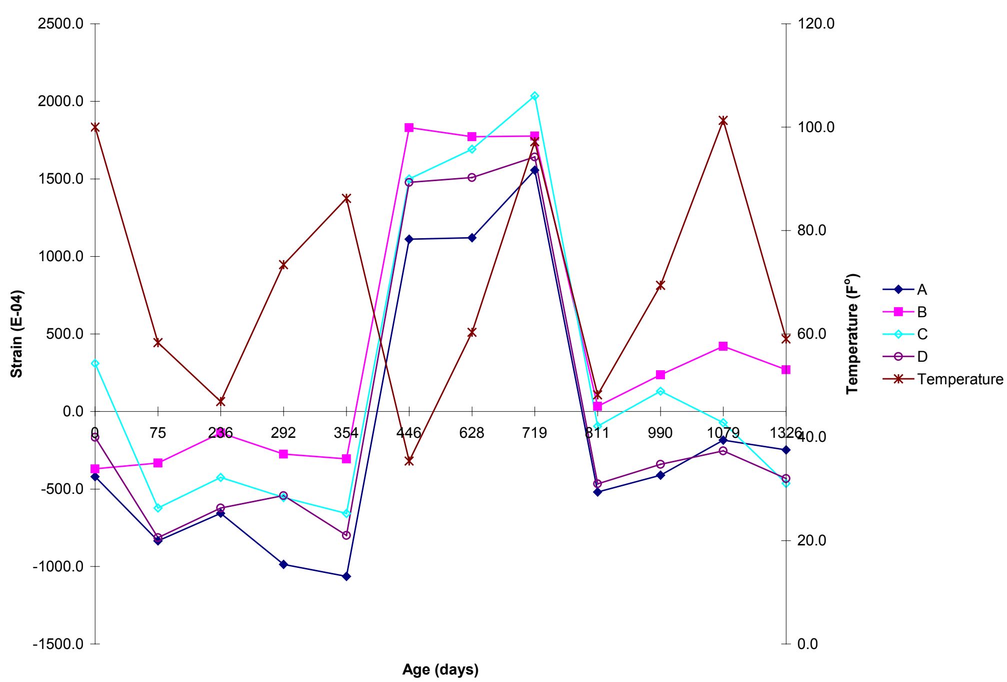


Figure 3.17 Temperature and Strain Versus Age for Site 29

into tension occurred along with increased magnitude. Strains remained at this elevated level of tension until approximately 760 days, when they returned to less compressive and more tensile conditions to those encountered before 480 days.

The substantial movement into tension may have occurred from a sudden widespread event or testing errors. The widespread nature of the event implies a connection to environmental conditions. Considering that the change occurred in 1995 between the months of August and November, temperature data shown were reviewed. Major temperature differentials did occur during September and October of 1995. Complex structural modeling may reveal the impact of these temperature differentials. The change is unlikely to have occurred from testing errors considering that all testing conditions were kept constant and the change was observed over an extended period of time. These observations indicate that temperature and age do impact strain.

Appendix B contains plots of average strain AB and CD versus PCC thickness, joint spacing, ACC surface preparation, synthetic fiber reinforcement usage, temperature, and age. The plots revealed slight relationships between average strains and PCC thickness, ACC surface preparation, temperature, and age. No relationships were observed between average strains and joint spacing or synthetic fiber reinforcement usage. The plots also revealed the existence of several outlying data points.

To compare the effect of PCC thickness, joint spacing, ACC surface preparation, synthetic fiber reinforcement usage, temperature, and age on average strains in detail, 2-way factorial analysis of variance with interaction was conducted. Individual 2-way factorial analysis of variance with interaction was used to limit complexity and make interactions more interpretable. PCC thickness was believed to be the most influential factor and therefore was used in all analyses. A significance level of 0.05 was used.

Boxplots in conjunction with histograms were used to evaluate whether the data were normally distributed. Examining the means for patterns of variance was used to evaluate whether the data exhibited equal variance. None of the data were found to be normally distributed or of equal variance. In an effort to satisfy the assumptions, outlying data points above the 99th percentile were examined and removed if considered erroneous and then a log transformation was applied. The log transformed data satisfied the assumptions of being normally distributed and of equal variance the best and therefore was used in all analyses.

Analyses were conducted by leaving missing data blank and by replacing missing data with factor level averages. A substantial difference was not observed when the two approaches were compared; therefore, results from leaving the missing data blank are discussed herein. Appendix B contains ANOVA tables for each individual 2-way factorial analysis of variance with interaction. Table 3.3 summarizes the results of the analyses. The results indicate the following:

1. None of the models adequately explain the variance in the dependent variable
2. The factor of ACC surface preparation was significant for AB
3. The factor of joint spacing was significant for CD
4. The covariate temperature was significant for all models
5. The covariate age was significant for all models of CD

Considering none of the models adequately explained the variance in the dependent variable, additional models were explored with varying combinations of factors and covariates. None were found to explain the variance in the dependent variable better than those presented in Table 3.3. All factors except synthetic fiber reinforcement usage were

Table 3.3 Summary of Two-Way Factorial Analysis of Variance with Interaction for Transformed Average Strain AB and CD

Strain	Model	Significant Factors Or Covariates	Model/Total Sum Of Squares	Notes
AB	T/JS/TEMP/AGE	TEMP	0.049	Incomplete Matrix
	T/SP/TEMP/AGE	TEMP, SP	0.110	Interaction Was Significant
	T/FU/TEMP/AGE	TEMP	0.041	-
CD	T/JS/TEMP/AGE	TEMP, AGE, JS	0.080	Incomplete Matrix
	T/SP/TEMP/AGE	TEMP, AGE	0.054	-
	T/FU/TEMP/AGE	TEMP, AGE	0.060	-

T = PCC thickness
JS = joint spacing
TEMP = temperature
AGE = age
SP = ACC surface preparation
FU = synthetic fiber usage

explored independently using 1-way analysis of variance with post HOC tests. Synthetic fiber reinforcement usage was explored using a 2-sample T test. A significance level of 0.05 was used. Methods similar to those previously mentioned were used to evaluate whether the data were normally distributed and of equal variance. The data were found to satisfy the assumptions. Appendix B contains multiple comparison tables for each individual 1-way analysis of variance with post HOC tests and a table for the 2-sample T test. Table 3.4 summarizes the results of the analyses. The results indicate the following:

1. Patch only surface preparation is significantly different from CIPR surface preparation for AB.
2. 4-foot joint spacing is significantly different from 6-foot joint spacing for CD.

The results concur with those obtained from the 2-way factorial analysis of variance with interaction. However, it is difficult to interpret the reason for and the meaning of the significant comparisons observed. No explanation can be provided as to why significant comparisons were not observed for both average strain AB and CD. The clarity

Table 3.4 Summary of One-Way Analysis of Variance With Post HOC Tests and Two-Sample T Test for Transformed Average Strain AB and CD

Strain	Factor	Significant Level	Compared To Level
AB	T	-	-
	JS	-	-
	SP	Patch Only	CIPR
	FU	-	-
CD	T	-	-
	JS	4	6
	SP	-	-
	FU	-	-

T = PCC thickness
JS = joint spacing
SP = ACC surface preparation
FU = synthetic fiber usage

and meaning of the results are further diminished from the occurrence of significance for comparisons that are similar rather than dissimilar.

Graphical comparisons of mean average strain AB and CD were used to explore PCC thickness, joint spacing, ACC surface preparation, synthetic fiber reinforcement usage, temperature, and age in more general terms. Temperature and age versus mean average strains for 3, 5, and 7-inch PCC are shown in Figure 3.18 and Figure 3.19 respectively. All PCC thicknesses showed elevated mean average strains at low temperatures. At intermediate temperatures all PCC thicknesses had moderate and fairly constant mean average strains. At higher temperatures, 5 and 7-inch PCC displayed more variable and lower mean average strains while 3-inch PCC displayed moderate mean average strains. For all PCC thicknesses, a change in mean average strains at an age of approximately 480 days occurred. A discussion

about this change can be found on page 49. Mean average strains from before and after the change reveal a slight increasing trend and more variability as age increases for all PCC

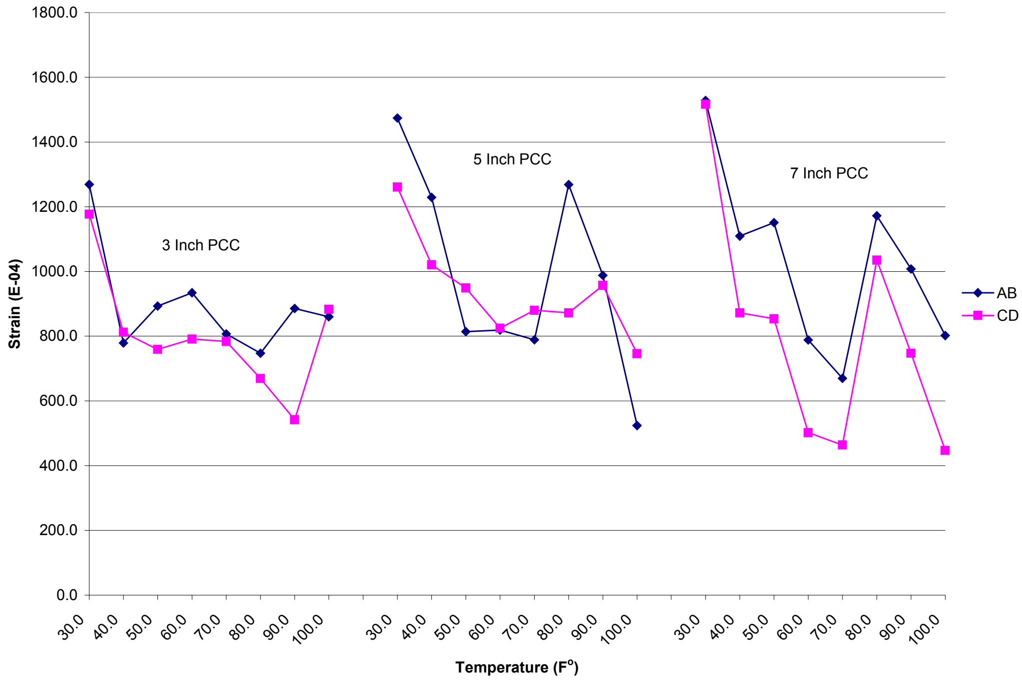


Figure 3.18 Mean Average Strain AB and CD Versus Temperature for 3, 5, and 7-Inch PCC

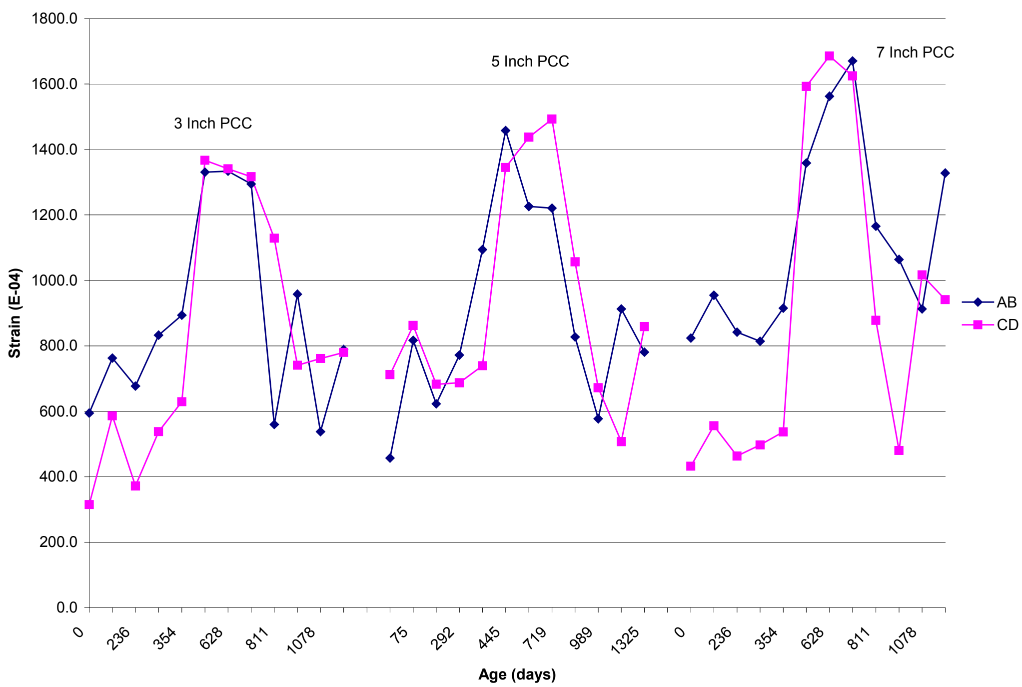


Figure 3.19 Mean Average Strain AB and CD Versus Age for 3, 5, and 7-Inch PCC

thicknesses. These observations indicate that temperature and age do impact strain. In particular, extreme temperatures and periods with drastic temperature changes appear to be the most influential.

Mean average strains versus PCC thickness are shown in Figure 3.20. Slightly higher mean average strains were observed as PCC thickness increased. This phenomenon was also observed across factors of joint spacing and ACC surface preparation as well as the covariates of temperature and age. Figure 3.21 shows mean average strains versus joint spacing for 3, 5, and 7-inch PCC. As joint spacing increased mean average strains were decreased for all PCC thicknesses. Observations for PCC thickness and joint spacing are

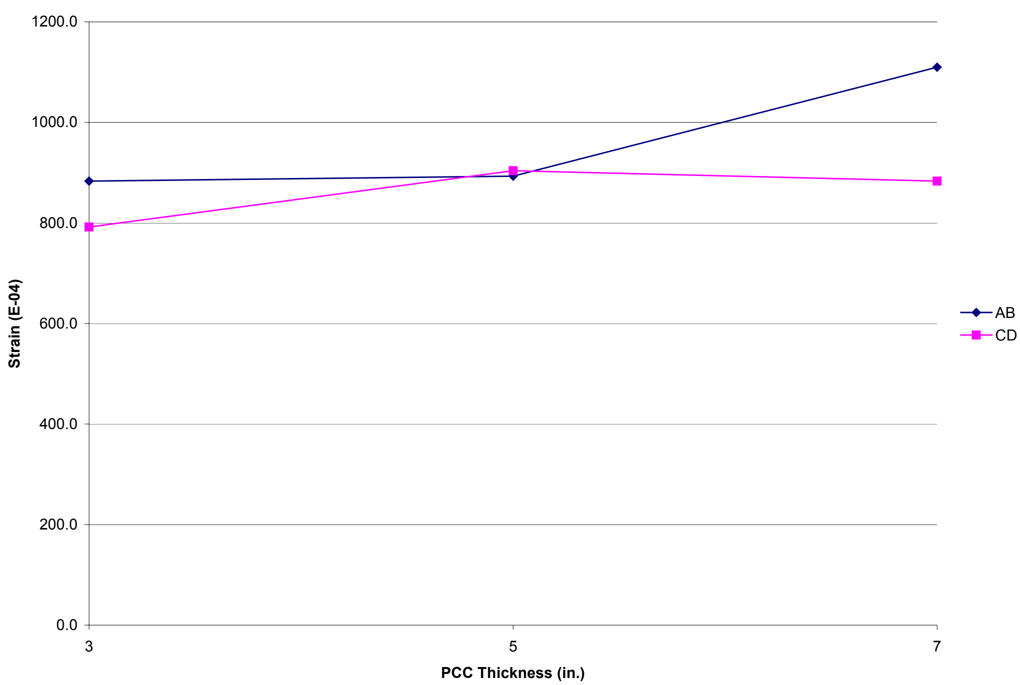


Figure 3.20 Mean Average Strain AB and CD Versus PCC Thickness

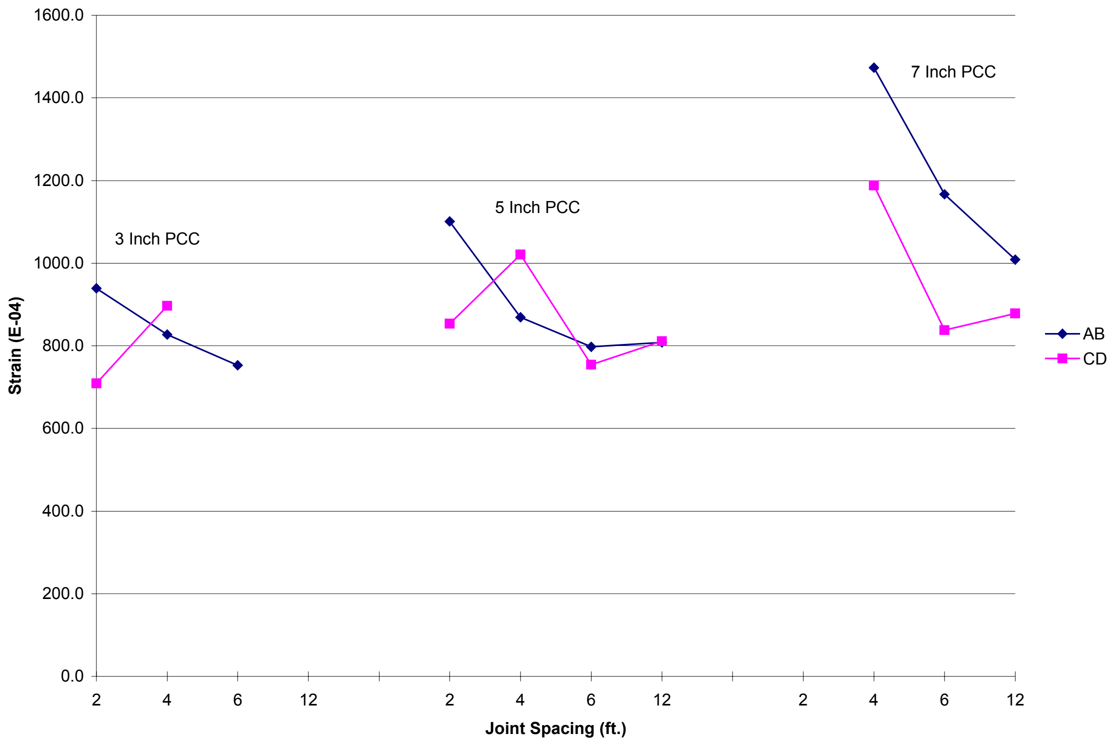


Figure 3.21 Mean Average Strain AB and CD Versus Joint Spacing for 3, 5, and 7-Inch PCC

contrary to conventional PCC pavement theory. Complex structural modeling may reveal the reason for these transgressions. Figure 3.22 shows mean average strains versus ACC surface preparation for 3, 5, and 7-inch PCC. For all PCC thicknesses, elevated mean average strains were observed for patch only surface preparation while milled and CIPR surface preparations had lower, similar mean average strains. No reason can be provided for these observations. Figure 3.23 shows mean average strains versus synthetic fiber reinforcement usage for 3, 5, and 7-inch PCC. No discernable trends were observed for synthetic fiber reinforcement usage.

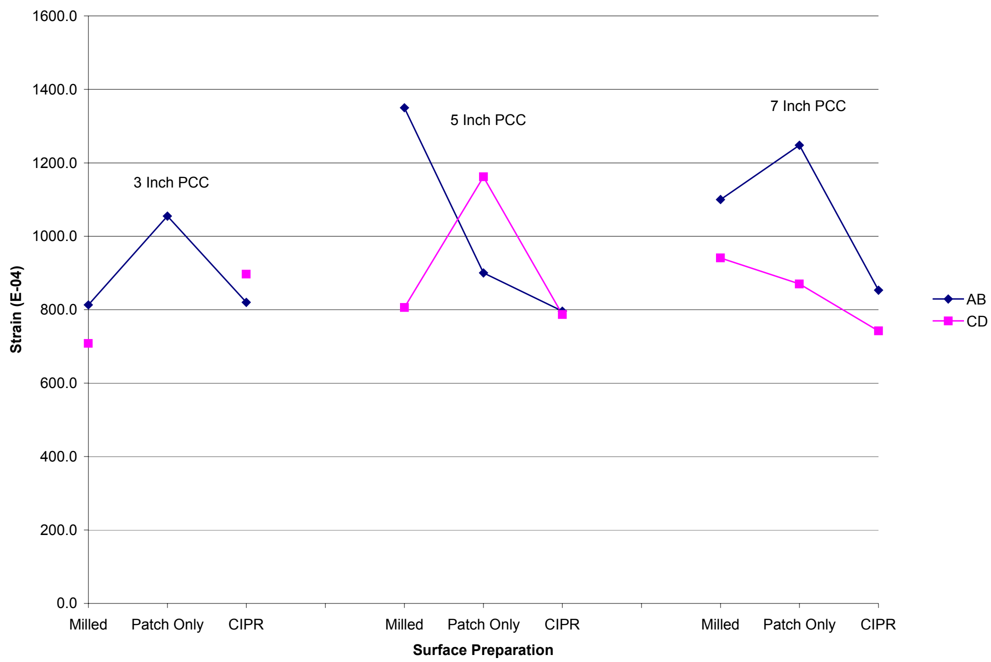


Figure 3.22 Mean Average Strain AB and CD Versus ACC Surface Preparation for 3, 5, and 7-Inch PCC

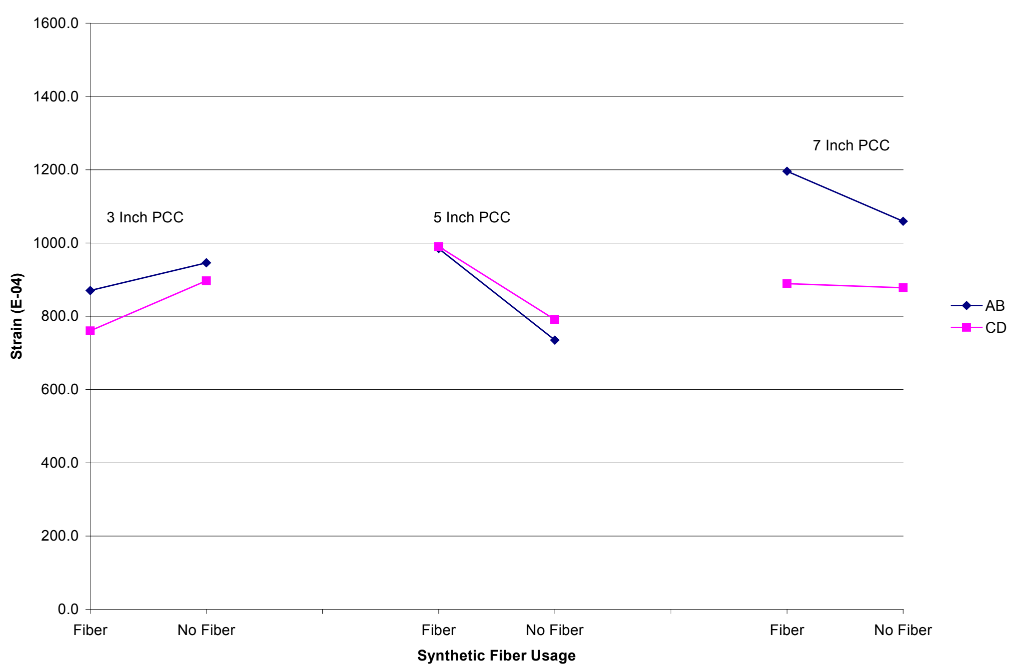


Figure 3.23 Mean Average Strain AB and CD Versus Synthetic Fiber Usage for 3, 5, and 7-Inch PCC

3.5 Falling Weight Deflectometer Testing

The objective of FWD testing was to monitor deflection responses in relation to the bonding condition over time. Several back calculation techniques were investigated to model and evaluate bonded and unbonded conditions but none were found that appropriately represented UTW. Due to the limitations of available backcalculation techniques, efforts of this research concentrated on assembling data and identifying variables that most significantly impacted deflection responses.

3.5.1 Data Preparation

FWD data from each testing period were assembled into an Excel spreadsheet. The data were reviewed for erroneous measurements resulting from reading errors. No erroneous measurements were found. Data were organized by station, date, and applied load. Observations of D4, D5, and D6 were removed because the upper pavement region, measured by D0, D1, D2, and D3, was the only area of interest. In addition, D4, D5, and D6 were often positioned across joints, resulting in variable conditions due to load transfer differences. Only data for an applied load of 9 kips were analyzed, considering deflection responses would only be shifted up or down as a result of different load magnitudes. Deflection responses were normalized to exactly 9 kips using a linear relationship.

Percent reductions in deflection responses for each testing period after UTW construction were calculated. Deflection responses before UTW construction were used as the baseline. The use of percent reduction in deflection responses eliminated any bias resulting from variations in existing foundation support. Changes in percent reduction in deflection responses between testing periods were calculated. Deflection responses immediately after UTW construction were used as the baseline. Plots of percent reduction in deflection responses and changes in percent reduction in deflection responses versus PCC thickness, joint spacing, ACC surface preparation, synthetic fiber reinforcement usage, and age were developed.

Data assembled on the Excel spreadsheet were copied into SPSS. Percent reduction in deflection responses and changes in percent reduction in deflection responses were identified as dependent variables. PCC thickness, joint spacing, ACC surface preparation, and synthetic fiber reinforcement usage were identified as factors. Levels within each factor were assigned dummy variables. Dummy variables assigned can be found on page 48. Age was considered a covariate.

3.5.2 Statistical Treatment and Results

Statistical analysis was difficult because of the large number of variables, lack of repetition, and incomplete matrix in the experimental design. Considering these factors, it was determined that an easier more meaningful evaluation could be made by grouping data based on PCC thickness. PCC thickness groupings used for strain and temperature testing were believed to be appropriate and were employed. PCC thickness groupings can be found on page 49.

3.5.2.1 Percent Reduction in Deflection Responses

Appendix C contains plots of percent reduction in deflection responses D0, D1, D2, and D3 versus PCC thickness, joint spacing, ACC surface preparation, and synthetic fiber reinforcement usage. The plots revealed substantial relationships between percent reduction in deflection responses and PCC thickness and joint spacing. No relationships were observed between percent reduction in deflection responses and ACC surface preparation or synthetic fiber reinforcement usage. The plots also revealed the existence of outlying data points.

To compare the effect of PCC thickness, joint spacing, ACC surface preparation, and synthetic fiber reinforcement usage on percent reduction in deflection responses in detail, 2-way factorial analysis of variance with interaction was conducted. Individual 2-way factorial analysis of variance with interaction was used to limit complexity and make interactions more interpretable. PCC thickness was believed to be the most influential factor and therefore was used in all analyses. A significance level of 0.05 was used.

Boxplots in conjunction with histograms were used to evaluate whether the data were normally distributed. Examining the means for patterns of variance was used to evaluate whether the data exhibited equal variance. Percent reduction in deflection responses D0 and D1 were found to only marginally satisfy assumptions of normality and equal variance. In an effort to satisfy the assumptions more fully, outlying data points above the 99th percentile were examined and removed if considered erroneous and then a log transformation was investigated. None of the outlying data points were found to be erroneous. The transform did not improve the data with respect to satisfying the assumptions; therefore, the nontransformed data were considered acceptable and are discussed herein.

Appendix C contains ANOVA tables for each individual 2-way factorial analysis of variance with interaction. Table 3.5 summarizes the results of the analyses. The results indicate the following:

1. All of the models adequately explain the variance in the dependent variable
2. The factor of thickness was significant for all models

Table 3.5 Summary of Two-Way Factorial Analysis of Variance With Interaction for Percent Reduction in Deflection Responses D0, D1, D2, and D3

Radial Distance	Model	Significant Factors	Model/Total Sum Of Squares	Notes
D0	T/JS	T	0.571	Incomplete Matrix
	T/SP	T	0.551	-
	T/FU	T	0.511	-
D1	T/JS	T	0.597	Incomplete Matrix
	T/SP	T	0.563	-
	T/FU	T	0.504	-
D2	T/JS	T	0.655	Incomplete Matrix
	T/SP	T	0.577	-
	T/FU	T	0.545	-
D3	T/JS	T	0.589	Incomplete Matrix
	T/SP	T	0.650	-
	T/FU	T	0.567	-

T = PCC thickness
JS = joint spacing
SP = ACC surface preparation
FU = synthetic fiber usage

All factors except synthetic fiber reinforcement usage were explored independently using 1-way analysis of variance with post HOC tests. Synthetic fiber reinforcement usage was explored using a 2-sample T test. A significance level of 0.05 was used. Methods similar to those previously mentioned were used to verify that the data were normally distributed and of equal variance. Appendix C contains multiple comparison tables for each individual 1-way analysis of variance with post HOC tests and a table for the 2-sample T test. Table 3.6 summarizes the results of the analyses. The results indicate the following:

1. 3-inch PCC is significantly different from 5 and 7-inch PCC for D0, D1, D2, and D3
2. 12-foot joint spacing is significantly different from 2 and 6-foot joint spacing for D0, D1, D2, and D3
3. 4-foot joint spacing is significantly different from 6-foot joint spacing for D2
4. No fiber sections are significantly different from sections with fiber for D2 and D3

Table 3.6 Summary of One-Way Analysis of Variance With Post HOC Tests and Two-Sample T Test for Percent Reduction in Deflection Responses D0, D1, D2, and D3

Radial Distance	Factor	Significant Level	Compared To Level
D0	T	3	5, 7
	JS	12	2, 4, 6
	SP	-	-
	FU	-	-
D1	T	3	5, 7
	JS	12	2, 4, 6
	SP	-	-
	FU	-	-
D2	T	3	5, 7
	JS	12; 6	2, 4; 4
	SP	-	-
	FU	No Fiber	Fiber
D3	T	3	5, 7
	JS	12	2, 4
	SP	-	-
	FU	No Fiber	Fiber

T = PCC thickness SP = ACC surface preparation
JS = joint spacing FU = synthetic fiber usage

The results concur with those obtained from the 2-way factorial analysis of variance with interaction for PCC thickness. The significant comparisons observed for joint spacing are explained from the inherent relationship of larger joint spacing for thicker PCC. No explanation can be provided as to why the significant comparisons for synthetic fiber usage are observed. The repeated significance of comparisons for all radial distances coupled with the occurrence of significance for comparisons that are dissimilar enhanced the clarity and meaning of the results.

Graphical comparisons of mean percent reduction in deflection responses D0, D1, D2, and D3 were used to explore PCC thickness, joint spacing, ACC surface preparation, and synthetic fiber reinforcement usage in more general terms. Mean percent reduction in deflection responses versus PCC thickness are shown in Figure 3.24. Substantially higher mean percent reduction in deflection responses were observed as PCC thickness increased. This phenomenon was also observed across factors of joint spacing, ACC surface preparation, and synthetic fiber reinforcement usage. These observations indicate that PCC thickness is the primary factor controlling deflection responses initially. As the PCC became thicker, the rate of increase in mean percent reduction in deflection responses diminished. This suggests that an optimal PCC thickness exists.

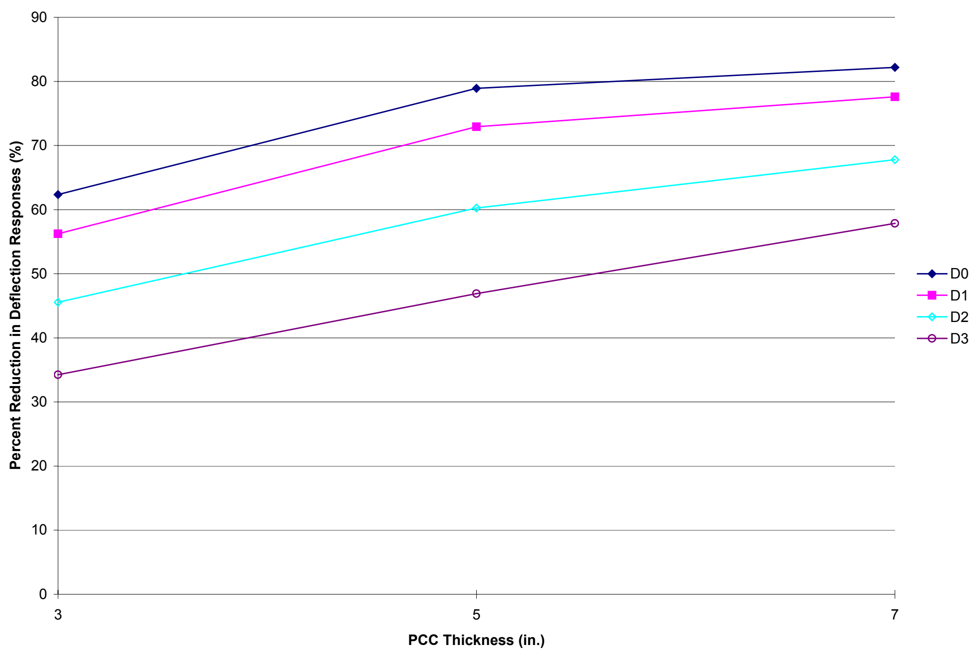


Figure 3.24 Mean Percent Reduction in Deflection Responses D0, D1, D2, and D3 Versus PCC Thickness

Figure 3.25 shows mean percent reduction in deflection responses versus joint spacing for 3, 5, and 7-inch PCC. For 3-inch PCC, mean percent reduction in deflection responses decreased as joint spacing increased. For 5 and 7-inch PCC, mean percent reduction in deflection responses increased as joint spacing increased. These observations indicate that thinner PCC dissipates loads more effectively with smaller joint spacing while

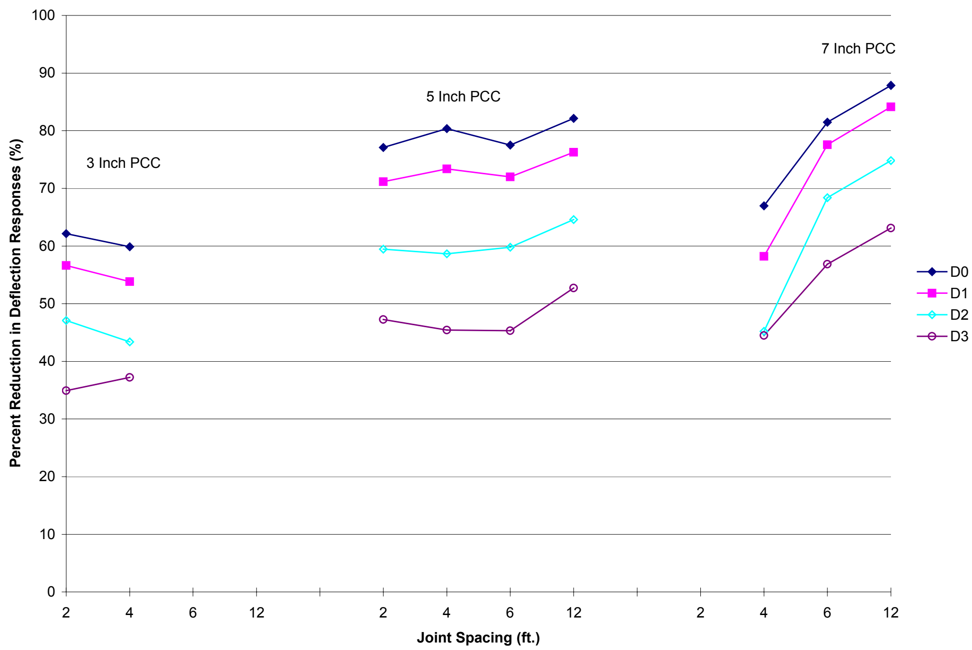


Figure 3.25 Mean Percent Reduction in Deflection Responses D0, D1, D2, and D3 Versus Joint Spacing for 3, 5, and 7-Inch PCC

thicker PCC dissipates loads more effectively with larger joint spacing. This is explained by considering the load dissipation method in relation to PCC thickness. Loads are dissipated by compression for smaller joint spacing and by bending for larger joint spacing. Thicker PCC can resist bending more effectively and therefore reduces deflections more effectively with larger joint spacing. Thinner PCC cannot resist bending as well and therefore reduces deflections more effectively with smaller joint spacing through compression. Figure 3.26 shows mean percent reduction in deflection responses versus ACC surface preparation for 3, 5, and 7-inch PCC. For 3 and 7-inch PCC, elevated mean percent reduction in deflection responses were observed for patch only surface preparation while milled and CIPR surface

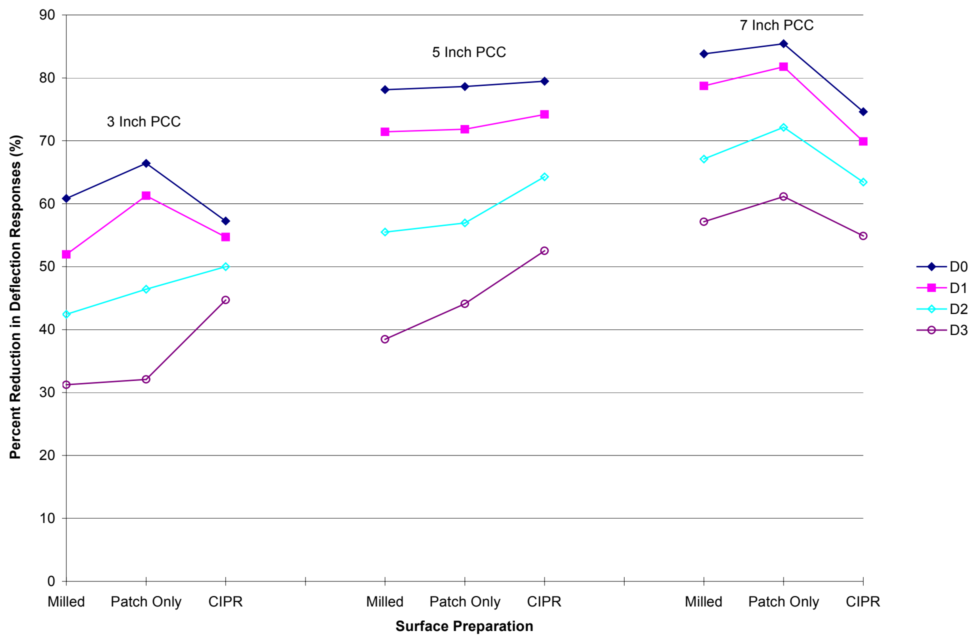


Figure 3.26 Mean Percent Reduction in Deflection Responses D0, D1, D2, and D3 Versus ACC Surface Preparation for 3, 5, and 7-Inch PCC

preparations had lower, similar mean percent reduction in deflection responses. These observations indicate that the milling and CIPR provide less structure initially. Milling provides less structure due to the removal of ACC material while CIPR provides less structure because it is recently placed and has not age hardened. Figure 3.27 shows mean percent reduction in deflection responses versus synthetic fiber reinforcement usage for 3, 5, and 7-inch PCC. For 3-inch PCC, no fiber had higher mean percent reduction in deflection responses. No explanation for this observation can be provided. Trends were not observed for synthetic fiber reinforcement usage, for 5 and 7-inch PCC.

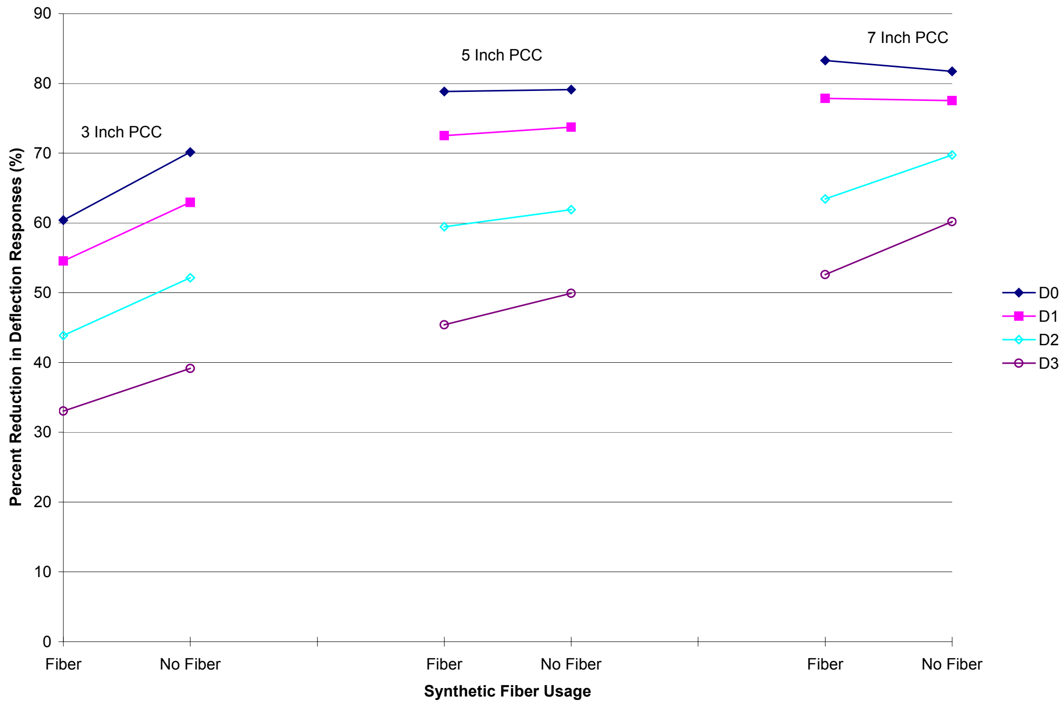


Figure 3.27 Mean Percent Reduction in Deflection Responses D0, D1, D2, and D3 Versus Synthetic Fiber Usage for 3, 5, and 7-Inch PCC

3.5.2.2 Change in Percent Reduction in Deflection Responses

Appendix D contains plots of changes in percent reduction in deflection responses D0, D1, D2, and D3 versus PCC thickness, joint spacing, ACC surface preparation, synthetic fiber reinforcement usage, and age. The plots revealed a substantial relationship between change in percent reduction in deflection responses and PCC thickness. No relationships were observed between change in percent reduction in deflection responses and joint spacing, ACC surface preparation, synthetic fiber reinforcement usage, or age. In addition, the plots revealed the existence of a few outlying data points.

To compare the effect of PCC thickness, joint spacing, ACC surface preparation, synthetic fiber reinforcement usage, and age on change in percent reduction in deflection responses in detail, 2-way factorial analysis of variance with interaction was conducted.

Individual 2-way factorial analysis of variance with interaction was used to limit complexity and make interactions more interpretable. PCC thickness was believed to be the most influential factor and therefore was used in all analyses. A significance level of 0.05 was used.

Boxplots in conjunction with histograms were used to evaluate whether the data were normally distributed. Examining the means for patterns of variance was used to evaluate whether the data exhibited equal variance. Change in percent reduction in deflection responses D0, D1, D2, and D3 were found to satisfy the assumption of normality but only marginally satisfied the assumption of equal variance. In an effort to satisfy the assumption of equal variance more fully, outlying data points above the 99th percentile were examined and removed if considered erroneous and then a log transformation was investigated. None of the outlying data points were found to be erroneous. The transform did not improve the data with respect to satisfying the assumption of equal variance; therefore, the nontransformed data were considered acceptable and is discussed herein.

Appendix D contains ANOVA tables for each individual 2-way factorial analysis of variance with interaction. Table 3.7 summarizes the results of the analyses. The results indicate the following:

1. All of the models adequately explain the variance in the dependent variable
2. The factor of thickness was significant for all models except T/FU/AGE for D3
3. The factor of joint spacing was significant for all models except for D2
4. The factor of ACC surface preparation was significant for all models except for D3
5. The covariate of age was significant for all models of D2

Table 3.7 Summary of Two-Way Factorial Analysis of Variance With Interaction for Change in Percent Reduction in Deflection Responses D0, D1, D2, and D3

Radial Distance	Model	Significant Factors	Model/Total Sum Of Squares	Notes
D0	T/JS/AGE	T, JS	0.340	Incomplete Matrix
	T/SP/AGE	T, SP	0.393	Interaction Was Significant
	T/FU/AGE	T	0.220	-
D1	T/JS/AGE	T, JS	0.245	Incomplete Matrix
	T/SP/AGE	T, SP	0.429	Interaction Was Significant
	T/FU/AGE	T	0.202	-
D2	T/JS/AGE	T, AGE	0.363	Incomplete Matrix
	T/SP/AGE	T, SP, AGE	0.437	Interaction Was Significant
	T/FU/AGE	T, AGE	0.329	-
D3	T/JS/AGE	JS	0.305	Incomplete Matrix
	T/SP/AGE	T	0.193	Interaction Was Significant
	T/FU/AGE	-	0.161	-

T = PCC thickness
JS = joint spacing
AGE = age
SP = ACC surface preparation
FU = synthetic fiber usage

All factors except synthetic fiber reinforcement usage were explored independently using 1-way analysis of variance with post HOC tests. Synthetic fiber reinforcement usage was explored using a 2-sample T test. A significance level of 0.05 was used. Methods similar to those previously mentioned were used to verify that the data were normally distributed and of equal variance. Unequal variance of change in percent reduction in deflection responses D0, D1, D2, and D3 was observed for some factors. Results from Tamhane's multiple range test and 2-sample T test equal variances not assumed were used when unequal variances occurred. Appendix D contains multiple comparison tables for each individual 1-way analysis of variance with post HOC tests and a table for the 2-sample T test. Table 3.8 summarizes the results of the analyses. The results indicate the following:

1. 3-inch PCC is significantly different from 5 and 7-inch PCC for D0, D1, D2, and D3
2. 12-foot joint spacing is significantly different from 2 and 6-foot joint spacing for D0, D1, D2, and D3
3. 4-foot joint spacing is significantly different from 6-foot joint spacing for D2
4. No fiber sections are significantly different from sections with fiber for D2 and D3

Table 3.8 Summary of One-Way Analysis of Variance With Post HOC Tests and Two-Sample T Test for Change in Percent Reduction in Deflection Responses D0, D1, D2, and D3

Radial Distance	Factor	Significant Level	Compared To Level
D0	T	3	5, 7
	JS	6	4
	SP	-	-
	FU	No Fiber	Fiber
D1	T	3	5, 7
	JS	6	4
	SP	Milled	CIPR
	FU	No Fiber	Fiber
D2	T	3	5, 7
	JS	6	2
	SP	-	-
	FU	No Fiber	Fiber
D3	T	3	5, 7
	JS	6	2, 4, 12
	SP	-	-
	FU	No Fiber	Fiber

T = PCC thickness SP = ACC surface preparation
JS = joint spacing FU = synthetic fiber usage

The results concur with those obtained from the 2-way factorial analysis of variance with interaction for PCC thickness. The significant comparisons observed for joint spacing are explained from the inherent relationship of larger joint spacing for thicker PCC coupled with how loads are dissipated relative to joint spacing and PCC thickness. No explanation can be provided as to why significant comparisons are not observed for ACC surface preparation but are observed for synthetic fiber usage. The repeated significance of comparisons for all radial distances coupled with the occurrence of significance for comparisons that are dissimilar enhanced the clarity and meaning of the results.

Graphical comparisons of mean change in percent reduction in deflection responses D0, D1, D2, and D3 for year 3 were used to explore PCC thickness, joint spacing, ACC surface preparation, and synthetic fiber reinforcement usage in more general terms. Only year 3 was considered because it was representative of all other ages and allowed for the most recent data to be presented. Mean change in percent reduction in deflection responses versus PCC thickness are shown in Figure 3.28. Substantially lower mean change in percent

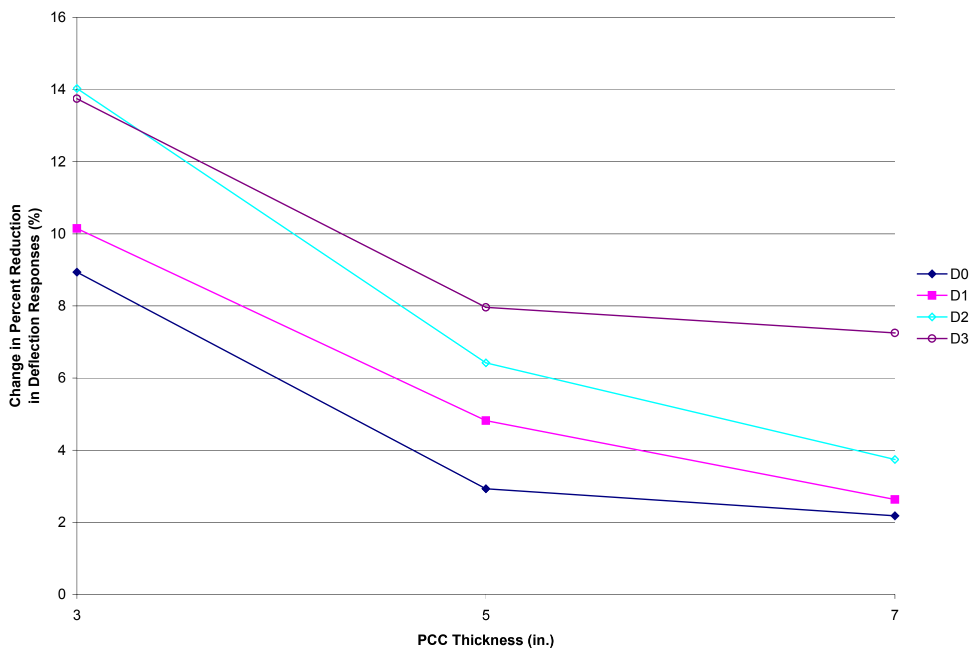


Figure 3.28 Mean Change in Percent Reduction in Deflection Responses D0, D1, D2, and D3 Versus PCC Thickness

reduction in deflection responses were observed as PCC thickness increased. This phenomenon was also observed across factors of joint spacing, ACC surface preparation, and synthetic fiber reinforcement usage. These observations indicate that PCC thickness is the primary factor controlling deflection responses over time. As the PCC became thicker, the rate of decrease in mean change in percent reduction in deflection responses diminished. This suggests that an optimal PCC thickness exists.

Figure 3.29 shows mean change in percent reduction in deflection responses versus joint spacing for 3, 5, and 7-inch PCC. Mean change in percent reduction in deflection responses increased as joint spacing increased for 3-inch PCC and decreased for 5-inch PCC. These observations can be explained by how loads are dissipated and indicate that less

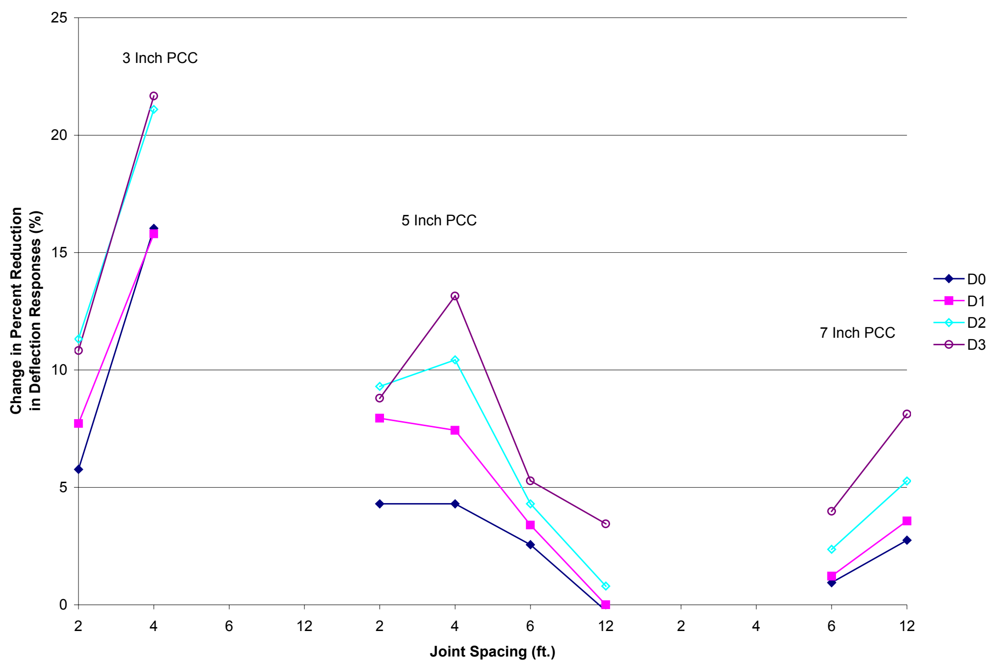


Figure 3.29 Mean Change in Percent Reduction in Deflection Responses D0, D1, D2, and D3 Versus Joint Spacing for 3, 5, and 7-Inch PCC

efficient methods of load dissipation result in increased deflections responses over time. For 7-inch PCC, mean change in percent reduction in deflection responses increased as joint spacing increased. This observation cannot be explained; however, magnitudes were extremely small and other factors may have shown their influence.

Figure 3.30 shows mean change in percent reduction in deflection responses versus

ACC surface preparation for 3, 5, and 7-inch PCC. For 3 and 5-inch PCC, elevated mean change in percent reduction in deflection responses were observed for CIPR surface preparation while milled and patch only surface preparations had lower, similar mean change in percent reduction in deflection responses. These observations indicate that the milling and

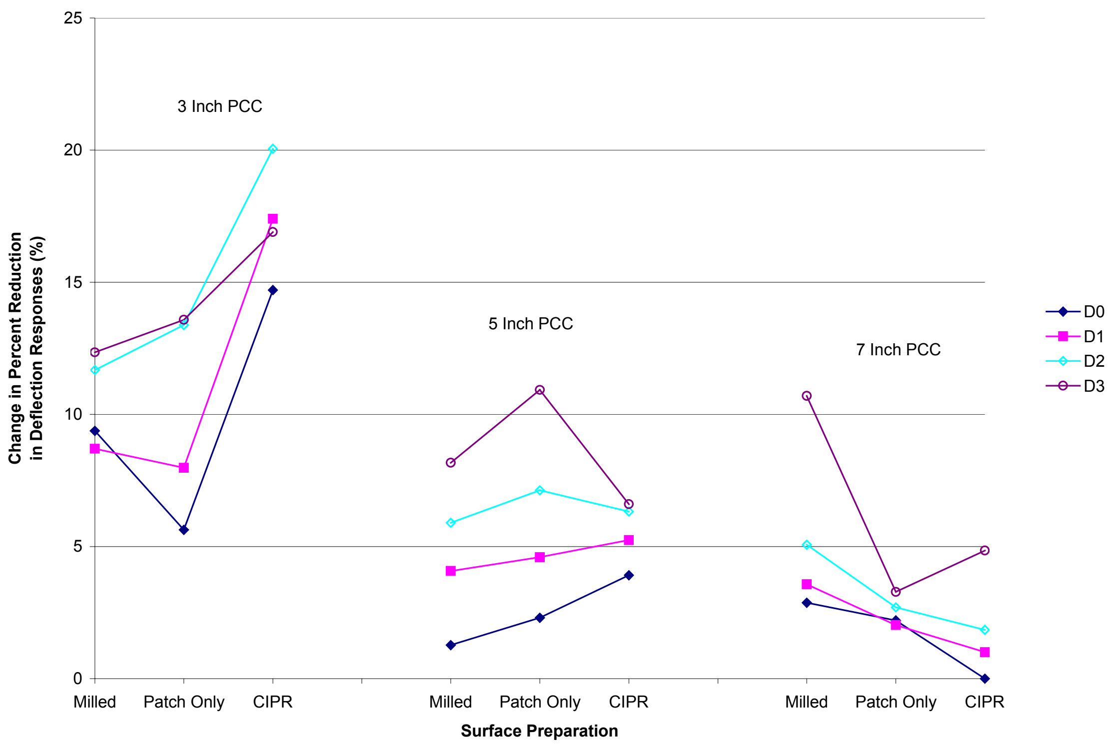


Figure 3.30 Mean Change in Percent Reduction in Deflection Responses D0, D1, D2, and D3 Versus ACC Surface Preparation for 3, 5, and 7-Inch PCC

patch only maintain their structure better over time. They do so because they are age hardened and more stabilized. For 7-inch PCC, elevated mean change in percent reduction in deflection responses were observed for milled and patch only surface preparations. This observation cannot be explained; however, magnitudes were extremely small and other factors may have shown their influence. Figure 3.31 shows mean change in percent reduction in deflection responses versus synthetic fiber reinforcement usage for 3, 5, and 7-inch PCC. For all PCC thicknesses, mean changes in percent reduction in deflection responses were less for no fiber. No explanation for this observation can be provided.

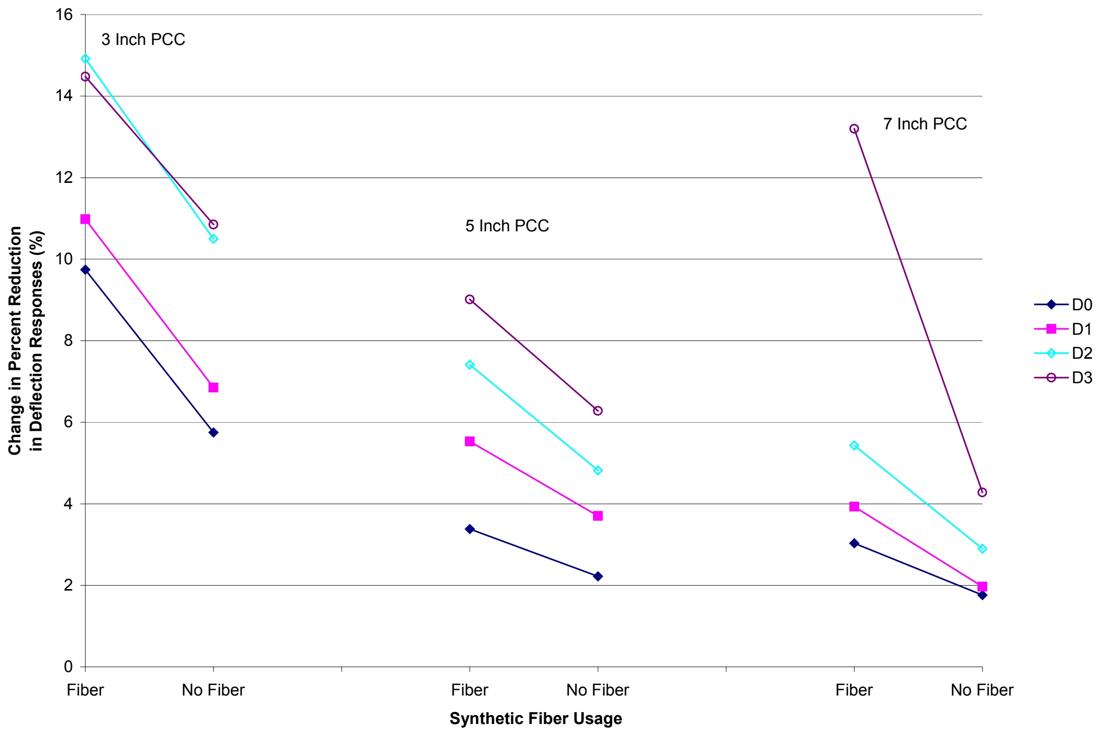


Figure 3.31 Mean Change in Percent Reduction In Deflection Responses D0, D1, D2, and D3 Versus Synthetic Fiber Usage For 3, 5, and 7-Inch PCC

3.5.3 Base Prewetting

The asphalt base surface was wet in sections 1-11, immediately in front of the paving machine. Water was sprayed on the surface with a hose from the readymix concrete trucks in an attempt to enhance bond and reduce concrete water loss from the hot base surface. Subsequent deflection indicated a weaken section in these areas during the initial pavement life. Prewetting may be used sufficiently in advance of the paving machine to cool the asphalt surface. This distance should be long enough to allow the pavement to surface dry prior to the overlay application.

3.6 Direct Shear Testing

The primary objective of direct shear testing was to quantitatively measure the interface bond over time. A secondary objective of direct shear testing was to visually observe the interface bonding condition. Direct shear testing was added to the initial scope of field testing and was conducted when the project was 3 and 5 years old. Future testing is scheduled when the project will be 7 years old. Data presented herein represents testing conducted when the project was 3 and 5 years old.

3.6.1 Data Preparation

Data collected for each core obtained were assembled onto an Excel spreadsheet. Conditional observations related to bond condition when cores were obtained, acceptability of cores for testing, and break location were summarized numerically based on occurrence for each of the 8 sections tested. Data assembled on the Excel spreadsheet were copied into SPSS. Direct shear strength was identified as the dependent variable, and joint spacing, ACC surface preparation, and age were identified as factors. Levels within each factor were assigned dummy variables. Dummy variables assigned can be found on page 48.

3.6.2 Statistical Treatment and Results

The percent of cores visually observed to have a bonded interface when obtained in the field is shown in Figure 3.32. A high percent of cores were observed to be bonded when obtained in the field for both year 3 and 5, indicating that a bonded interface was normal regardless of age or variables considered and that the coring method was nondestructive.

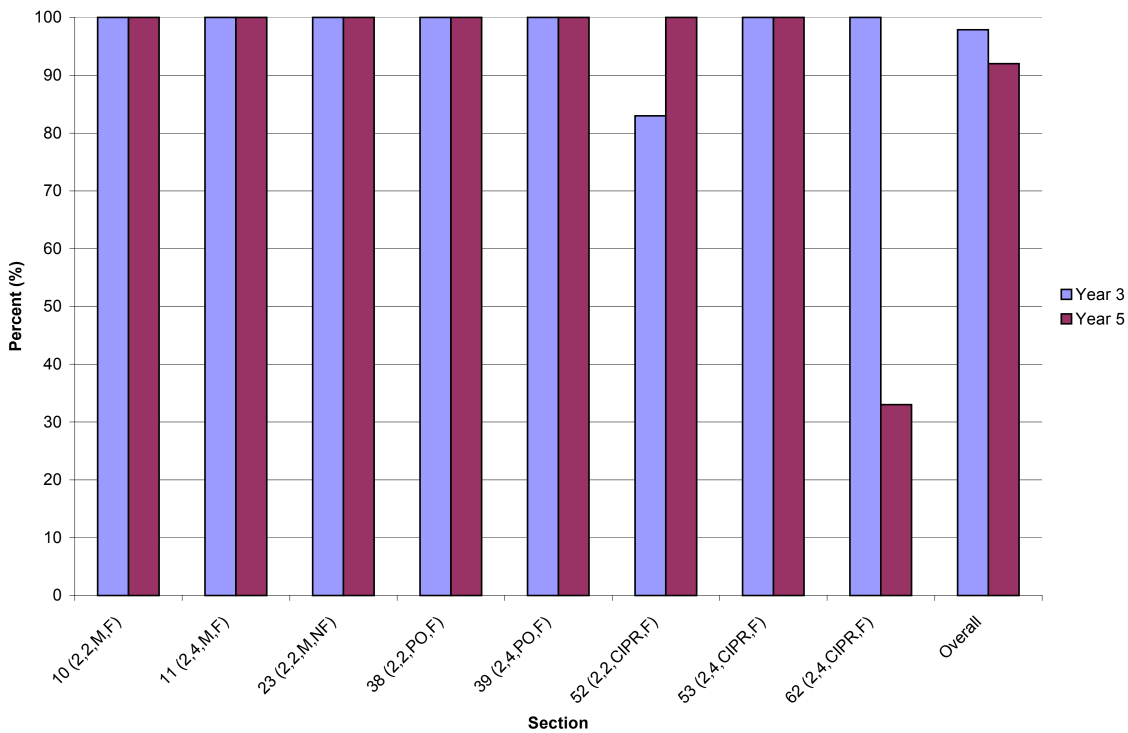


Figure 3.32 Percent of Cores Visually Observed to Have a Bonded Interface When Obtained in The Field

Figure 3.33 shows the percent of cores with bonded interfaces that were usable for testing. Cores considered usable for testing had at least 1 inch of sound ACC. In year 3, all sections except 52 and 62 had a high percent of cores that were usable for testing. In year 5, all sections except 62 had a high percent of cores that were usable for testing. This observation illustrates that the overall integrity of the ACC was good but variability with localized weak areas did exist. Additionally, the observations reaffirm that the methods used to obtain the cores were nondestructive.

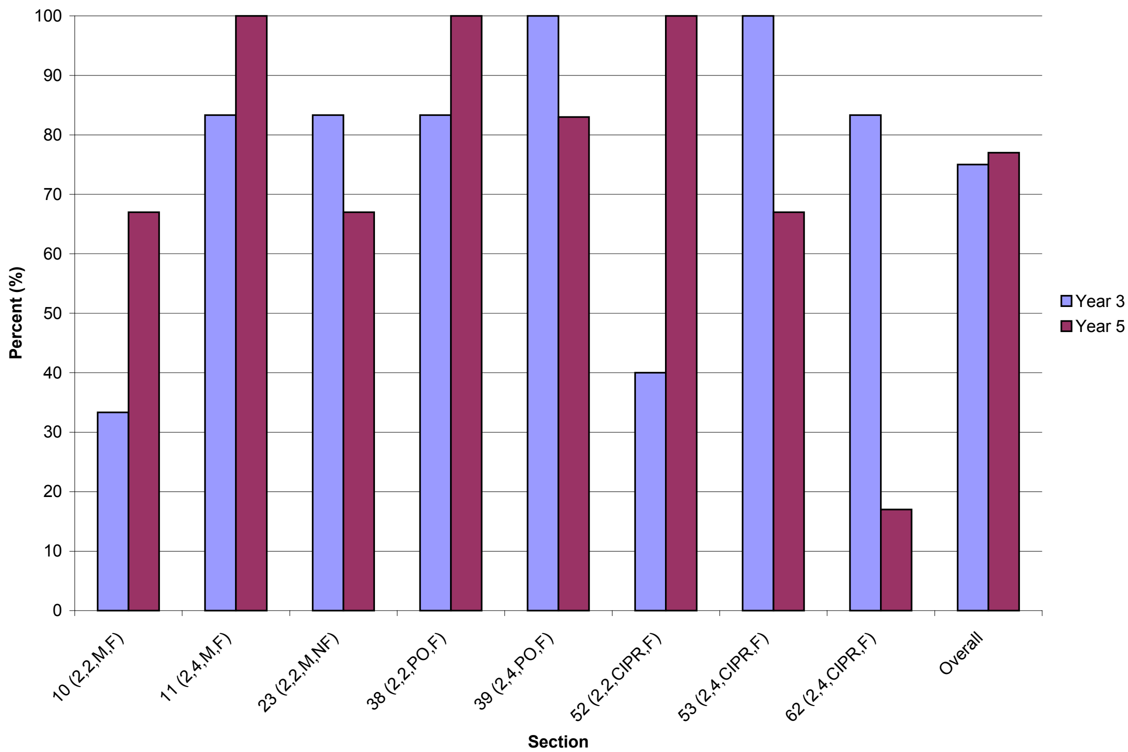


Figure 3.33 Percent of Cores With Bonded Interfaces That Were Usable for Testing

To compare the effect of joint spacing and ACC surface preparation on direct shear strength, 2-way factorial analysis of variance with interaction was conducted. A significance level of 0.05 was used. Boxplots in conjunction with histograms were used to evaluate if the data were normally distributed. Examining the means for patterns of variance was used to evaluate whether the data exhibited equal variance. The data were found to satisfy the assumptions. The analysis was conducted by leaving missing data blank and by replacing missing data with factor level averages. A substantial difference was not observed when the 2 analyses were compared; therefore, results from leaving the missing data blank are discussed herein. Appendix E contains the ANOVA table for the 2-way factorial analysis of variance with interaction. Table 3.9 summarizes the results of the analysis. The results indicate the following:

1. The model adequately explains the variance in the dependent variable
2. The factor of ACC surface preparation was significant

Table 3.9 Summary of Two-Way Factorial Analysis of Variance With Interaction for Direct Shear Strength

Model	Significant Factors	Model/Total Sum Of Squares	Notes
JS/SP/AGE	SP	0.491	Interaction Was Significant

JS = joint spacing AGE = age
SP = ACC surface preparation

To compare direct shear strengths of different ACC surface preparations, a 1-way analysis of variance with post HOC tests was conducted. A significance level of 0.05 was used. Methods similar to those previously mentioned were used to evaluate whether the data were normally distributed and of equal variance. The data were found to satisfy the assumptions. Appendix E contains multiple comparison tables for the 1-way analysis of variance with post HOC tests. Table 3.10 details the results of the post HOC tests. The results indicate the milled surface preparation is significantly different from patch only and CIPR surface preparations.

Table 3.10 Summary of One-Way Analysis of Variance With Post HOC Test For Direct Shear Strength

Factor	Significant Level	Compared To Level
SP	Milled	Patch Only, CIPR

SP = ACC surface preparation

Figure 3.34 depicts the percent of cores that were tested and broke at the interface or in the ACC. Cores considered to break at the interface had little to no ACC covering the PCC. Cores considered to break in the ACC had a thin layer of ACC completely covering the PCC. For both year 3 and 5, all sections except 10, 11, and 23 had a high percent of cores breaking in the ACC, indicating that the ACC is often weaker than the interface bond strength. Furthermore, sections 10, 11, and 23 have a milled surface preparation showing

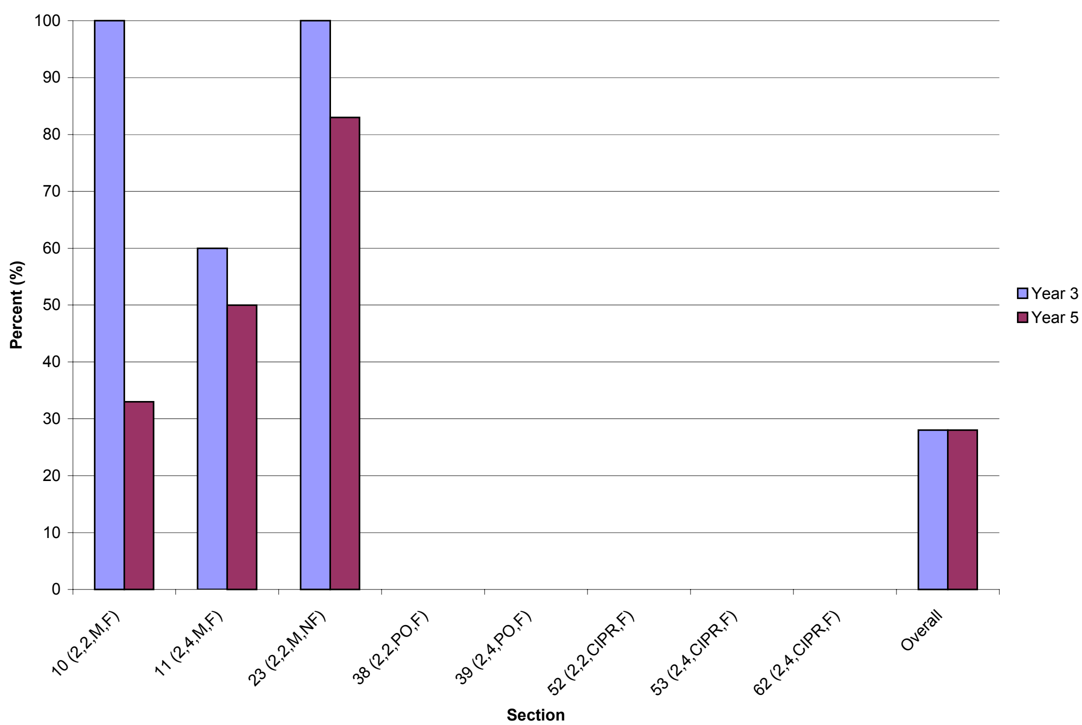


Figure 3.34 Percent of Cores Tested That Broke at the Interface

that regardless of age a relationship between ACC surface preparation and break location exists. This relationship exists because sounder, cleaner ACC is created by milling off the top 0.25 inches of ACC that is oxidized, worn, brittle, and/or contaminated.

Figure 3.35 shows the average direct shear strengths for different break locations. For both years 3 and 5, greater direct shear strength was obtained with breaks at the interface than within the ACC, reaffirming that the ACC is often weaker than the interface bond strength. This observation, coupled with the propensity for interface breaks, explains the superior performance of the milled surface preparation.

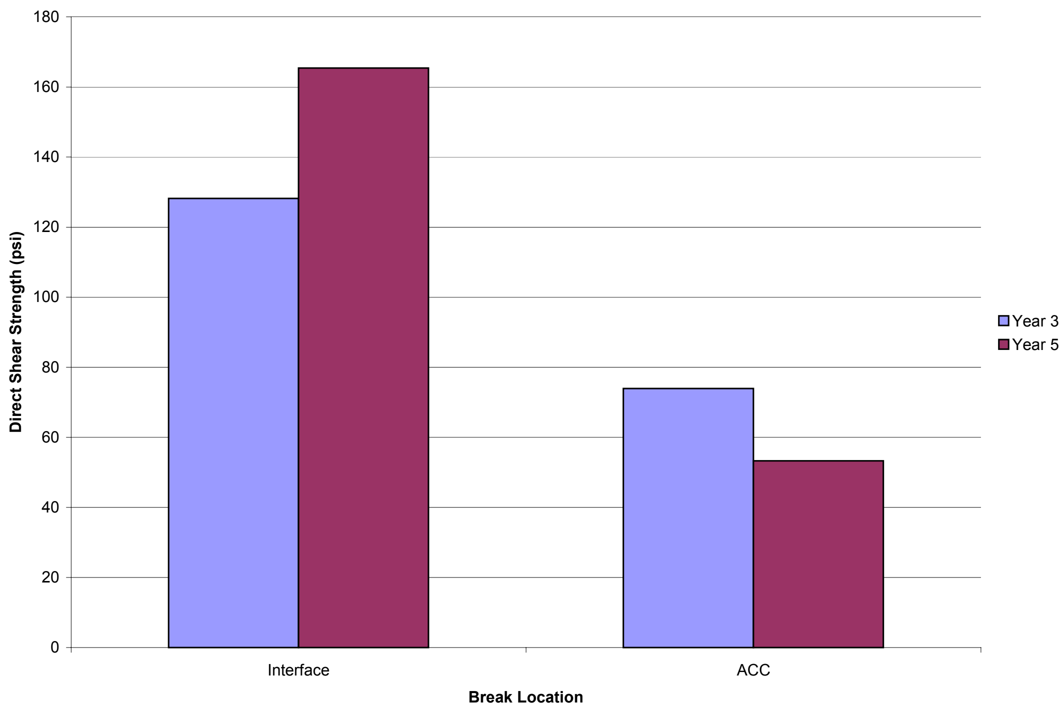


Figure 3.35 Average Direct Shear Strengths for Different Break Locations

3.7 Visual Distress Surveys

The primary objective of visual distress surveys was to monitor distresses in relation to the serviceability and bonding condition over time.

The visual distress surveys were conducted on a quarterly basis over the 5 years. Distresses were noted on each survey in terms of type, location, and number of effected slabs. The location of the distresses was identified by station, lane, and distance from edge of lane

Table 3.11 Visual Distress Summary (5 year)

TEST SECTION	BEGIN/END STATION		SECTION LENGTH	DEPTH IN.	FIBER PRESENCE	JOINT SPACING	SURFACE PREP.	# OF TEST SLABS	PERCENTAGE OF CRACKED SLABS				FRACT. SLABS	% JOINT SPALLS
									TRANSV. CRACKS	LONG. CRACKS	CORNER CRACKS	DIAG. CRACKS		
10	2380+00	2387+00	700	2	F	2	S	4200	0.02	2.74	0.29	0.05	0.17	0.05
23	2449+00	2456+00	700	2	NF	2	S	4200	0.14	0.9	0.09	0	0.57	0.02
38	2540+00	2547+00	700	2	F	2	P	4200	0	0.02	0.02	0.02	0	0
52	2616+00	2624+00	800	2	F	2	C	4800	0.02	0.4	0.21	0.08	0.06	0
	Mean values								0.05	1	0.16	0.04	0.2	0.02
11	2387+00	2394+00	700	2	F	4	S	1050	0	9.24	0.95	0	0.76	0
39	2547+00	2554+00	700	2	F	4	P	1050	3.33	0.57	2.57	0	0	0
53	2624+00	2631+00	700	2	F	4	C	1050	0.19	0.29	1.62	0.1	0	0
62	2691+00	2698+00	700	2	NF	4	C	1050	0.67	1.52	5.14	0.19	5.71	0
	Mean values								1.05	2.9	2.57	0.07	1.62	0
7	2364+00	2371+00	700	4	F	2	S	4200	0	0.09	0.19	0	0	0
21	2441+00	2448+00	700	4	NF	2	S	4200	0	0	0	0	0	0.02
42	2562+00	2569+00	700	4	F	2	P	4200	0	0	0	0	0	0.02
49	2601+00	2608+00	700	4	F	2	C	4200	0	0	0	0	0	0
	Mean values								0	0.02	0.04	0	0	0.01
8	2371+00	2378+00	700	4	F	4	S	1050	0	0	0	0	0	0
29	2480+00	2487+00	700	4	NF	4	P	1050	0.48	0.48	0.1	0.1	0	0.1
41	2555+00	2562+00	700	4	F	4	P	1050	0.67	0	0	0	0	0
50	2608+00	2615+00	700	4	F	4	C	1050	0	0	0.1	0	0	0
	Mean values								0.29	0.12	0.05	0.02	0	0.02
6	2357+00	2364+00	700	4	F	6	S	468	0	1.07	0	0	0	0
43	2569+00	2576+00	700	4	F	6	P	468	2.35	0.43	0	0	0	0.21
48	2594+00	2601+00	700	4	F	6	C	468	0	1.5	0	0	0	0
58	2654+00	2661+00	700	4	NF	6	C	468	0	0.21	0	0	0	0
	Mean values								0.58	0.8	0	0	0	0.5

Table 3.11 Visual Distress Summary (5 year) continued

TEST SECTION	BEGIN/END STATION		SECTION LENGTH	DEPTH IN.	FIBER PRESENCE	JOINT SPACING	SURFACE PREP.	# OF TEST SLABS	PERCENTAGE OF CRACKED SLABS TRANSV. CRACKS	LONG. CRACKS	CORNER CRACKS	DIAG. CRACKS	FRACT. SLABS	% JOINT SPALLS
4	2349+00	2356+00	700	6	F	6	S	468	0	1.71	0	0	0	0
13	2396+00	2403+00	700	6	F	6	S	468	0	0	0	0	0	0
19	2433+00	2440+00	700	6	NF	6	S	468	0	0	0	0	0	0.43
25	2458+00	2460+00	200	6	NF	6	S	136	0	0	0	0	0	0.74
26	2460+00	2468+00	600	6	NF	6	P	400	0	0	0	0	0	0
36	2516+00	2538+00	1200	6	NF	6	P	800	0.38	0	0	0	0	0.12
46	2585+00	2593+00	800	6	F	6	C	536	0	0.19	0	0	0	0
55	2633+00	2640+00	700	6	NF	6	C	468	0	0	0	0	0	0
	Mean values								0.08	0.24	0	0	0	0.08
3	2342+00	2349+00	700	6	F	12	S	116	0	2.59	0.86	0	0	0
14	2403+00	2414+00	1100	6	F	12	S	184	0	2.72	0	0	0	0
18	2426+00	2433+00	700	6	NF	12	S	116	0	0	0	0	0	0
27	2468+00	2479+00	1100	6	NF	12	P	184	0	0.54	0	0	0	0.54
45	2577+00	2585+00	800	6	F	12	P	134	3.73	0.75	0.75	0	0	0
56	2640+00	2653+00	1300	6	NF	12	C	216	0	0	0	0	0	0
60	2662+00	2689+00	2700	6	NF	12	C	450	0	0.67	0.44	0	0	0
	Mean values								0.36	0.93	0.29	0	0	0.07
1	2335+64	2340+00	436	8	N/A	20	R	44	2.27	9.09	9.09	2.27	0	0
31	2489+00	2496+00	700	8	NF	15	P	94	1.06	0	0	0	0	1.06
32	2496+00	2503+00	700	8	NF	15	P	94	1.06	21.28	3.19	0	0	0
	Mean values								1.29	11.64	3.02	0.43	0	0.43
Asphaltic Concrete Sections									NUMBER OF CRACKS					
16	2415+00	2425+00	1000	4.5	NF	N/A	S	N/A	10		N/A	0	N/A	0
34	2505+00	2515+00	1000	4.5	NF	N/A	P	N/A	18	1	N/A	0	N/A	2
65	2704+00	2714+08	1008	4.5	NF	N/F	C	N/A	20	0	N/A	3	N/A	0

NOTES:

F = FIBERS PRESENT
NF = NO FIBERS
N/A = NOT APPLICABLE
R = SURFACE AND BASE RECONSTRUCTION

S = SCARIFY BASE PREPARATION
P = PATCH BASE PREPARATION
C = COLD IN PLACE RECYCLE BASE PREPARATION

TRANSV.= TRANSVERSE CRACKS
LONG. = LONGITUDINAL CRACKS
DIAG. = DIAGONAL CRACKS
FRACT. = FRACTURED SLABS

or centerline. A summary of the accumulation of distress over the 5-year evaluation period is shown in Table 3.11. The test sections have been arranged in ascending order of overlay depth and joint spacing. The last group includes the 3 asphaltic concrete overlay sections that were compared as control section. The depth of asphaltic concrete overlay is the same one originally selected for the project. The information displayed in Table 3.11 is further discussed below in the same manner as presented in the table.

3.7.1 Two-Inch PCC Overlay

In general the cracking in the 2-inch overlay sections was minor in nature and limited to isolated areas in the tests sections. It was found in both directions of travel and limited to the outer wheel path of the roadway lane. Loss of the slabs was minimal and attributed to the cracking and the lack of paved shoulder to retain the slabs.

In the case of the 2-inch depth overlay depth, with 2-foot joint spacing, the predominate distresses that occurred were longitudinal, corner, and transverse cracking in descending order of magnitude. In total these distresses impacted less than 2% of the total test section slabs in this group. Performance was very good over the 5-year evaluation. The noted distresses were located primarily in the outer wheel path, in the outside 2 rows of slabs. The distresses began as longitudinal or corner cracking and over time evolved into fractured slabs. Such slabs remained in place and carried traffic until slabs in the outside edge row fractured and allowed the cracked slabs to move and dislocate. Fractured slabs represented only 0.2% of the test slabs and those dislocated or debonded slabs represented only 0.11% of the test slabs. The addition of fiber did appear to reduce the potential for longitudinal cracking and assist in the retention of slab integrity after cracking. Of the 3-base surface preparations, the broom and patch section exhibited the least amount of distress.

Changing the joint spacing to 4 feet and retaining the 2-inch overlay depth, increased the total amount of cracking to near 7% of the test slabs in the second group of sections. The predominate distresses continued to be longitudinal, corner and transverse cracking. As in the 2-foot squares, the location of the distress was concentrated in the outer wheel path or first row of slabs near the edge of the pavement. Changing the slab dimensions did increase the amount of the corner and transverse cracking levels and resulted in some 1.62% of cracked slabs that occurred in 1 section. The addition of fiber did assist in the retention of cracked slab integrity, but did not indicate a trend in the reduction of cracking. In this case the cold in place recycled base provided the location for the least amount of cracking.

3.7.2 Four-Inch PCC Overlay

Changing the depth of overlay to 4 inches resulted in a major decrease in the level of cracking. Distresses were again found primarily in the outer wheel path, in each direction of travel. Predominate distresses noted in the 4-inch overlay sections with 2-foot joint spacing were longitudinal and corner cracks as found in the 2-inch overlays. Cracking was limited to less than 0.1% of the test slabs. Distresses were located in the outer wheel path and along the longitudinal joint between row 1 and 2 from the pavement edge. Cracking was not reduced with the addition of fiber reinforcement. There were no instances of fractured slabs or debonding. The cold in place recycled base provided the lowest level of cracking and the milled surface exhibited minor cracking.

Increasing the joint spacing from 2 feet to 4 feet, in the 4-inch overlay, decreased the total amount of cracking to less than 0.5% of the total slabs. In this case the transverse and longitudinal cracking were the primary distresses noted, at only minimal levels. The distresses were concentrated in 2 sections. The addition of fiber reinforcement appears to have reduced the number of cracks in this case. Milling the base provided for the lowest level of cracking while brooming and patching accounted for the highest level of distress. No fractured slabs or evidence of debonding was noted over the test period in these sections.

The 4-inch overlay sections with 6-foot joint spacing exhibited primarily longitudinal and transverse cracking. The total amount of cracked slabs increased to less than 1.4% as compared to the other 4-inch slabs. Longitudinal cracking was the primary contributor in the distress and may be associated with joint formation timing and environmental conditions during construction. The addition of fiber reinforcement did not appear to have an impact of crack reduction. Milled base section provided for the lowest level of distress and the broom and patch sections provided for increased levels of cracking. No fractured slabs or evidence of debonding were noted over the test period in these test sections.

3.7.3 Six-Inch PCC Overlay

Less than 0.4% of the test slabs in the 6-inch overlay depth with 6-foot joint spacing exhibited any cracking or joint spalling. Longitudinal and transverse cracking accounted for the majority of distresses. The longitudinal distresses were located near the centerline and appear to be the result of improper joint formation timing. Fiber reinforcement appeared to have no impact on reduction in cracking levels. The cold in place recycled base provided for the least amount of cracking while milled surfaces provided a small amount of increase in the cracking levels. No fractured slabs or evidence of debonding were noted over the test period in these test sections.

Longitudinal, transverse, and corner cracking were the predominate signs of distress in the 6-inch depth of overlay with 12-foot transverse joint spacing. Less than 1.6% of the slabs in the test area exhibited cracking and it was confined to the areas parallel to the centerline and a transverse crack at the midslab location. Levels of cracking were greater in the sections with fiber reinforcement. The type of base preparation made no difference in the amount or rate of cracking in this case and there were no fractured slabs encounter over the test period.

3.7.4 Eight-Inch PCC Overlay

In the case of the 8-inch depth overlay sections, only 3 small sections were considered for the experiment. In this case some 11.0% of the slabs exhibited some type of visual distress in the form of longitudinal or transverse cracking. The majority of the cracking was found in the longitudinal cracks adjacent to the centerline. Visual inspection leads the research team to believe that the crack formed before the centerline joint was cut. Removal of the cement treated base in section 1 caused the pavement replacement to exhibit increased levels of cracking over section 30. In the case of the centerline longitudinal cracks in sections 30 and 31, joint development timing is the primary source of distress.

3.7.5 Asphaltic Concrete Overlay Sections

The asphaltic concrete overlay sections, built to a depth of 4.5 inches also exhibited distress over the 5-year test period. Transverse cracks, spaced evenly, and in the form of thermal cracks appeared in the middle of the test period during the same winter that the cracks began to appear in the portland cement concrete sections. The level of cracking was independent of the base preparation and consisted primarily of full pavement width cracks with an occasional lane width transverse crack or diagonal cracks. These cracks have remained open during the remainder of the test period, even though the maintenance staff has filled them once with liquid joint filler. The edges of the cracks are beginning to show signs of folding down into the cracks and secondary cracks are being formed parallel to the original cracks.

3.7.6 Portland Cement Concrete Overlay Sections

Areas of high distress in which debonding had occurred, was suspected, or was probable were targeted for additional investigation with aforementioned testing.

3.7.7 Data Preparation

Distress data were assembled into an Excel spreadsheet. Sections exhibiting a high amount of cracking and fractured slabs were identified. Distress locations were reviewed to determine specific areas of interest within the identified sections. FWD deflection responses and field observations from distressed and normal areas were assembled into an Excel spreadsheet for comparison. Comparisons of the deflection responses focused on deflection basin shapes and percent decrease in percent reduction in deflection over time. Comparisons of the field observation focused on material soundness and bond condition of cores obtained.

3.7.8 Special Statistical Treatment and Results (Sections 23 and 62)

Sections 23 and 62 were identified as exhibiting a high amount of cracking and fractured slabs. Table 3 details the cumulative occurrence of distresses from 11/95 to 12/97 for sections 23 and 62. These sections were the only sections exhibiting several fractured slabs in this time period. The fractured slabs were clustered together in 1 or 2 groupings, indicating the behavior was localized and was initiated by a unique set of circumstances. A limited amount of data was collected because distress development occurred near the end of the 3-year scope of this research and in a small number of areas. Graphical and visual comparisons were used to evaluate the data.

The deflection basins resulting from normal and fractured slab locations for section 23 and 62 are shown in Figure 3.36 and Figure 3.37 respectively. The deflection basins for section 23, year 3, fractured and normal slabs are almost identical. This observation is unexplained considering the substantial amount of distress observed in the tested area. The deflection basins for section 62, year 3, fractured and normal slabs are substantially different. Year 3 fractured has a greater magnitude for every radial distance and appears more bow shaped. These characteristics create a distinct similarity to pre-UTW, indicating bonding and structural integrity was compromised.

Several cores were obtained from normal and fractured slab locations of section 23 and 62. Cores from the fractured locations of section 23 showed dirt contamination at the interface with little to no bonding. Cores from the fractured locations of section 62 had completely rubblized ACC with no bonding. Cores from the normal areas of these sections had no contamination or rubblized ACC, indicating that the debonding and distresses resulted from a unique set of circumstances not characteristic of the whole section. The circumstances are believed to have occurred due to construction problems. In section 23, dirt contamination is believed to have occurred as a result of trucks driving on the prepared ACC surface with muddy tires. In section 62, rubblized ACC is believed to have occurred as a result of heavily loaded trucks driving on the CIPR prior to adequate curing.

Table 3.12 Cumulative Occurrence of Distresses From 11/4/95 to 12/19/97 for Sections 23 and 62

Sectio n	Distress	Date								
		11/95	02/96	05/96	08/96	11/96	03/97	05/97	08/97	12/97

23	Transverse Cracking	-	-	-	4	4	4	4	4	4
	Longitudinal Cracking	-	-	-	25	28	28	28	28	28
	Corner Cracking	-	-	-	3	3	3	3	3	3
	Diagonal Cracking	-	-	-	-	-	-	-	-	-
	Fractured Slabs	-	-	-	-	-	-	-	12	19
	Popouts	-	-	-	-	-	-	-	1	1
	Joint Spalls	-	-	-	-	-	-	-	-	-
62	Transverse Cracking	1	1	1	1	1	1	1	1	4
	Longitudinal Cracking	-	5	7	7	9	10	14	14	14
	Corner Cracking	-	30	30	30	31	40	48	48	48
	Diagonal Cracking	-	-	-	-	-	1	1	1	1
	Fractured Slabs	-	-	12	26	26	26	26	27	27
	Popouts	3	3	3	3	3	3	3	3	3
	Joint Spalls	-	-	-	-	-	-	-	-	-

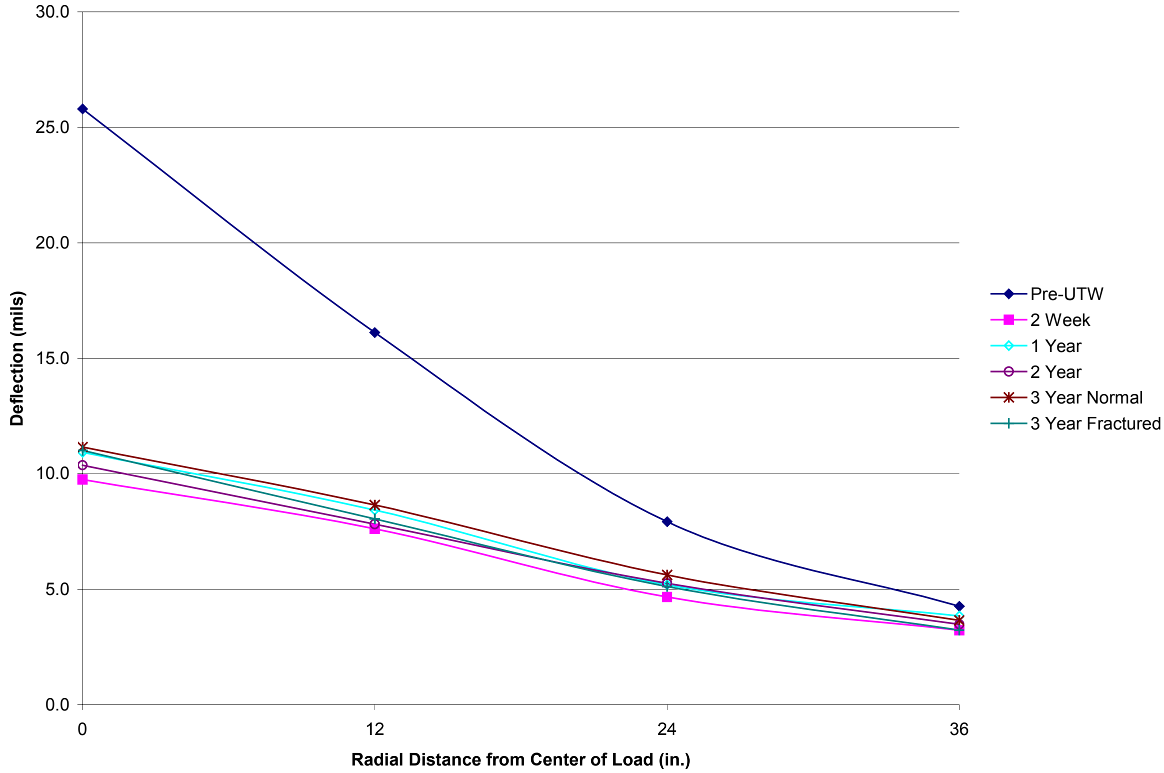


Figure 3.36 Deflection Basins Resulting From Normal and Fractured Slab Locations for Section 23

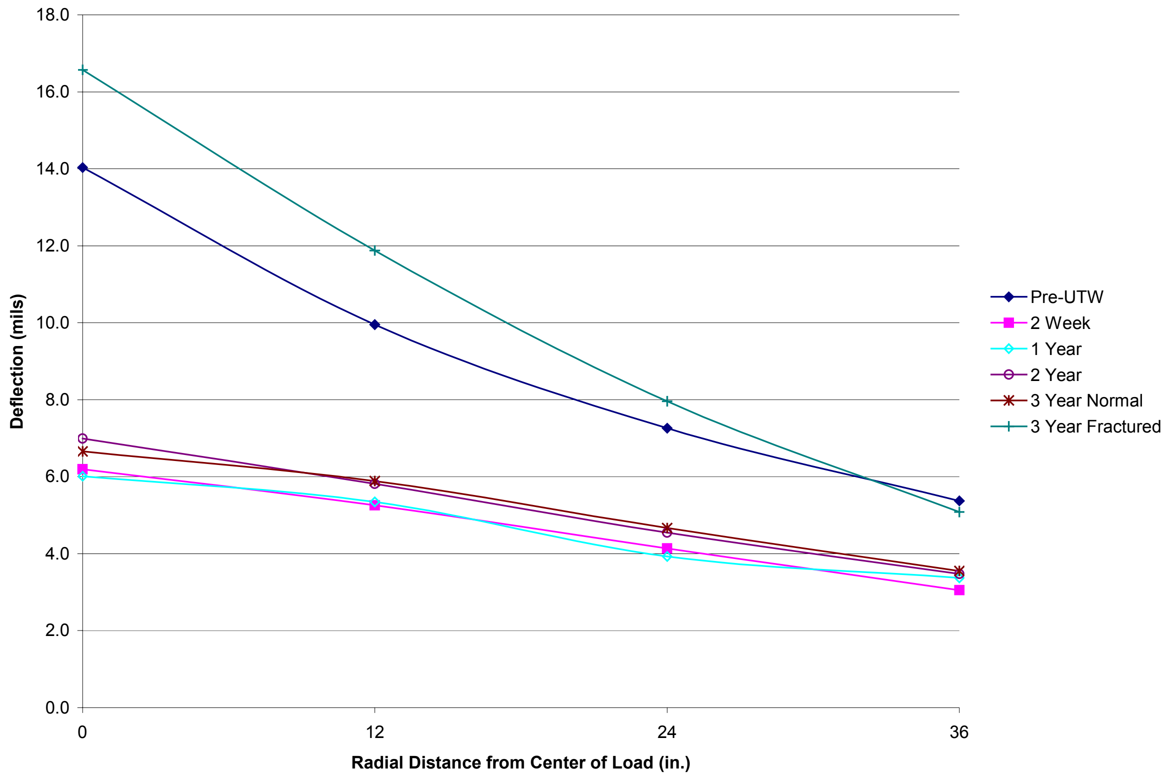


Figure 3.37 Deflection Basins Resulting From Normal and Fractured Slab Locations for Section 62

4. SUMMARY

4.1 Introduction

The objective of the research project as noted in the contract with the Iowa DOT and FHWA was the evaluation of bond development and retention between the portland cement concrete overlay and the underlying asphaltic concrete base material. The evaluation was to be done in relationship to various base surface preparation methods, overlay depths, and jointing patterns. The project also allows for the indirect evaluation of sealed versus unsealed joints in the overlay and the impact of the addition of fiber reinforcement to the overlay material in effort to limit distresses.

The research staff chose to evaluate the bonding between layers in many ways. The primary methods employed included:

1. Direct shear testing and visual observations of cores from the pavement.
2. Deflection testing to determine modulus values for each of the pavement layers assuming bonded or unbonded conditions, and load transfer between slabs.
3. Horizontal and vertical strain at the corners of selected slabs with sensors positioned at the interface of portland cement concrete and asphaltic concrete.
4. Visual surface distress type and magnitude that are associated with bonded and unbonded overlays.

4.2 Bond Evaluation Conclusions

1. Bonding of the overlay to the asphaltic concrete was achieved in all sections at construction through conventional paving methods.
   a. Direct shear tests throughout the project duration indicated the failure plane to

be located approximately 1 inch into the asphaltic concrete.

b. Deflection measurements taken in the field matched those associated with theoretical values assuming full bonding of layers.

c. No visual distresses associated with the lack of bond were noted immediately after construction.

d. Interface strain measurements were inconclusive, but did tend to be reduced as the overlay cured, indicating the development of bond and the interaction of materials.

2. Bond strength varied with base surface preparation methods.

   a. Direct shear test indicate the highest shear strengths on milled base surfaces, average shear values on broomed surfaces and lowest values for shear strength on the cold in place recycled surfaces.

   b. Direct shear tests indicate that the bond relationship with surface preparation is retained over the evaluation period of 5 years.

   c. Prewetting of the base at the paving machine produced a negative impact on bond strength development.

3. Deflection testing over the evaluation period indicated that traffic loadings and environmental conditions did contribute to increasing deflections over time that indicate a loss of composite action in the cross section. Deflection increases may be the result of the overlay debonding, asphalt layers delaminating, or both.

4. Visual cracking increased over time in isolated areas of the outer wheel path in the 2-inch depth of overlay sections.

   a. Distress development rates accelerated at times of severe freeze-thaw cycling and periods of high moisture and air temperature combinations.

5. Structural integrity and bond was retained on 99.9% of all slabs in the 2 and 4 inch, ultrathin overlay sections, over the 5 years.
6. Bond can be restored in individual sections through the use of epoxy injection repair methods.

4.3 General Project Conclusions

The following conclusions are drawn from the distress survey information and relate the variables of base surface preparation, overlay depth, and joint pattern sizes.

4.3.1 Base Surface Preparation

1. Milling of the base surface provides an excellent bonding surface, longitudinal and transverse profile and overlay depth control surface.
2. Broom and patch base surfaces provide adequate bonding if kept clean of dirt and debris, but requires more quality and quantity control to meet overlay depth requirements.
3. Cold-in-place recycled base surfaces provide the lowest bond strengths. They must be adequately cured prior to the concrete placement to retain stability. This method provides good concrete overlay depth control.

4.3.2 Concrete Overlay Depth

1. Two-inch depth concrete overlays do perform well in excess of 5 years when placed with good depth control at construction.
2. Two-inch depth concrete overlays exhibit surface distresses in the form of longitudinal or corner cracks leading to fractured slabs and debonding.

3. Two-inch depth concrete overlay distress occurs primarily in the outside wheel path (4 feet) areas.
4. Fiber reinforcement can add durability and life to the 2-inch depth overlays in terms of holding cracks together.
5. Four-inch depth concrete overlays performed well over the 5-year evaluation period with minimal visual distress.
6. Distress in the 4-inch depth concrete overlay sections was limited to longitudinal, transverse and corner cracking in the outer wheel path (4 foot) of each lane.
7. No debonding was associated with the 4-inch depth concrete overlay sections.
8. The benefits of adding fiber reinforcement in the 4-inch depth concrete overlays were not conclusive.
9. The 6-inch depth concrete overlays performed well as expected with only occasional longitudinal and transverse cracking noted.
10. Cracking in the 6 inch depth concrete overlay sections was primarily associated with longitudinal and transverse joint development construction practices.
11. Fiber reinforcement impacts on the 6-inch depth concrete overlay sections were inconclusive.
12. No debonding was associated with the 6-inch depth concrete overlay sections.
13. Eight inch depth concrete overlay sections exhibited only minimal cracking that was associated with construction practices, such as base removal or late joint development.

4.3.3 Longitudinal and Transverse Joint Patterns

1. The use of 2-foot by 2-foot joints in the 2-inch depth concrete overlays places a

longitudinal joint in the wheel path and can provide a line of weakness and distresses.

2. Application of the 2-foot by 2-foot joints with the 4-inch depth concrete overlays eliminated the longitudinal joint, wheel path distress problem.
3. Cracking rates were greatly increased when 4-foot by 4-foot joints were employed with 2-inch depth concrete overlays.
4. The use of 4-foot by 4-foot or 6-foot by 6-foot joint patterns with 4-inch depth concrete overlays provided very good performance in terms of minimizing distress.
5. Application of 6-foot by 6-foot joint patterns provided improved cracking performance over the 6-foot by 12-foot joint pattern, when used with the 6-inch depth concrete overlays.

4.3.4 Joint Preparation

1. The performance of narrow, unsealed joints (longitudinal and transverse) was successful over the 5-year evaluation period with no signs of raveling or joint spalling of any magnitude being identified.

Based on the information gained from this research, the research team believes that the optimum conditions that promote good performance in an ultrathin concrete overlay are milling of the existing base surface, leaving a minimum of 3 to 4 inches of sound asphaltic concrete base, existing asphalt surface milling, overlay depths of a minimum of 3 to 4 inches with good construction grade and depth control, the addition fibers in 3-inch depths, 4 to 6-foot joint spacings, and the use of early cut narrow joints with no sealant.

4.4 Future Research Needs

1. Evaluation of rehabilitation methods for ultrathin pavements using portland cement concrete patching materials and methods.
2. Extended evaluation of this project to gage ultrathin life expectancy in excess of 5 years.
3. Consideration of the use of ultrathin depths of overlay and joint patterns for use on existing composite pavements.

APPENDIX A. CONSTRUCTION INSPECTION AND TESTING RESULTS

PCC and Air Temperatures

Date	Section Number	PCC Temperature (°F)	Air Temperature (°F)
6/24/94	1	75.2	-
	2	84.2	77.0
6/25/94	3	75.2	75.2
	6	78.8	84.2
	7	80.6	84.2
6/27/94	7	75.2	64.4
	8	77.0	68.0
6/28/94	10	75.2	80.6
	11	75.2	68.0
	12	75.2	77.0
	13	78.8	82.4
	14	78.8	82.4
6/30/94	17	73.4	64.4
	19	75.2	75.2
	21	80.6	84.2
7/01/94	22	75.2	68.0
	23	78.8	71.6
	25	78.8	78.8
7/05/94	26	78.8	75.2
	27	82.4	82.4
	29	84.2	89.6
7/06/94	31	80.6	84.2
	32	84.2	84.2
7/07/94	35	78.8	69.8
	36	78.8	78.8
7/11/94	36	75.2	66.2
	38	78.8	80.6
	39	80.6	84.2
7/12/94	41	77.0	73.4
	42	78.8	75.2
	43	80.6	78.8
	45	82.4	82.4
	48	84.2	87.8
7/13/94	48	78.8	73.4
	49	75.2	77.0
	50	75.2	78.8
7/14/94	50	75.2	62.6
	52	75.2	64.4
	53	71.6	64.4
	54	75.2	-
	55	75.2	64.4
7/15/94	56	71.6	64.4
	58	71.6	73.4
	59	-	80.6
	60	75.2	77.0
7/18/94	60	71.6	64.4
	61	75.2	80.6
	62	77.0	84.2
	64	75.2	82.4

PCC Thickness

Section Number	Minimum (in.)			Maximum (in.)			Average (in.)			Design (in.)	Sample Size
	L	C	R	L	C	R	L	C	R		
3	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	6	1
4	5.9	6.3	5.1	8.7	8.7	7.1	7.1	7.5	5.9	6	5
6	3.9	3.9	3.9	5.1	6.3	6.3	4.7	5.1	5.1	4	3
7	4.3	4.3	3.2	4.3	4.7	5.1	4.3	4.3	3.9	4	2
8	4.3	3.9	5.9	6.7	5.5	7.1	5.5	4.7	6.7	4	5
10	3.9	3.2	1.6	3.9	3.5	2.4	3.9	3.2	2.0	2	2
14	5.1	5.5	5.9	7.5	7.5	7.5	6.3	6.7	6.7	6	6
18	5.5	5.9	6.3	6.7	7.1	6.3	5.9	6.7	7.5	6	4
21	2.0	3.2	3.2	3.9	5.5	5.5	3.2	4.3	4.3	4	3
23	2.4	3.2	2.4	5.1	5.5	5.1	3.9	3.9	3.9	2	3
25	7.1	7.1	7.9	7.1	7.1	7.9	7.1	7.1	7.9	6	2
26	5.9	6.7	6.7	7.9	7.9	7.9	6.7	7.5	7.5	6	4
27	5.9	6.7	6.7	7.5	7.9	7.5	6.7	7.5	7.5	6	4
29	5.9	5.9	5.5	5.9	5.9	5.5	5.9	5.9	5.5	4	1
31	7.9	8.3	7.1	10.6	10.6	11.0	8.7	9.5	9.5	8	4
32	7.9	9.5	8.3	9.1	11.0	10.6	8.3	10.2	9.1	8	4
36	3.9	5.9	6.7	7.5	8.7	7.1	5.9	7.5	6.7	6	8
38	1.6	3.2	3.2	3.2	3.9	3.9	2.4	3.5	3.5	2	3
39	2.0	3.2	2.8	3.9	3.5	4.3	2.8	3.2	3.2	2	3
41	3.5	4.3	4.3	5.1	5.1	5.1	4.3	4.7	4.3	4	4
42	4.3	5.1	4.3	5.5	5.5	5.1	4.7	5.5	4.7	4	3
43	2.8	3.9	3.9	4.7	5.9	4.3	3.9	4.7	3.9	4	3
45	5.9	5.9	5.9	6.7	7.9	6.7	6.3	6.7	6.3	6	3
46	6.3	5.9	5.1	6.7	6.3	6.3	6.3	5.9	5.5	6	3
48	4.3	3.9	3.9	5.5	8.7	5.1	5.1	6.3	4.3	4	3
49	5.1	5.9	5.5	5.9	8.7	5.9	5.5	7.1	5.5	4	4
50	3.2	4.7	4.7	7.1	7.9	4.7	5.1	6.3	4.7	4	2
52	2.0	3.2	2.0	2.0	3.2	2.0	2.0	3.2	2.0	2	1
53	2.4	2.4	1.6	2.4	2.4	1.6	2.4	2.4	1.6	2	1
55	5.1	5.9	4.3	8.3	8.7	6.7	6.3	7.1	5.5	6	4
56	5.9	5.1	5.1	8.3	8.7	7.9	7.5	7.5	6.7	6	5
58	4.3	4.3	4.3	5.9	5.9	5.1	5.1	5.1	4.7	4	2
60	4.7	5.5	5.5	7.9	7.1	6.7	5.9	6.3	5.9	6	9
62	1.6	3.2	3.2	2.4	4.3	4.7	2.0	3.5	3.9	2	2

Flexural Beam Strengths

Section Number	Beam Number	Testing Age (days)	Mix	Fiber Usage	Strength (psi)
1	1	7	C-3WR-C	N	565
2	2	7	C-3WR-C	F	715
3	3	10	C-3WR-C	F	765
	3-F-1	7	C-3WR-C	F	625
4	3A	16	C-3WR-C	F	695
	4-F-2	7	C-3WR-C	F	565
	4-F-3	7	C-3WR-C	F	610
7	4	8	C-3WR-C	F	615
9	4A	14	C-3WR-C	F	750
11	5	7	C-3WR-C	M	645
	11-M-1	9	C-3WR-C	M	505
	11-M-2	9	C-3WR-C	M	595
	11-M-3	9	C-3WR-C	M	565
	11-M-4	14	C-3WR-C	M	595
	11-M-5	14	C-3WR-C	M	695
	11-M-6	14	C-3WR-C	M	695
13	13-M-7	28	C-3WR-C	M	755
14	5A	14	C-3WR-C	M	845
	14-M-8	28	C-3WR-C	M	695
	14-M-9	28	C-3WR-C	M	695
18	7	7	C-3WR-C	N	630
	18-C-1	7	C-3WR-C	N	710
	18-C-2	7	C-3WR-C	N	695
	18-C-3	7	C-3WR-C	N	770
19	19-C-4	14	C-3WR-C	N	710
21	7A	14	C-3WR-C	N	810
	21-C-5	14	C-3WR-C	N	710
	21-C-6	14	C-3WR-C	N	695
23	8	7	C-3WR-C	N	680
	8A	14	C-3WR-C	N	800
26	9	7	C-3WR-C	N	705
27	27-C-7	28	C-3WR-C	N	640
	27-C-8	28	C-3WR-C	N	725
28	28-C-9	28	C-3WR-C	N	725
30	9A	14	C-3WR-C	N	680
31	10	7	C-3WR-C	N	815
33	10A	14	C-3WR-C	N	675
36	11	7	C-3WR-C	N	690
	11A	14	C-3WR-C	N	865
	12	7	C-3WR-C	N	660
	12A	14	C-3WR-C	N	715
38	12B	7	C-3WR-C	F	730
	38-F-6	14	C-3WR-C	F	695
39	39-F-7	14	C-3WR-C	F	665
	39-F-4	28	C-3WR-C	F	665
	39-F-8	28	C-3WR-C	F	665
	39-F-5	28	C-3WR-C	F	680
40	40-F-9	14	C-3WR-C	F	595
42	13	7	C-3WR-C	F	755
48	13A	22	C-3WR	N	785
	14	7	C-3WR	F	690
50	15	7	C-3WR-C	F	730
55	15A	14	C-3WR	N	715
56	15B	7	C-3WR	N	645
	16	7	C-3WR-C	N	765
60	16A	17	C-3WR-C	N	930
	17	7	C-3WR-C	N	800
62	17A	16	C-3WR-C	N	755

Slump and Air Measurements

Section Number	Slump (in.)			Percent Air Before Paver			Percent Air After Paver		
	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.
1 - 2	0	$3\frac{1}{2}$	$1\frac{3}{8}$	6.2	9.5	7.8	5.8	6.4	6.0
2 -7	$\frac{3}{4}$	$2\frac{3}{8}$	$1\frac{5}{8}$	7.1	9.0	8.3	6.0	7.1	6.5
7 - 10	$\frac{3}{4}$	$2\frac{3}{8}$	$1\frac{1}{2}$	6.6	8.6	8.0	6.6	6.6	6.6
10 - 15, 17	1	$2\frac{1}{2}$	$1\frac{3}{8}$	7.1	9.6	8.1	5.6	7.5	6.5
17 - 21	1	$1\frac{1}{2}$	$1\frac{3}{8}$	6.5	7.8	7.3	-	-	-
21 - 25	$1\frac{3}{8}$	2	$1\frac{1}{2}$	7.4	7.9	7.6	-	-	-
25 - 30	$\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{1}{4}$	5.5	9.0	7.0	-	-	-
30 - 33	$\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{1}{4}$	7.0	8.5	7.0	-	-	-
35 - 36	$\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{1}{8}$	6.6	8.3	7.6	-	-	-
36 - 41	1	$2\frac{1}{4}$	$1\frac{3}{4}$	7.6	10.5	8.7	5.5	7.1	6.5
41 - 48	1	$3\frac{3}{4}$	$1\frac{5}{8}$	6.3	9.0	7.9	-	-	-
48 - 50	1	$2\frac{1}{2}$	$1\frac{5}{8}$	7.3	9.5	8.1	-	-	-
50 - 55	$1\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{3}{4}$	7.0	9.5	7.8	5.0	6.0	5.5
56 - 60	$1\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{8}$	6.6	8.2	7.4	-	-	-
60 - 64	$1\frac{1}{2}$	$2\frac{1}{2}$	2	7.5	8.5	8.0	-	-	-

CIPR Dry Density and Percent Moisture

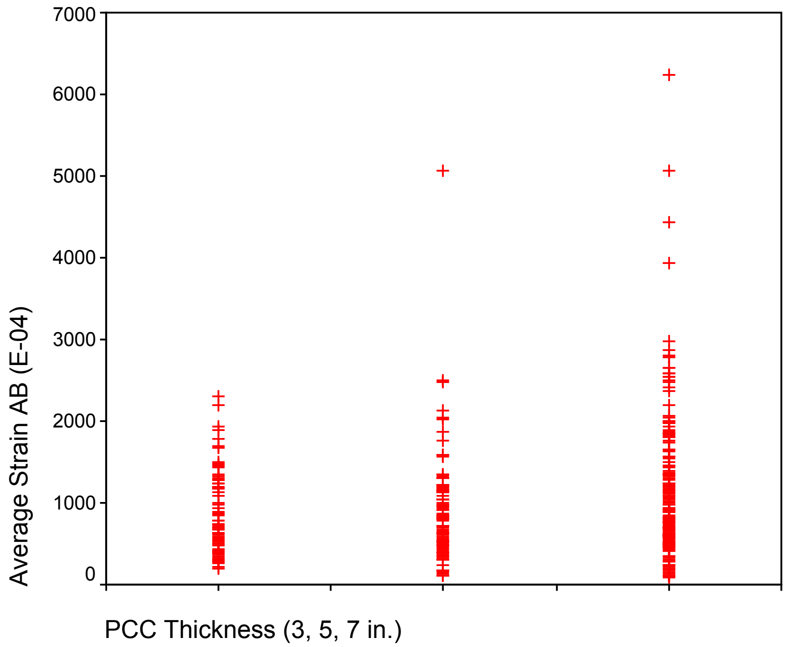
Date	Dry Density (pcf)	Percent Moisture
6/03/94	122.0	3.7
6/04/94	124.2	4.9
6/05/94	125.4	4.1

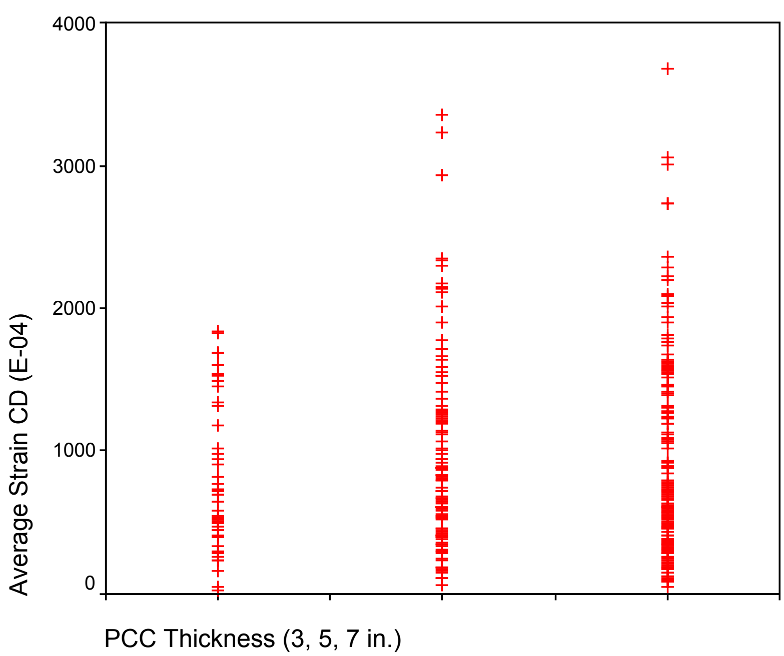
ACC Density, Percent Voids, and Percent AC

Section Number	Station	Mix	Specific Gravity	Percent of Lab Density	Percent Voids	Percent AC
16,34 (lab)	-	B Binder $^3/_4$	2.355	100.000	3.0	6.37
	-	A Surface $^1/_2$	2.359	100.000	3.1	6.18
	-	A Surface $^1/_2$	2.363	100.000	2.7	-
16	2416+96	B Binder $^3/_4$	2.285	97.028	5.9	6.50
	2418+61	B Binder $^3/_4$	2.279	96.773	6.1	6.50
	2423+85	B Binder $^3/_4$	2.281	96.858	6.1	6.50
	2424+41	B Binder $^3/_4$	2.250	95.541	7.3	6.50
	2417+58	A Surface $^1/_2$	2.274	96.397	6.6	6.29
	2419+80	A Surface $^1/_2$	2.206	93.514	9.4	6.29
	2422+48	A Surface $^1/_2$	2.238	94.871	8.1	6.29
34	2506+22	B Binder $^3/_4$	2.290	97.240	5.7	6.50
	2509+41	B Binder $^3/_4$	2.286	97.070	5.8	6.50
	2513+15	B Binder $^3/_4$	2.296	97.495	5.4	6.50
	2507+85	A Surface $^1/_2$	2.285	96.863	6.2	6.29
	2508+00	A Surface $^1/_2$	2.261	95.847	7.1	6.29
	2513+01	A Surface $^1/_2$	2.247	95.252	7.7	6.29
	2514+50	A Surface $^1/_2$	2.243	95.083	7.9	6.29
65 (lab)	-	B Binder $^3/_4$	2.346	100.000	3.1	6.05
	-	A Surface $^1/_2$	2.338	100.000	3.6	6.27
65	2703+95	B Binder $^3/_4$	2.295	97.826	5.2	6.34
	2705+45	B Binder $^3/_4$	2.244	95.652	7.3	6.34
	2706+56	B Binder $^3/_4$	2.293	97.741	5.3	6.34
	2709+07	B Binder $^3/_4$	2.253	96.036	6.9	6.34
	2710+01	B Binder $^3/_4$	2.273	96.888	6.1	6.34
	2711+06	B Binder $^3/_4$	2.295	97.826	5.2	6.34
	2712+12	B Binder $^3/_4$	2.275	96.974	6.0	6.34
	2705+11	A Surface $^1/_2$	2.321	99.273	4.3	6.41
	2705+38	A Surface $^1/_2$	2.295	98.161	5.4	6.41
	2707+63	A Surface $^1/_2$	2.286	97.776	5.8	6.41
	2708+36	A Surface $^1/_2$	2.224	95.124	8.3	6.41
	2710+35	A Surface $^1/_2$	2.228	95.295	8.2	6.41
	2710+61	A Surface $^1/_2$	2.297	98.246	5.3	6.41
	2712+81	A Surface $^1/_2$	2.265	96.878	6.6	6.41

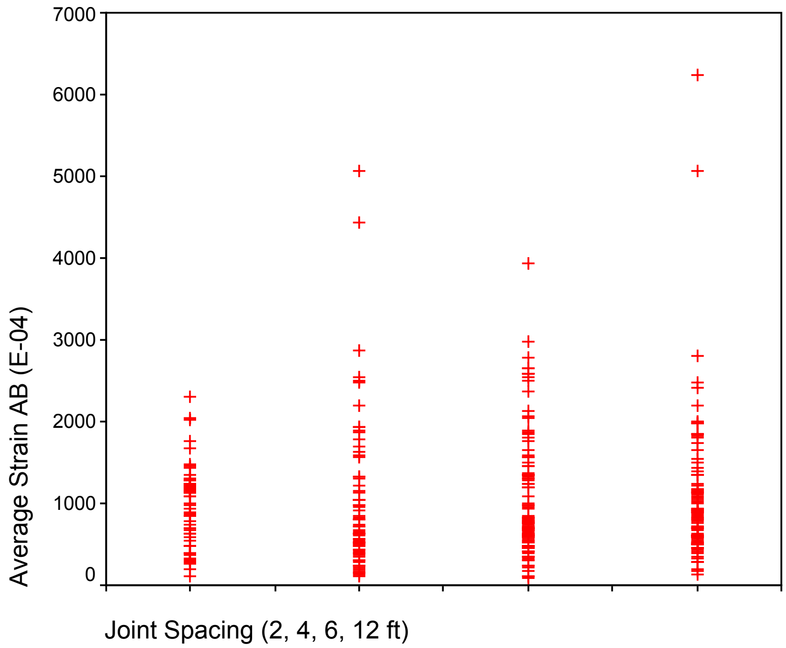
APPENDIX B. STRAIN AND TEMPERATURE STATISTICAL ANALYSIS

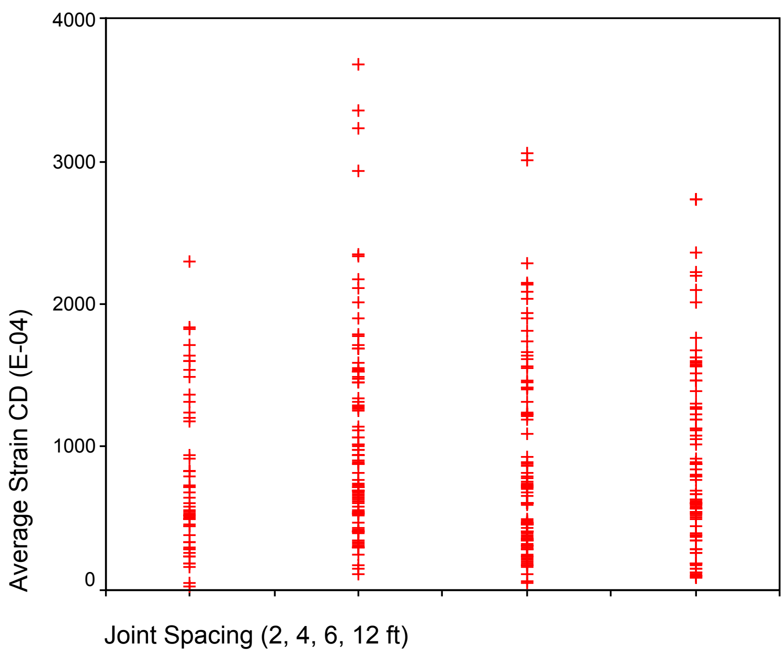
Plots of average strain AB and CD versus PCC thickness



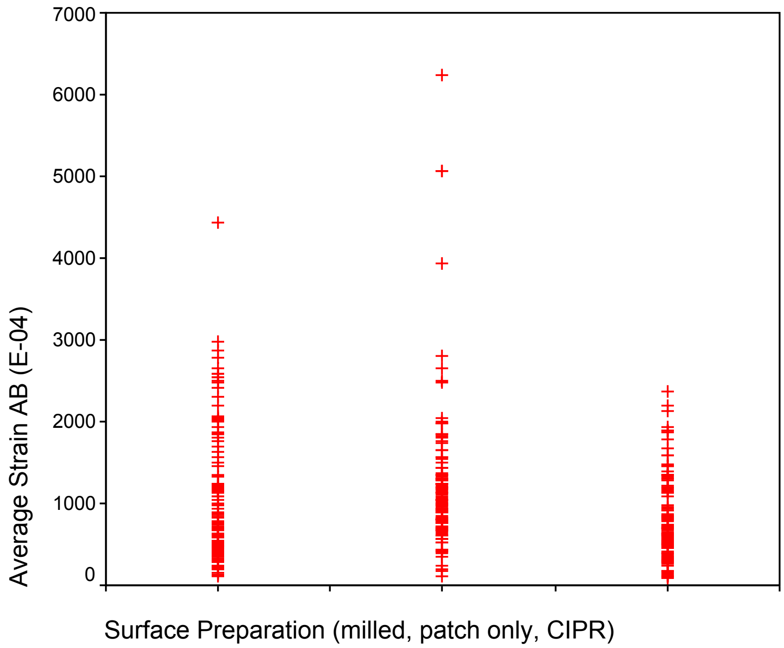


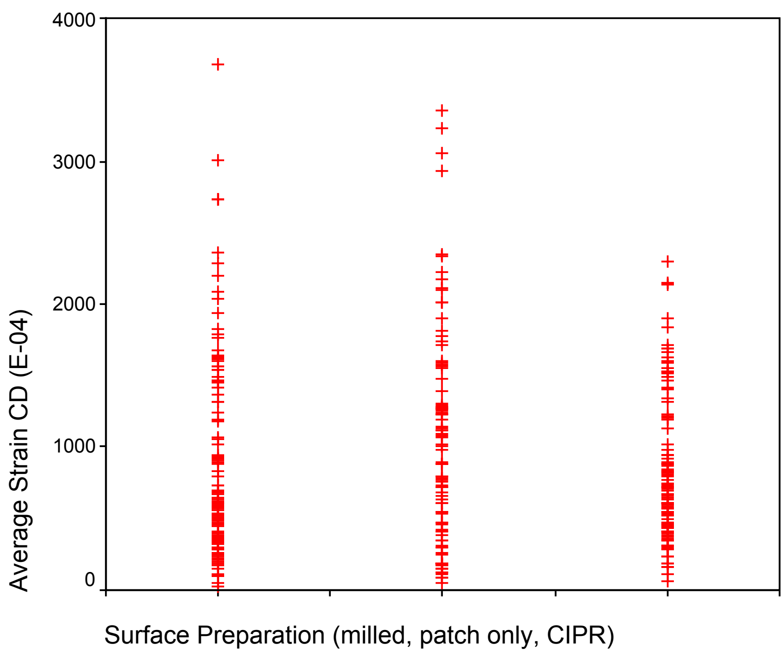
Plots of average strain AB and CD versus joint spacing



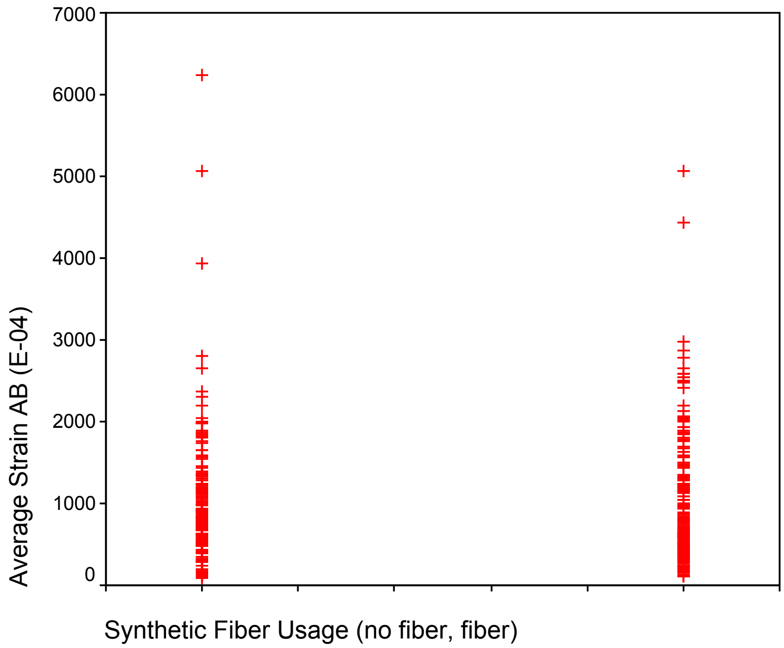


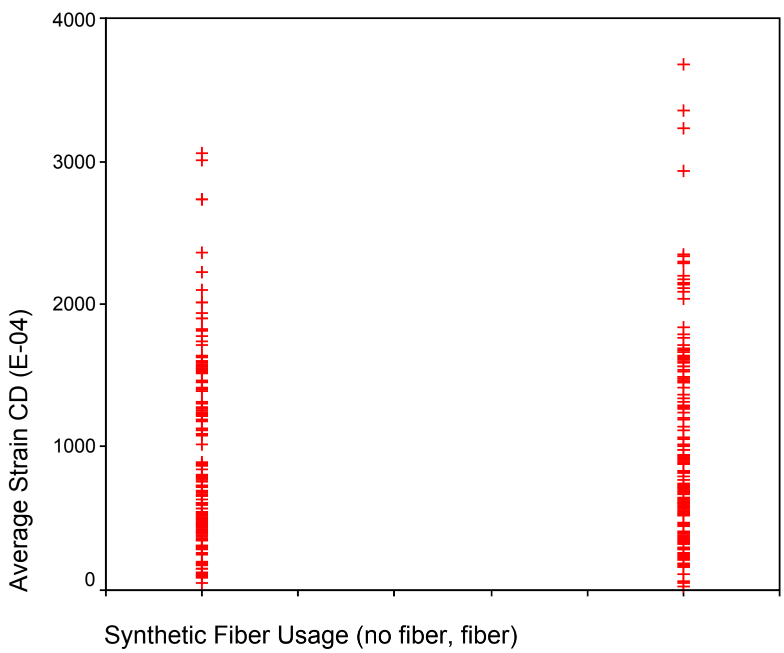
Plots of average strain AB and CD versus ACC surface preparation



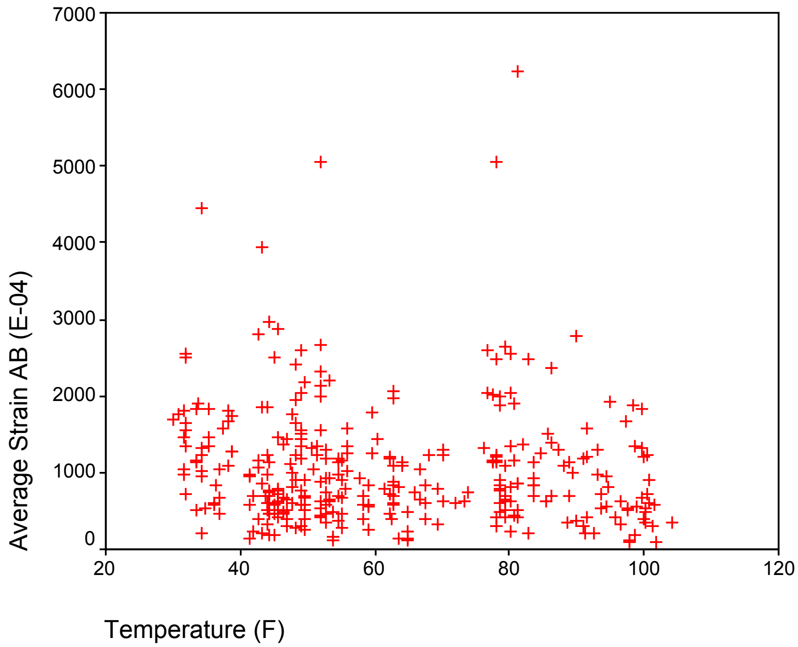


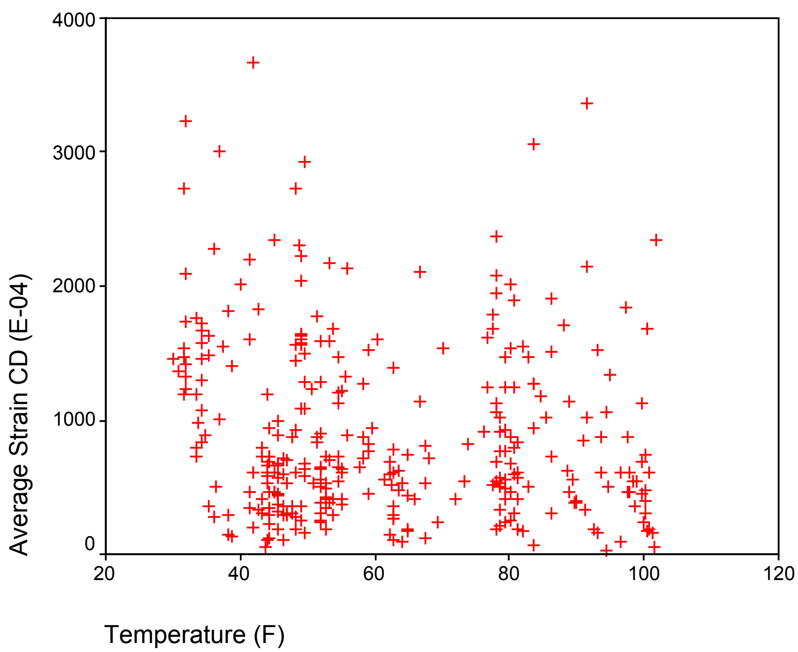
Plots of average strain AB and CD versus synthetic fiber usage



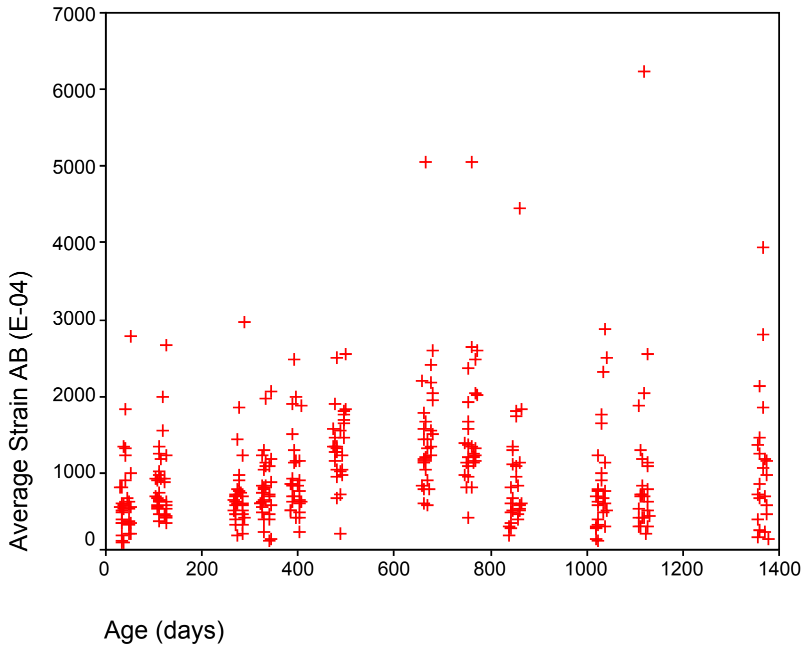


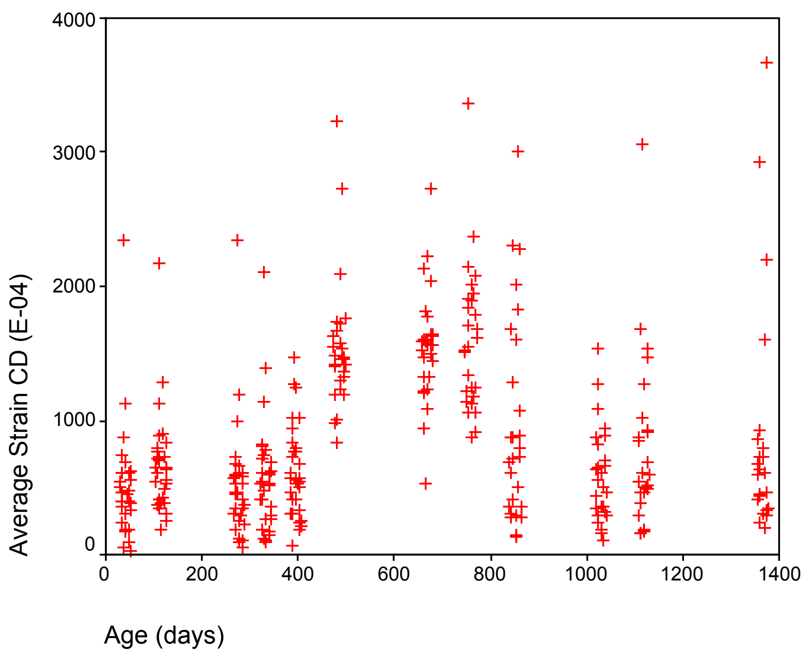
Plots of average strain AB and CD versus temperature





Plots of average strain AB and CD versus age





Two-way factorial analysis of variance with interaction for transformed average strain AB and CD by PCC thickness (T), joint spacing (JS) with temperature (Temp) and age (AGE)

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
LOGAB	Covariates	(Combined)	.796	2	.398	4.390	.013
		TEMP	.489	1	.489	5.398	.021
		AGE	.173	1	.173	1.915	.167
	Main Effects	(Combined)	.554	5	.111	1.222	.299
		T	.188	2	9.390E-02	1.036	.356
		JS	.397	3	.132	1.461	.225
	Model		1.481	7	.212	2.335	.025
	Residual		28.177	311	9.060E-02		
	Total		29.658	318	9.326E-02		

a. LOGAB by T, JS with TEMP, AGE

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
LOGCD	Covariates	(Combined)	1.842	2	.921	7.758	.001
		TEMP	.582	1	.582	4.903	.028
		AGE	.903	1	.903	7.608	.006
	Main Effects	(Combined)	1.338	5	.268	2.254	.049
		T	.186	2	9.301E-02	.783	.458
		JS	1.121	3	.374	3.146	.025
	Model		3.174	7	.453	3.818	.001
	Residual		36.571	308	.119		
	Total		39.745	315	.126		

a. LOGCD by T, JS with TEMP, AGE

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

Two-way factorial analysis of variance with interaction for transformed average strain AB and CD by PCC thickness (T), ACC surface preparation (SP) with temperature (Temp) and age (AGE)

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
LOGAB	Covariates	(Combined)	.664	2	.332	3.869	.022
		TEMP	.418	1	.418	4.876	.028
		AGE	.137	1	.137	1.593	.208
	Main Effects	(Combined)	.894	4	.224	2.608	.036
		T	7.430E-02	2	3.715E-02	.433	.649
		SP	.820	2	.410	4.783	.009
	2-Way Interactions	T * SP	1.168	4	.292	3.407	.010
	Model		3.250	10	.325	3.791	.000
	Residual		26.407	308	8.574E-02		
	Total		29.658	318	9.326E-02		

a. LOGAB by T, SP with TEMP, AGE

b. All effects entered simultaneously

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
LOGCD	Covariates	(Combined)	1.850	2	.925	7.607	.001
		TEMP	.598	1	.598	4.915	.027
		AGE	.898	1	.898	7.384	.007
	Main Effects	(Combined)	.329	4	8.215E-02	.675	.609
		T	.128	2	6.415E-02	.527	.591
		SP	.111	2	5.551E-02	.456	.634
	Model		2.164	6	.361	2.965	.008
	Residual		37.581	309	.122		
	Total		39.745	315	.126		

a. LOGCD by T, SP with TEMP, AGE

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

Two-way factorial analysis of variance with interaction for transformed average strain AB and CD by PCC thickness (T), synthetic fiber usage (FU) with temperature (Temp) and age (AGE)

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
LOGAB	Covariates	(Combined)	.795	2	.398	4.352	.014
		TEMP	.506	1	.506	5.533	.019
		AGE	.159	1	.159	1.737	.188
	Main Effects	(Combined)	.155	3	5.161E-02	.565	.639
		T	.144	2	7.225E-02	.791	.454
		FU	2.938E-03	1	2.938E-03	.032	.858
	2-Way Interactions	T * FU	.157	2	7.829E-02	.857	.426
	Model		1.240	7	.177	1.939	.063
	Residual		28.417	311	9.137E-02		
	Total		29.658	318	9.326E-02		

a. LOGAB by T, FU with TEMP, AGE

b. All effects entered simultaneously

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
LOGCD	Covariates	(Combined)	1.814	2	.907	7.476	.001
		TEMP	.549	1	.549	4.528	.034
		AGE	.916	1	.916	7.545	.006
	Main Effects	(Combined)	7.849E-02	3	2.616E-02	.216	.886
		T	7.051E-02	2	3.525E-02	.291	.748
		FU	2.741E-03	1	2.741E-03	.023	.881
	2-Way Interactions	T * FU	.239	2	.119	.983	.375
	Model		2.372	7	.339	2.792	.008
	Residual		37.373	308	.121		
	Total		39.745	315	.126		

a. LOGCD by T, FU with TEMP, AGE

b. All effects entered simultaneously

One-way analysis of variance with post HOC tests for transformed average strain AB and CD by PCC thickness (T)

Multiple Comparisons

Dependent Variable		(I) T	(J) T	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
LOGAB	Bonferroni	3.00	5.00	2.574E-03	.047	1.000	-.1112	.1163
			7.00	-6.63E-02	.043	.363	-.1688	3.626E-02
		5.00	3.00	-2.57E-03	.047	1.000	-.1163	.1112
			7.00	-6.88E-02	.039	.235	-.1626	2.495E-02
		7.00	3.00	6.625E-02	.043	.363	-3.63E-02	.1688
			5.00	6.883E-02	.039	.235	-2.49E-02	.1626
	Tamhane	3.00	5.00	2.574E-03	.047	1.000	-.1014	.1065
			7.00	-6.63E-02	.043	.265	-.1622	2.968E-02
		5.00	3.00	-2.57E-03	.047	1.000	-.1065	.1014
			7.00	-6.88E-02	.039	.221	-.1630	2.536E-02
		7.00	3.00	6.625E-02	.043	.265	-2.97E-02	.1622
			5.00	6.883E-02	.039	.221	-2.54E-02	.1630
LOGCD	Bonferroni	3.00	5.00	-6.93E-02	.060	.735	-.2125	7.391E-02
			7.00	-2.52E-02	.056	1.000	-.1606	.1102
		5.00	3.00	6.929E-02	.060	.735	-7.39E-02	.2125
			7.00	4.409E-02	.043	.932	-6.04E-02	.1486
		7.00	3.00	2.520E-02	.056	1.000	-.1102	.1606
			5.00	-4.41E-02	.043	.932	-.1486	6.039E-02
	Tamhane	3.00	5.00	-6.93E-02	.060	.572	-.2138	7.526E-02
			7.00	-2.52E-02	.056	.963	-.1670	.1166
		5.00	3.00	6.929E-02	.060	.572	-7.53E-02	.2138
			7.00	4.409E-02	.043	.651	-5.71E-02	.1453
		7.00	3.00	2.520E-02	.056	.963	-.1166	.1670
			5.00	-4.41E-02	.043	.651	-.1453	5.711E-02

One-way analysis of variance with post HOC tests for transformed average strain AB and CD by joint spacing (JS)

Multiple Comparisons

Dependent Variable		(I) JS	(J) JS	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LOGAB	Bonferroni	.00	1.00	8.730E-02	.053	.590	-5.25E-02	.2271
			2.00	1.645E-02	.049	1.000	-.1126	.1455
			3.00	1.197E-02	.050	1.000	-.1204	.1443
		1.00	.00	-8.73E-02	.053	.590	-.2271	5.246E-02
			2.00	-7.08E-02	.046	.757	-.1935	5.180E-02
			3.00	-7.53E-02	.047	.682	-.2014	5.075E-02
		2.00	.00	-1.64E-02	.049	1.000	-.1455	.1126
			1.00	7.085E-02	.046	.757	-5.18E-02	.1935
			3.00	-4.47E-03	.043	1.000	-.1186	.1096
		3.00	.00	-1.20E-02	.050	1.000	-.1443	.1204
			1.00	7.532E-02	.047	.682	-5.07E-02	.2014
			2.00	4.474E-03	.043	1.000	-.1096	.1186
	Tamhane	.00	1.00	8.730E-02	.053	.487	-5.57E-02	.2303
			2.00	1.645E-02	.049	1.000	-.1065	.1394
			3.00	1.197E-02	.050	1.000	-.1043	.1282
		1.00	.00	-8.73E-02	.053	.487	-.2303	5.574E-02
			2.00	-7.08E-02	.046	.680	-.2089	6.718E-02
			3.00	-7.53E-02	.047	.567	-.2075	5.684E-02
		2.00	.00	-1.64E-02	.049	1.000	-.1394	.1065
			1.00	7.085E-02	.046	.680	-6.72E-02	.2089
			3.00	-4.47E-03	.043	1.000	-.1141	.1052
		3.00	.00	-1.20E-02	.050	1.000	-.1282	.1043
			1.00	7.532E-02	.047	.567	-5.68E-02	.2075
			2.00	4.474E-03	.043	1.000	-.1052	.1141
LOGCD	Bonferroni	.00	1.00	-.1475	.061	.100	-.3102	1.513E-02
			2.00	-1.43E-02	.060	1.000	-.1731	.1445
			3.00	-4.15E-02	.061	1.000	-.2021	.1191
		1.00	.00	.1475	.061	.100	-1.51E-02	.3102
			2.00	.1332	.052	.064	-4.43E-03	.2708
			3.00	.1060	.053	.269	-3.37E-02	.2457
		2.00	.00	1.433E-02	.060	1.000	-.1445	.1731
			1.00	-.1332	.052	.064	-.2708	4.433E-03
			3.00	-2.72E-02	.051	1.000	-.1624	.1080
		3.00	.00	4.153E-02	.061	1.000	-.1191	.2021
			1.00	-.1060	.053	.269	-.2457	3.371E-02
			2.00	2.720E-02	.051	1.000	-.1080	.1624
	Tamhane	.00	1.00	-.1475	.061	.098	-.3108	1.577E-02
			2.00	-1.43E-02	.060	1.000	-.1827	.1540
			3.00	-4.15E-02	.061	.988	-.2147	.1316
		1.00	.00	.1475	.061	.098	-1.58E-02	.3108
			2.00	.1332*	.052	.038	4.602E-03	.2618
			3.00	.1060	.053	.208	-2.90E-02	.2410
		2.00	.00	1.433E-02	.060	1.000	-.1540	.1827
			1.00	-.1332*	.052	.038	-.2618	-4.60E-03
			3.00	-2.72E-02	.051	.996	-.1685	.1141
		3.00	.00	4.153E-02	.061	.988	-.1316	.2147
			1.00	-.1060	.053	.208	-.2410	2.904E-02
			2.00	2.720E-02	.051	.996	-.1141	.1685

*. The mean difference is significant at the .05 level.

One-way analysis of variance with post HOC tests for transformed average strain AB and CD by ACC surface preparation (SP)

Multiple Comparisons

Dependent Variable		(I) SP	(J) SP	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
LOGAB	Bonferroni	.00	1.00	-7.85E-02	.040	.152	-.1747	1.774E-02
			2.00	8.815E-02	.039	.073	-5.63E-03	.1819
		1.00	.00	7.847E-02	.040	.152	-1.77E-02	.1747
			2.00	.1666*	.041	.000	6.807E-02	.2652
		2.00	.00	-8.81E-02	.039	.073	-.1819	5.635E-03
			1.00	-.1666*	.041	.000	-.2652	-6.81E-02
	Tamhane	.00	1.00	-7.85E-02	.040	.129	-.1721	1.517E-02
			2.00	8.815E-02	.039	.094	-1.03E-02	.1866
		1.00	.00	7.847E-02	.040	.129	-1.52E-02	.1721
			2.00	.1666*	.041	.000	7.476E-02	.2585
		2.00	.00	-8.81E-02	.039	.094	-.1866	1.031E-02
			1.00	-.1666*	.041	.000	-.2585	-7.48E-02
LOGCD	Bonferroni	.00	1.00	-4.49E-02	.049	1.000	-.1634	7.368E-02
			2.00	-1.23E-02	.046	1.000	-.1227	9.809E-02
		1.00	.00	4.487E-02	.049	1.000	-7.37E-02	.1634
			2.00	3.256E-02	.050	1.000	-8.71E-02	.1522
		2.00	.00	1.231E-02	.046	1.000	-9.81E-02	.1227
			1.00	-3.26E-02	.050	1.000	-.1522	8.707E-02
	Tamhane	.00	1.00	-4.49E-02	.049	.793	-.1755	8.573E-02
			2.00	-1.23E-02	.046	.989	-.1160	9.142E-02
		1.00	.00	4.487E-02	.049	.793	-8.57E-02	.1755
			2.00	3.256E-02	.050	.887	-8.85E-02	.1536
		2.00	.00	1.231E-02	.046	.989	-9.14E-02	.1160
			1.00	-3.26E-02	.050	.887	-.1536	8.845E-02

*. The mean difference is significant at the .05 level.

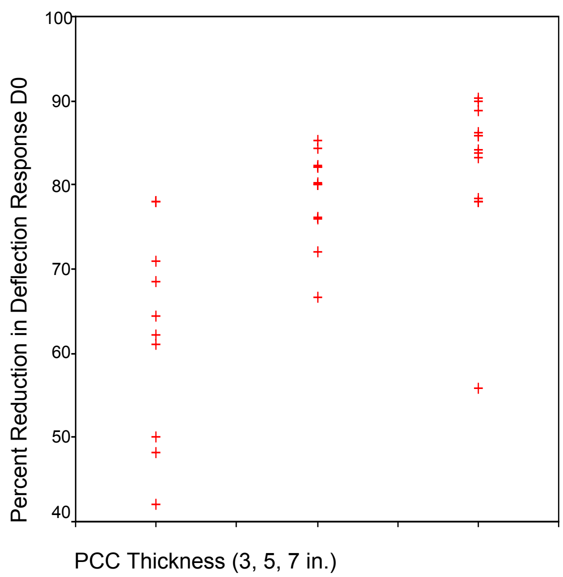
Two-sample T test for transformed average strain AB and CD by synthetic fiber usage (FU)

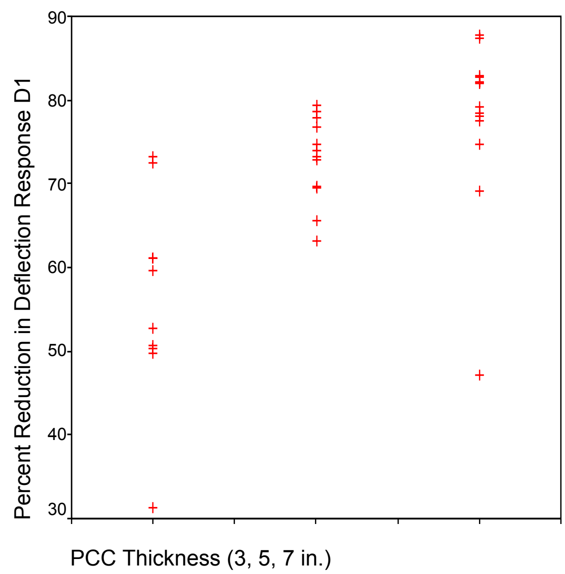
Independent Samples Test

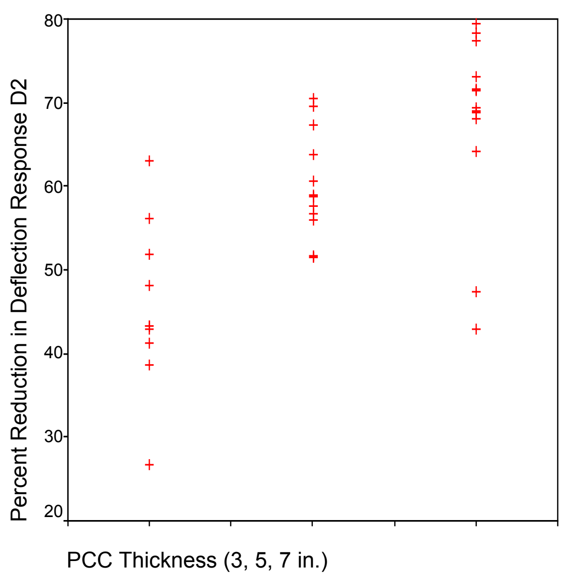
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LOGAB	Equal variances assumed	9.975	.002	.446	330	.656	1.488E-02	3.341E-02	-5.08E-02	8.060E-02
	Equal variances not assumed			.452	329.999	.652	1.488E-02	3.294E-02	-4.99E-02	7.968E-02
LOGCD	Equal variances assumed	.662	.416	-.857	327	.392	-3.34E-02	3.904E-02	-.1102	4.336E-02
	Equal variances not assumed			-.856	326.413	.392	-3.34E-02	3.905E-02	-.1103	4.337E-02

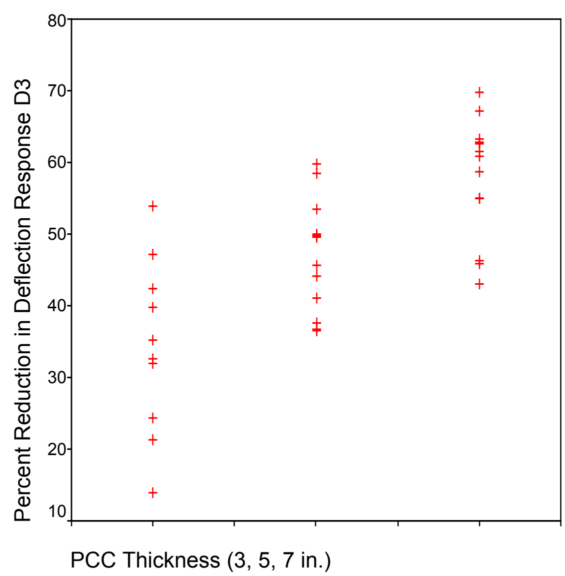
APPENDIX C. FALLING WEIGHT DEFLECTOMETER PERCENT REDUCTION IN DEFLECTION RESPONSES STATISTICAL ANALYSIS

Plots of percent reduction in deflection responses D0, D1, D2, and D3 versus PCC thickness

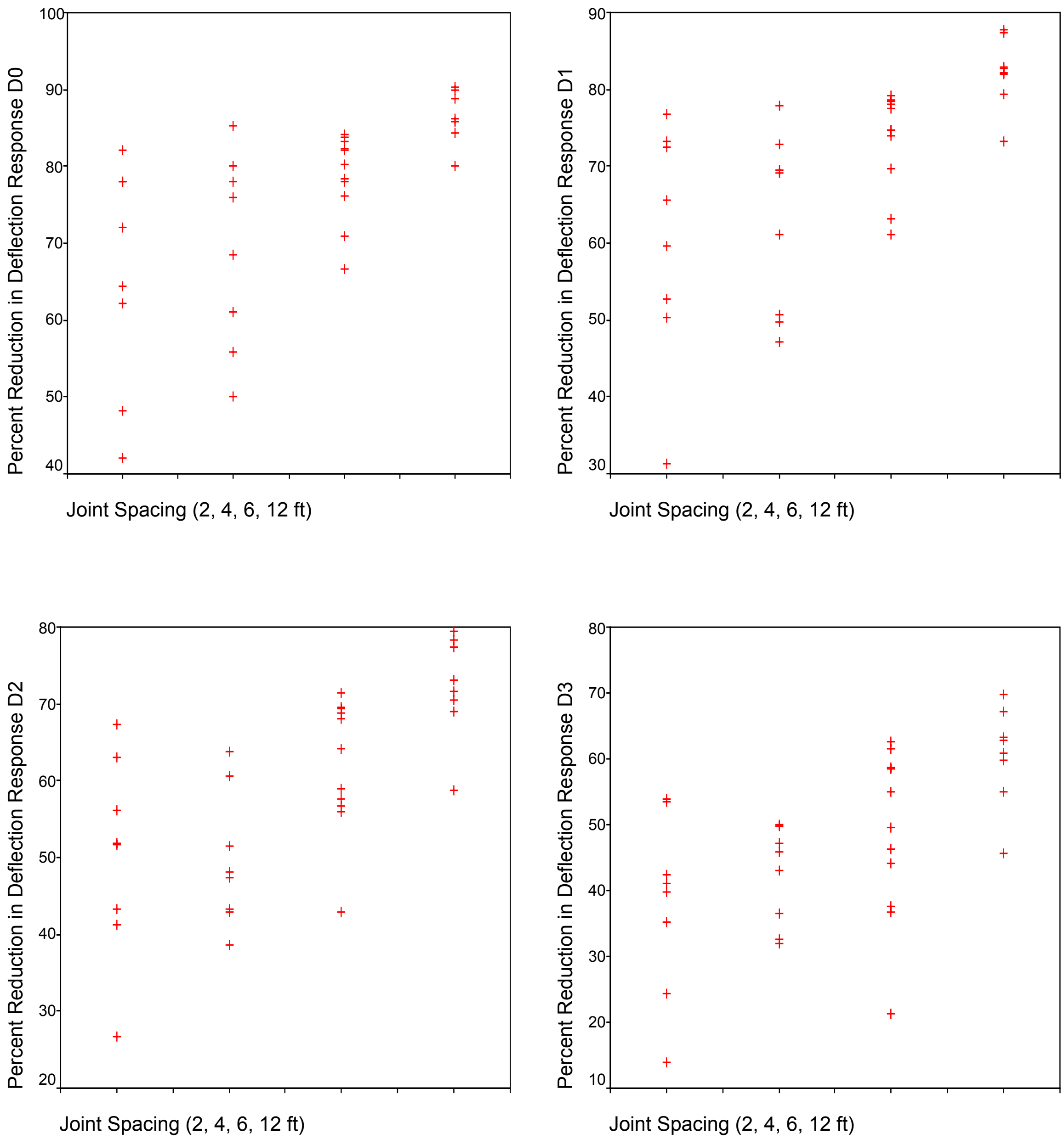




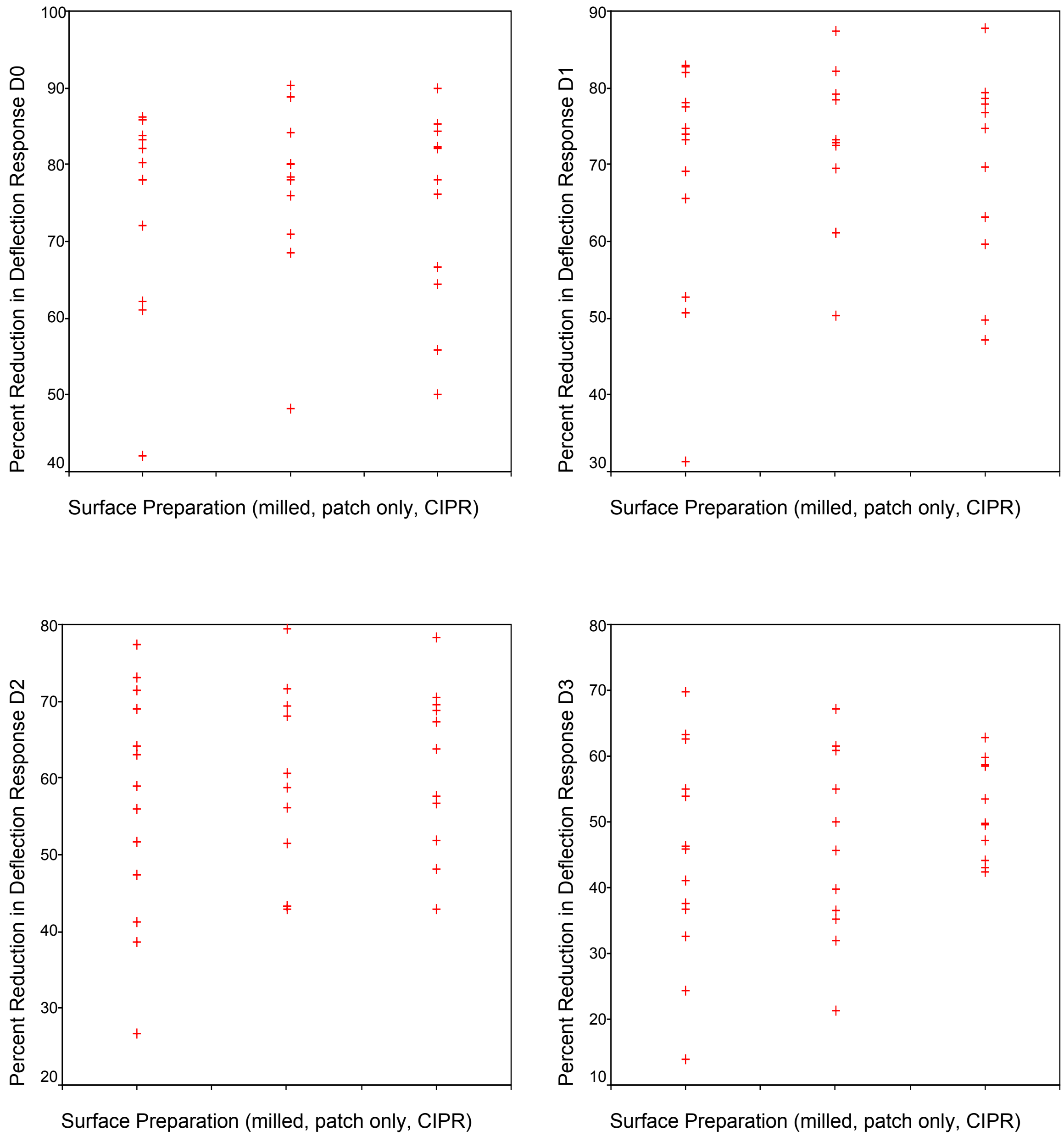




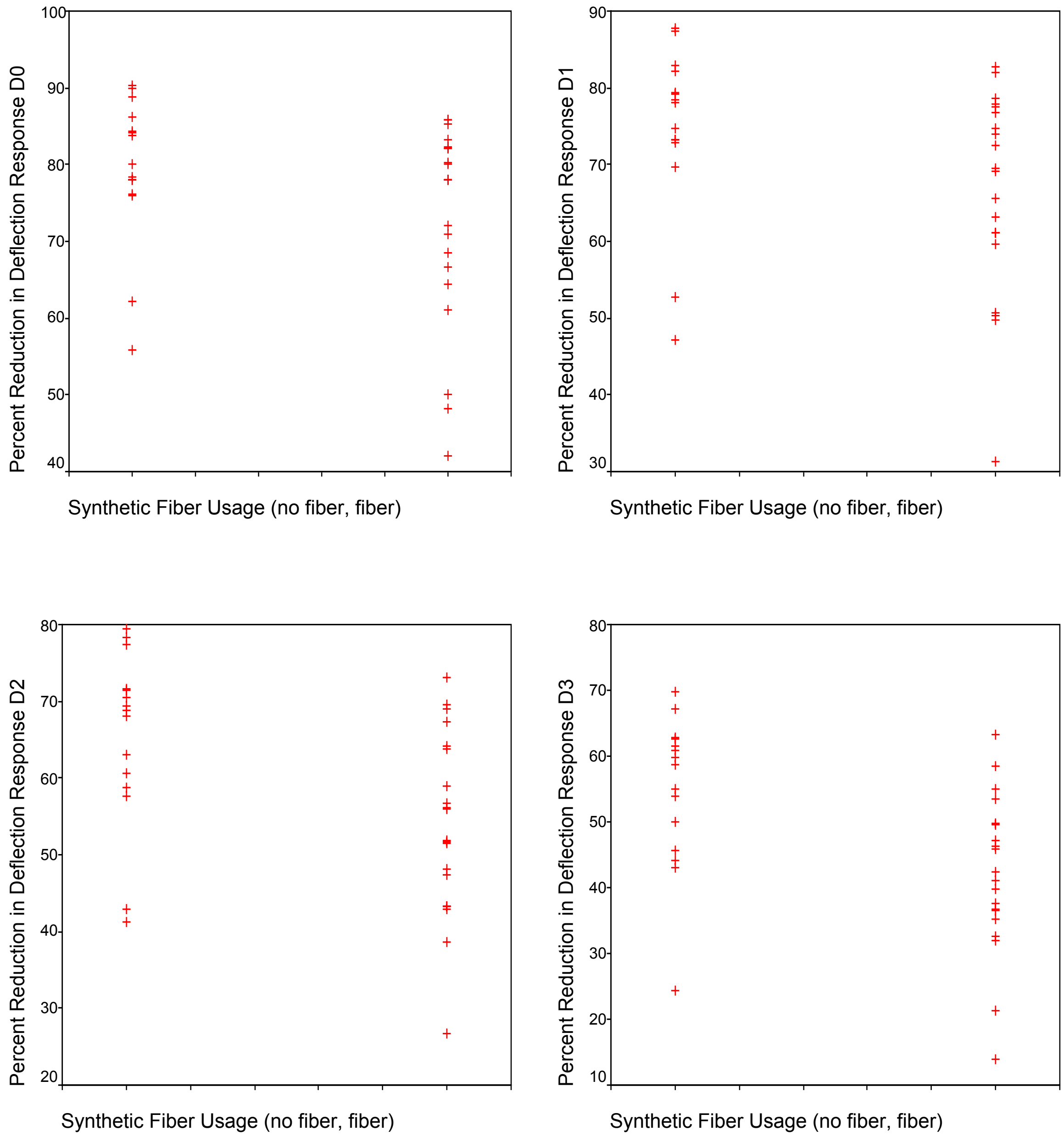
Plots of percent reduction in deflection responses D0, D1, D2, and D3 versus joint spacing



Plots of percent reduction in deflection responses D0, D1, D2, and D3 versus ACC surface preparation



Plots of percent reduction in deflection responses D0, D1, D2, and D3 versus synthetic fiber usage



Two-way factorial analysis of variance with interaction for percent reduction in deflection responses D0, D1, D2, and D3 by PCC thickness (T) and joint spacing (JS)

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D0	Main Effects	(Combined)	2914.293	5	582.859	7.705	.000
		T	800.637	2	400.318	5.292	.011
		JS	461.042	3	153.681	2.031	.131
	Model		2914.293	5	582.859	7.705	.000
	Residual		2193.866	29	75.651		
	Total		5108.159	34	150.240		

a. D0 by T, JS

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D1	Main Effects	(Combined)	3398.933	5	679.787	8.573	.000
		T	835.909	2	417.955	5.271	.011
		JS	645.644	3	215.215	2.714	.063
	Model		3398.933	5	679.787	8.573	.000
	Residual		2299.437	29	79.291		
	Total		5698.370	34	167.599		

a. D1 by T, JS

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D2	Main Effects	(Combined)	3689.519	5	737.904	11.005	.000
		T	832.386	2	416.193	6.207	.006
		JS	852.825	3	284.275	4.240	.013
	Model		3689.519	5	737.904	11.005	.000
	Residual		1944.468	29	67.051		
	Total		5633.987	34	165.705		

a. D2 by T, JS

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D3	Main Effects	(Combined)	3551.616	5	710.323	8.307	.000
		T	1235.346	2	617.673	7.223	.003
		JS	403.596	3	134.532	1.573	.217
	Model		3551.616	5	710.323	8.307	.000
	Residual		2479.869	29	85.513		
	Total		6031.486	34	177.397		

a. D3 by T, JS

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

Two-way factorial analysis of variance with interaction for percent reduction in deflection responses D0, D1, D2, and D3 by PCC thickness (T) and ACC surface preparation (SP)

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D0	Main Effects	(Combined)	2313.946	4	578.487	6.557	.001
		T	2266.586	2	1133.293	12.845	.000
		SP	200.521	2	100.261	1.136	.336
	2-Way Interactions	T * SP	198.250	4	49.562	.562	.692
	Model		2814.265	8	351.783	3.987	.003
	Residual		2293.894	26	88.227		
	Total		5108.159	34	150.240		

a. D0 by T, SP

b. All effects entered simultaneously

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D1	Main Effects	(Combined)	2449.294	4	612.324	6.392	.001
		T	2381.204	2	1190.602	12.428	.000
		SP	165.247	2	82.623	.862	.434
	2-Way Interactions	T * SP	300.617	4	75.154	.784	.546
	Model		3207.516	8	400.939	4.185	.003
	Residual		2490.854	26	95.802		
	Total		5698.370	34	167.599		

a. D1 by T, SP

b. All effects entered simultaneously

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D2	Main Effects	(Combined)	2487.485	4	621.871	6.785	.001
		T	2328.212	2	1164.106	12.701	.000
		SP	112.273	2	56.137	.612	.550
	2-Way Interactions	T * SP	287.049	4	71.762	.783	.547
	Model		3251.023	8	406.378	4.434	.002
	Residual		2382.964	26	91.652		
	Total		5633.987	34	165.705		

a. D2 by T, SP

b. All effects entered simultaneously

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D3	Main Effects	(Combined)	2916.164	4	729.041	8.985	.000
		T	2506.041	2	1253.020	15.442	.000
		SP	364.668	2	182.334	2.247	.126
	2-Way Interactions	T * SP	421.112	4	105.278	1.297	.297
	Model		3921.782	8	490.223	6.042	.000
	Residual		2109.704	26	81.142		
	Total		6031.486	34	177.397		

a. D3 by T, SP

b. All effects entered simultaneously

Two-way factorial analysis of variance with interaction for percent reduction in deflection responses D0, D1, D2, and D3 by PCC thickness (T) and synthetic fiber usage (FU)

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D0	Main Effects	(Combined)	1864.528	3	621.509	7.221	.001
		T	1254.420	2	627.210	7.287	.003
		FU	52.580	1	52.580	.611	.441
	2-Way Interactions	T * FU	138.494	2	69.247	.805	.457
	Model		2612.212	5	522.442	6.070	.001
	Residual		2495.947	29	86.067		
	Total		5108.159	34	150.240		

a. D0 by T, FU

b. All effects entered simultaneously

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D1	Main Effects	(Combined)	2237.242	3	745.747	7.647	.001
		T	1491.618	2	745.809	7.648	.002
		FU	63.335	1	63.335	.649	.427
	2-Way Interactions	T * FU	81.787	2	40.894	.419	.661
	Model		2870.403	5	574.081	5.887	.001
	Residual		2827.967	29	97.516		
	Total		5698.370	34	167.599		

a. D1 by T, FU

b. All effects entered simultaneously

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D2	Main Effects	(Combined)	2610.691	3	870.230	9.853	.000
		T	1403.363	2	701.682	7.945	.002
		FU	213.438	1	213.438	2.417	.131
	2-Way Interactions	T * FU	38.391	2	19.195	.217	.806
	Model		3072.685	5	614.537	6.958	.000
	Residual		2561.302	29	88.321		
	Total		5633.987	34	165.705		

a. D2 by T, FU

b. All effects entered simultaneously

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D3	Main Effects	(Combined)	3135.524	3	1045.175	11.613	.000
		T	1681.873	2	840.937	9.344	.001
		FU	243.769	1	243.769	2.708	.111
	2-Way Interactions	T * FU	12.662	2	6.331	.070	.932
	Model		3421.419	5	684.284	7.603	.000
	Residual		2610.067	29	90.002		
	Total		6031.486	34	177.397		

a. D3 by T, FU

b. All effects entered simultaneously

One-way analysis of variance with post HOC tests for percent reduction in deflection responses D0, D1, D2, and D3 by PCC thickness (T)

Multiple Comparisons

Dependent Variable		(I) T	(J) T	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
D0	Bonferroni	.00	1.00	-16.5750*	3.900	.001	-26.4282	-6.7218
			2.00	-19.8500*	3.831	.000	-29.5294	-10.1706
		1.00	.00	16.5750*	3.900	.001	6.7218	26.4282
			2.00	-3.2750	3.646	1.000	-12.4872	5.9372
		2.00	.00	19.8500*	3.831	.000	10.1706	29.5294
			1.00	3.2750	3.646	1.000	-5.9372	12.4872
	Tamhane	.00	1.00	-16.5750*	3.900	.006	-28.2560	-4.8940
			2.00	-19.8500*	3.831	.002	-32.2121	-7.4879
		1.00	.00	16.5750*	3.900	.006	4.8940	28.2560
			2.00	-3.2750	3.646	.621	-10.9033	4.3533
		2.00	.00	19.8500*	3.831	.002	7.4879	32.2121
			1.00	3.2750	3.646	.621	-4.3533	10.9033
D1	Bonferroni	.00	1.00	-16.6867*	4.108	.001	-27.0644	-6.3090
			2.00	-21.3931*	4.035	.000	-31.5877	-11.1984
		1.00	.00	16.6867*	4.108	.001	6.3090	27.0644
			2.00	-4.7064	3.840	.688	-14.4090	4.9962
		2.00	.00	21.3931*	4.035	.000	11.1984	31.5877
			1.00	4.7064	3.840	.688	-4.9962	14.4090
	Tamhane	.00	1.00	-16.6867*	4.108	.005	-28.2612	-5.1121
			2.00	-21.3931*	4.035	.001	-34.1443	-8.6418
		1.00	.00	16.6867*	4.108	.005	5.1121	28.2612
			2.00	-4.7064	3.840	.416	-13.2488	3.8360
		2.00	.00	21.3931*	4.035	.001	8.6418	34.1443
			1.00	4.7064	3.840	.416	-3.8360	13.2488
D2	Bonferroni	.00	1.00	-14.7183*	4.003	.003	-24.8323	-4.6044
			2.00	-22.2600*	3.933	.000	-32.1956	-12.3244
		1.00	.00	14.7183*	4.003	.003	4.6044	24.8323
			2.00	-7.5417	3.743	.157	-16.9977	1.9144
		2.00	.00	22.2600*	3.933	.000	12.3244	32.1956
			1.00	7.5417	3.743	.157	-1.9144	16.9977
	Tamhane	.00	1.00	-14.7183*	4.003	.003	-24.5798	-4.8569
			2.00	-22.2600*	3.933	.000	-33.6910	-10.8290
		1.00	.00	14.7183*	4.003	.003	4.8569	24.5798
			2.00	-7.5417	3.743	.135	-16.8304	1.7470
		2.00	.00	22.2600*	3.933	.000	10.8290	33.6910
			1.00	7.5417	3.743	.135	-1.7470	16.8304
D3	Bonferroni	.00	1.00	-12.6483*	4.064	.012	-22.9169	-2.3798
			2.00	-23.5862*	3.993	.000	-33.6736	-13.4987
		1.00	.00	12.6483*	4.064	.012	2.3798	22.9169
			2.00	-10.9378*	3.800	.021	-20.5384	-1.3373
		2.00	.00	23.5862*	3.993	.000	13.4987	33.6736
			1.00	10.9378*	3.800	.021	1.3373	20.5384
	Tamhane	.00	1.00	-12.6483*	4.064	.039	-24.7123	-.5843
			2.00	-23.5862*	3.993	.000	-35.6354	-11.5369
		1.00	.00	12.6483*	4.064	.039	.5843	24.7123
			2.00	-10.9378*	3.800	.009	-19.3823	-2.4933
		2.00	.00	23.5862*	3.993	.000	11.5369	35.6354
			1.00	10.9378*	3.800	.009	2.4933	19.3823

*. The mean difference is significant at the .05 level.

One-way analysis of variance with post HOC tests for percent reduction in deflection responses D0, D1, D2, and D3 by joint spacing (JS)

Multiple Comparisons

Depender Variable		(I) JS	(J) JS	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
D0	Bonferror	.00	1.00	-3.4500	4.914	1.000	-17.2997	10.3997
			2.00	-12.8307	4.567	.051	-25.7015	012E-02
			3.00	-20.5500*	4.914	.001	-34.3997	-6.7003
		1.00	.00	3.4500	4.914	1.000	-10.3997	17.2997
			2.00	-9.3807	4.567	.291	-22.2515	3.4901
			3.00	-17.1000*	4.914	.009	-30.9497	-3.2503
		2.00	.00	12.8307	4.567	.051	.01E-02	25.7015
			1.00	9.3807	4.567	.291	-3.4901	22.2515
			3.00	-7.7193	4.567	.606	-20.5901	5.1515
		3.00	.00	20.5500*	4.914	.001	6.7003	34.3997
			1.00	17.1000*	4.914	.009	3.2503	30.9497
			2.00	7.7193	4.567	.606	-5.1515	20.5901
	Tamhane	.00	1.00	-3.4500	4.914	.997	-24.3727	17.4727
			2.00	-12.8307	4.567	.237	-31.3370	5.6756
			3.00	-20.5500*	4.914	.030	-39.1153	-1.9847
		1.00	.00	3.4500	4.914	.997	-17.4727	24.3727
			2.00	-9.3807	4.567	.393	-25.2940	6.5326
			3.00	-17.1000*	4.914	.035	-33.0385	-1.1615
		2.00	.00	12.8307	4.567	.237	-5.6756	31.3370
			1.00	9.3807	4.567	.393	-6.5326	25.2940
			3.00	-7.7193*	4.567	.010	-13.8828	-1.5558
		3.00	.00	20.5500*	4.914	.030	1.9847	39.1153
			1.00	17.1000*	4.914	.035	1.1615	33.0385
			2.00	7.7193*	4.567	.010	1.5558	13.8828
D1	Bonferror	.00	1.00	-2.0000	5.028	1.000	-16.1716	12.1716
			2.00	-13.3045*	4.673	.047	-26.4745	-.1345
			3.00	-21.9125*	5.028	.001	-36.0841	-7.7409
		1.00	.00	2.0000	5.028	1.000	-12.1716	16.1716
			2.00	-11.3045	4.673	.130	-24.4745	1.8655
			3.00	-19.9125*	5.028	.002	-34.0841	-5.7409
		2.00	.00	13.3045*	4.673	.047	.1345	26.4745
			1.00	11.3045	4.673	.130	-1.8655	24.4745
			3.00	-8.6080	4.673	.450	-21.7780	4.5620
		3.00	.00	21.9125*	5.028	.001	7.7409	36.0841
			1.00	19.9125*	5.028	.002	5.7409	34.0841
			2.00	8.6080	4.673	.450	-4.5620	21.7780
	Tamhane	.00	1.00	-2.0000	5.028	1.000	-22.9945	18.9945
			2.00	-13.3045	4.673	.241	-32.5195	5.9104
			3.00	-21.9125*	5.028	.025	-41.1505	-2.6745
		1.00	.00	2.0000	5.028	1.000	-18.9945	22.9945
			2.00	-11.3045	4.673	.185	-26.3041	3.6950
			3.00	-19.9125*	5.028	.009	-34.8824	-4.9426
		2.00	.00	13.3045	4.673	.241	-5.9104	32.5195
			1.00	11.3045	4.673	.185	-3.6950	26.3041
			3.00	-8.6080*	4.673	.019	-16.0530	-1.1629
		3.00	.00	21.9125*	5.028	.025	2.6745	41.1505
			1.00	19.9125*	5.028	.009	4.9426	34.8824
			2.00	8.6080*	4.673	.019	1.1629	16.0530

*. The mean difference is significant at the .05 level.

Multiple Comparisons

Depender Variable		(I) JS	(J) JS	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
D2	Bonferror	.00	1.00	.6000	4.732	1.000	-12.7369	13.9369
			2.00	-12.0102	4.398	.062	-24.4045	.3840
			3.00	-22.1125*	4.732	.000	-35.4494	-8.7756
		1.00	.00	-.6000	4.732	1.000	-13.9369	12.7369
			2.00	-12.6102*	4.398	.044	-25.0045	-.2160
			3.00	-22.7125*	4.732	.000	-36.0494	-9.3756
		2.00	.00	12.0102	4.398	.062	-.3840	24.4045
			1.00	12.6102*	4.398	.044	.2160	25.0045
			3.00	-10.1023	4.398	.171	-22.4965	2.2920
		3.00	.00	22.1125*	4.732	.000	8.7756	35.4494
			1.00	22.7125*	4.732	.000	9.3756	36.0494
			2.00	10.1023	4.398	.171	-2.2920	22.4965
	Tamhane	.00	1.00	.6000	4.732	1.000	-16.7015	17.9015
			2.00	-12.0102	4.398	.231	-28.7261	4.7056
			3.00	-22.1125*	4.732	.009	-38.7681	-5.4569
		1.00	.00	-.6000	4.732	1.000	-17.9015	16.7015
			2.00	-12.6102*	4.398	.042	-24.8606	-.3598
			3.00	-22.7125*	4.732	.000	-34.7924	-10.6326
		2.00	.00	12.0102	4.398	.231	-4.7056	28.7261
			1.00	12.6102*	4.398	.042	.3598	24.8606
			3.00	-10.1023	4.398	.063	-20.5918	.3873
		3.00	.00	22.1125*	4.732	.009	5.4569	38.7681
			1.00	22.7125*	4.732	.000	10.6326	34.7924
			2.00	10.1023	4.398	.063	-.3873	20.5918
D3	Bonferror	.00	1.00	-4.1125	5.474	1.000	-19.5391	11.3141
			2.00	-10.3693	5.087	.301	-24.7056	3.9669
			3.00	-22.5125*	5.474	.002	-37.9391	-7.0859
		1.00	.00	4.1125	5.474	1.000	-11.3141	19.5391
			2.00	-6.2568	5.087	1.000	-20.5931	8.0794
			3.00	-18.4000*	5.474	.012	-33.8266	-2.9734
		2.00	.00	10.3693	5.087	.301	-3.9669	24.7056
			1.00	6.2568	5.087	1.000	-8.0794	20.5931
			3.00	-12.1432	5.087	.140	-26.4794	2.1931
		3.00	.00	22.5125*	5.474	.002	7.0859	37.9391
			1.00	18.4000*	5.474	.012	2.9734	33.8266
			2.00	12.1432	5.087	.140	-2.1931	26.4794
	Tamhane	.00	1.00	-4.1125	5.474	.978	-21.6919	13.4669
			2.00	-10.3693	5.087	.516	-29.0982	8.3595
			3.00	-22.5125*	5.474	.011	-40.1132	-4.9118
		1.00	.00	4.1125	5.474	.978	-13.4669	21.6919
			2.00	-6.2568	5.087	.734	-20.2031	7.6895
			3.00	-18.4000*	5.474	.001	-29.8198	-6.9802
		2.00	.00	10.3693	5.087	.516	-8.3595	29.0982
			1.00	6.2568	5.087	.734	-7.6895	20.2031
			3.00	-12.1432	5.087	.111	-26.1338	1.8475
		3.00	.00	22.5125*	5.474	.011	4.9118	40.1132
			1.00	18.4000*	5.474	.001	6.9802	29.8198
			2.00	12.1432	5.087	.111	-1.8475	26.1338

*. The mean difference is significant at the .05 level.

One-way analysis of variance with post HOC tests for percent reduction in deflection responses D0, D1, D2, and D3 by ACC surface preparation (SP)

Multiple Comparisons

Dependent Variable		(I) SP	(J) SP	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
D0	Bonferroni	.00	1.00	-1.2252	5.158	1.000	-14.2559	11.8056
			2.00	1.3294	5.158	1.000	-11.7014	14.3601
		1.00	.00	1.2252	5.158	1.000	-11.8056	14.2559
			2.00	2.5545	5.368	1.000	-11.0083	16.1174
		2.00	.00	-1.3294	5.158	1.000	-14.3601	11.7014
			1.00	-2.5545	5.368	1.000	-16.1174	11.0083
	Tamhane	.00	1.00	-1.2252	5.158	.993	-14.2120	11.7617
			2.00	1.3294	5.158	.993	-12.5003	15.1590
		1.00	.00	1.2252	5.158	.993	-11.7617	14.2120
			2.00	2.5545	5.368	.950	-11.0993	16.2084
		2.00	.00	-1.3294	5.158	.993	-15.1590	12.5003
			1.00	-2.5545	5.368	.950	-16.2084	11.0993
D1	Bonferroni	.00	1.00	-2.7923	5.443	1.000	-16.5441	10.9595
			2.00	-.6741	5.443	1.000	-14.4260	13.0777
		1.00	.00	2.7923	5.443	1.000	-10.9595	16.5441
			2.00	2.1182	5.665	1.000	-12.1952	16.4315
		2.00	.00	.6741	5.443	1.000	-13.0777	14.4260
			1.00	-2.1182	5.665	1.000	-16.4315	12.1952
	Tamhane	.00	1.00	-2.7923	5.443	.939	-16.6126	11.0280
			2.00	-.6741	5.443	.999	-15.6057	14.2574
		1.00	.00	2.7923	5.443	.939	-11.0280	16.6126
			2.00	2.1182	5.665	.967	-11.1385	15.3749
		2.00	.00	.6741	5.443	.999	-14.2574	15.6057
			1.00	-2.1182	5.665	.967	-15.3749	11.1385
D2	Bonferroni	.00	1.00	-1.8147	5.374	1.000	-15.3911	11.7617
			2.00	-4.6238	5.374	1.000	-18.2001	8.9526
		1.00	.00	1.8147	5.374	1.000	-11.7617	15.3911
			2.00	-2.8091	5.593	1.000	-16.9398	11.3216
		2.00	.00	4.6238	5.374	1.000	-8.9526	18.2001
			1.00	2.8091	5.593	1.000	-11.3216	16.9398
	Tamhane	.00	1.00	-1.8147	5.374	.985	-16.4314	12.8021
			2.00	-4.6238	5.374	.778	-18.3894	9.1418
		1.00	.00	1.8147	5.374	.985	-12.8021	16.4314
			2.00	-2.8091	5.593	.927	-15.8858	10.2677
		2.00	.00	4.6238	5.374	.778	-9.1418	18.3894
			1.00	2.8091	5.593	.927	-10.2677	15.8858
D3	Bonferroni	.00	1.00	-1.0566	5.475	1.000	-14.8895	12.7762
			2.00	-6.8839	5.475	.653	-20.7168	6.9489
		1.00	.00	1.0566	5.475	1.000	-12.7762	14.8895
			2.00	-5.8273	5.699	.943	-20.2250	8.5704
		2.00	.00	6.8839	5.475	.653	-6.9489	20.7168
			1.00	5.8273	5.699	.943	-8.5704	20.2250
	Tamhane	.00	1.00	-1.0566	5.475	.998	-17.1365	15.0232
			2.00	-6.8839	5.475	.459	-20.0599	6.2921
		1.00	.00	1.0566	5.475	.998	-15.0232	17.1365
			2.00	-5.8273	5.699	.576	-18.8836	7.2291
		2.00	.00	6.8839	5.475	.459	-6.2921	20.0599
			1.00	5.8273	5.699	.576	-7.2291	18.8836

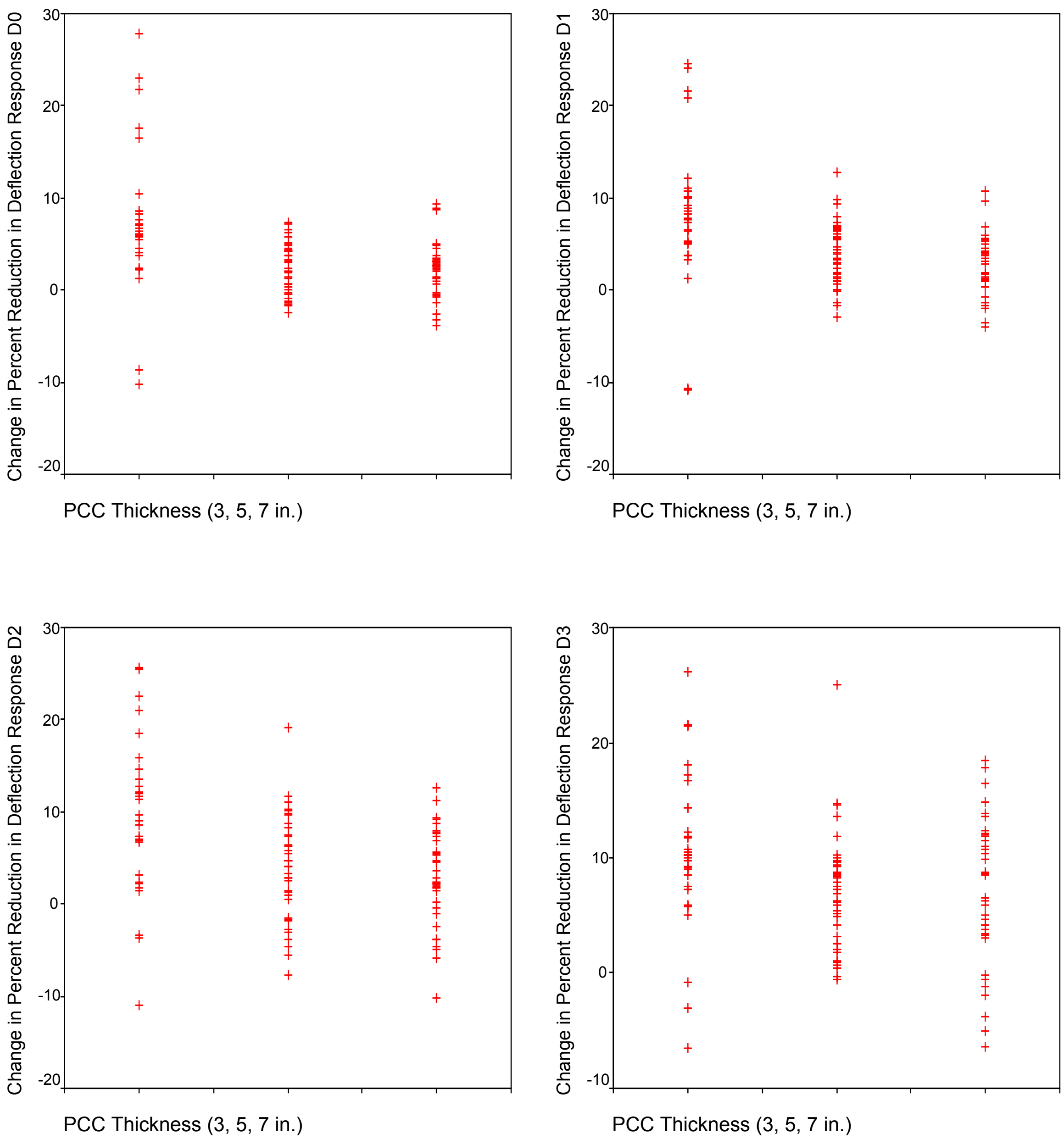
Two-sample T test for percent reduction in deflection responses D0, D1, D2, and D3 by synthetic fiber usage (FU)

Independent Samples Test

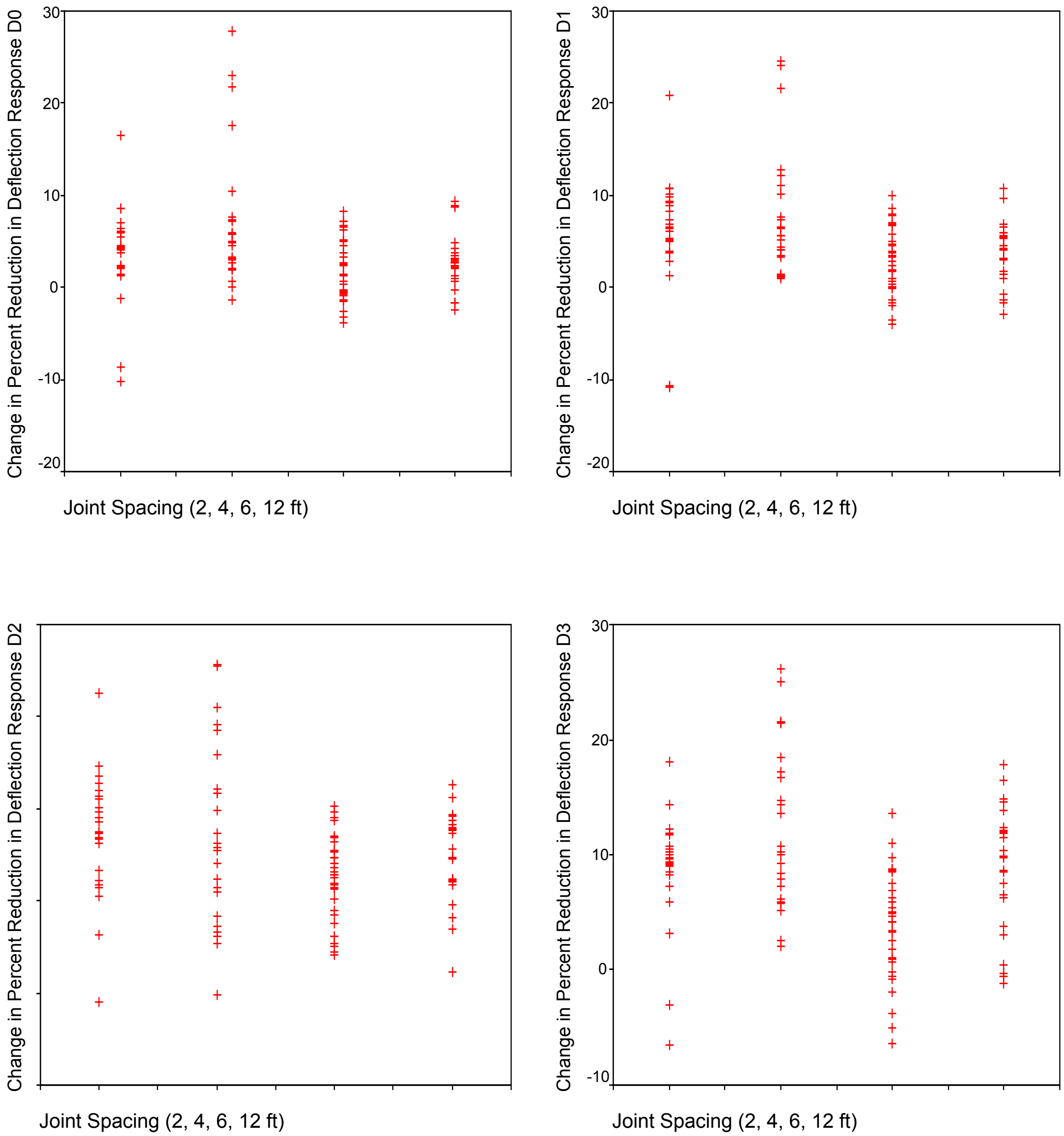
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
D0	Equal variances assumed	2.489	.124	1.754	33	.089	7.1300	4.0643	-1.1389	15.3989
	Equal variances not assumed			1.836	32.983	.075	7.1300	3.8836	-.7714	15.0314
D1	Equal variances assumed	1.015	.321	1.920	33	.064	8.1717	4.2570	-.4893	16.8326
	Equal variances not assumed			1.964	32.372	.058	8.1717	4.1602	-.2986	16.6419
D2	Equal variances assumed	.043	.837	2.818	33	.008	11.2917	4.0068	3.1398	19.4436
	Equal variances not assumed			2.829	30.742	.008	11.2917	3.9910	3.1493	19.4340
D3	Equal variances assumed	.019	.891	3.147	33	.003	12.7450	4.0498	4.5055	20.9845
	Equal variances not assumed			3.160	30.743	.004	12.7450	4.0338	4.5153	20.9747

APPENDIX D. FALLING WEIGHT DEFLECTOMETER CHANGE IN PERCENT REDUCTION IN DEFLECTION RESPONSES STATISTICAL ANALYSIS

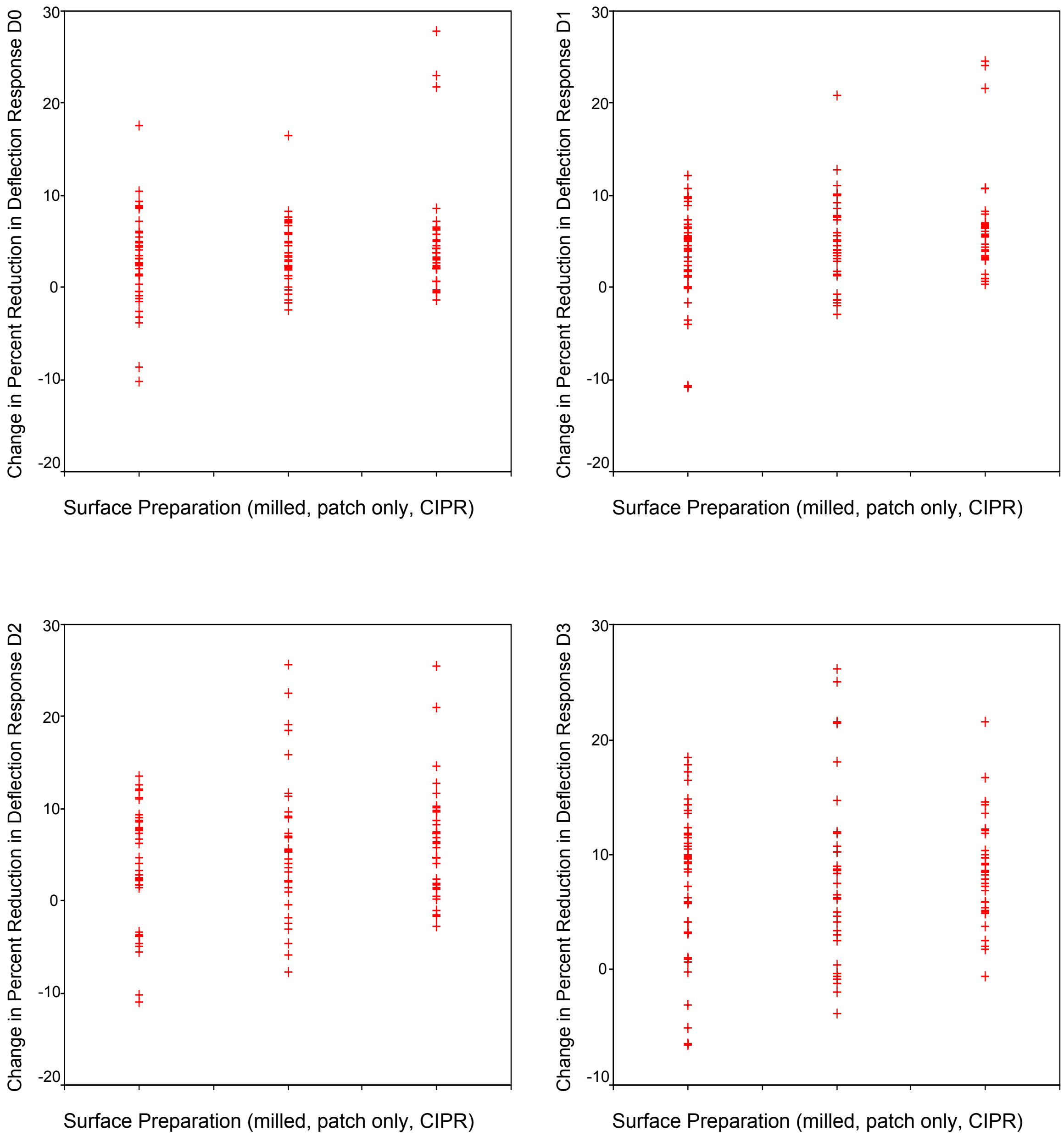
Plots of change in percent reduction in deflection responses D0, D1, D2, and D3 versus PCC thickness



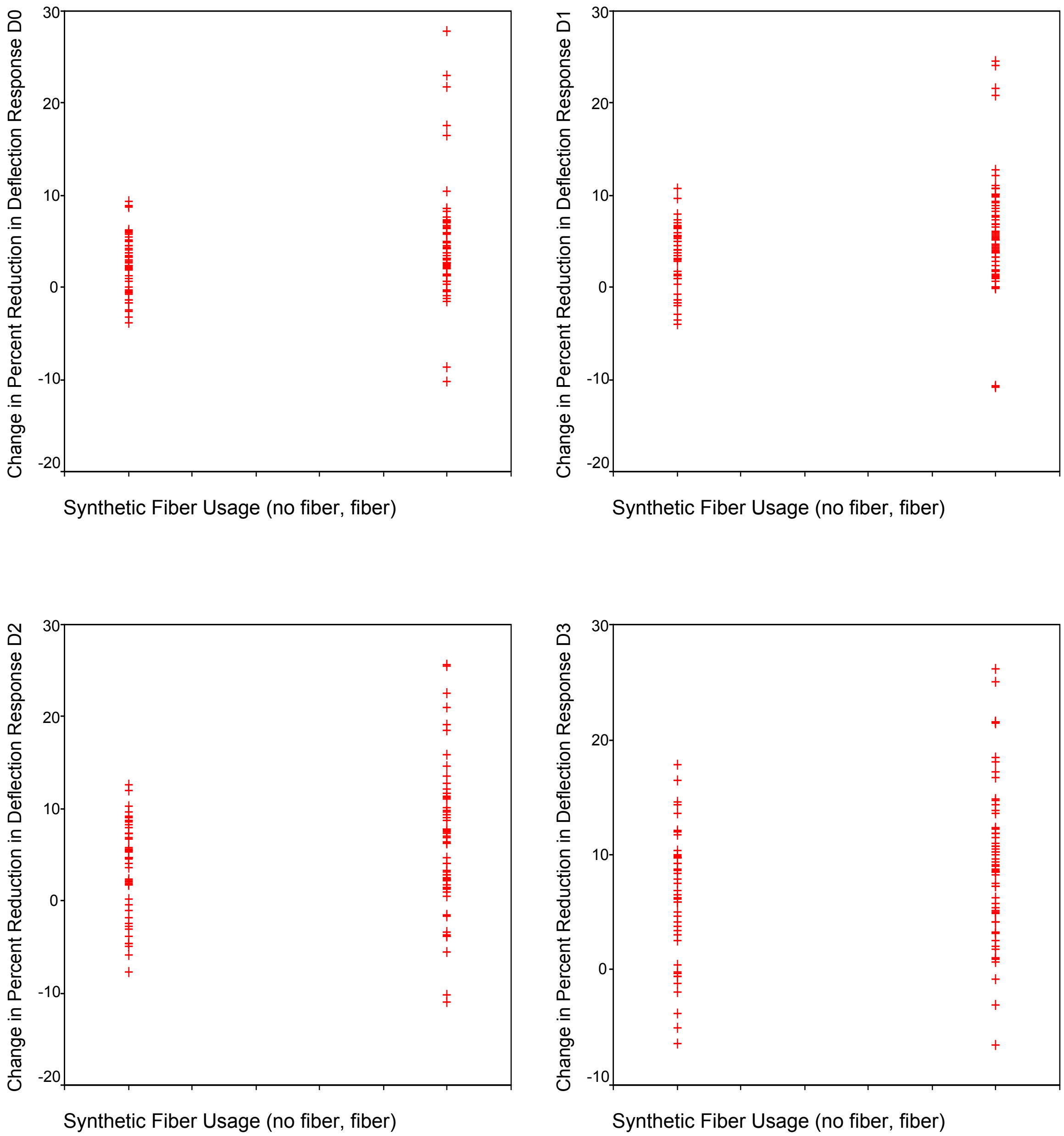
Plots of change in percent reduction in deflection responses D0, D1, D2, and D3 versus joint spacing



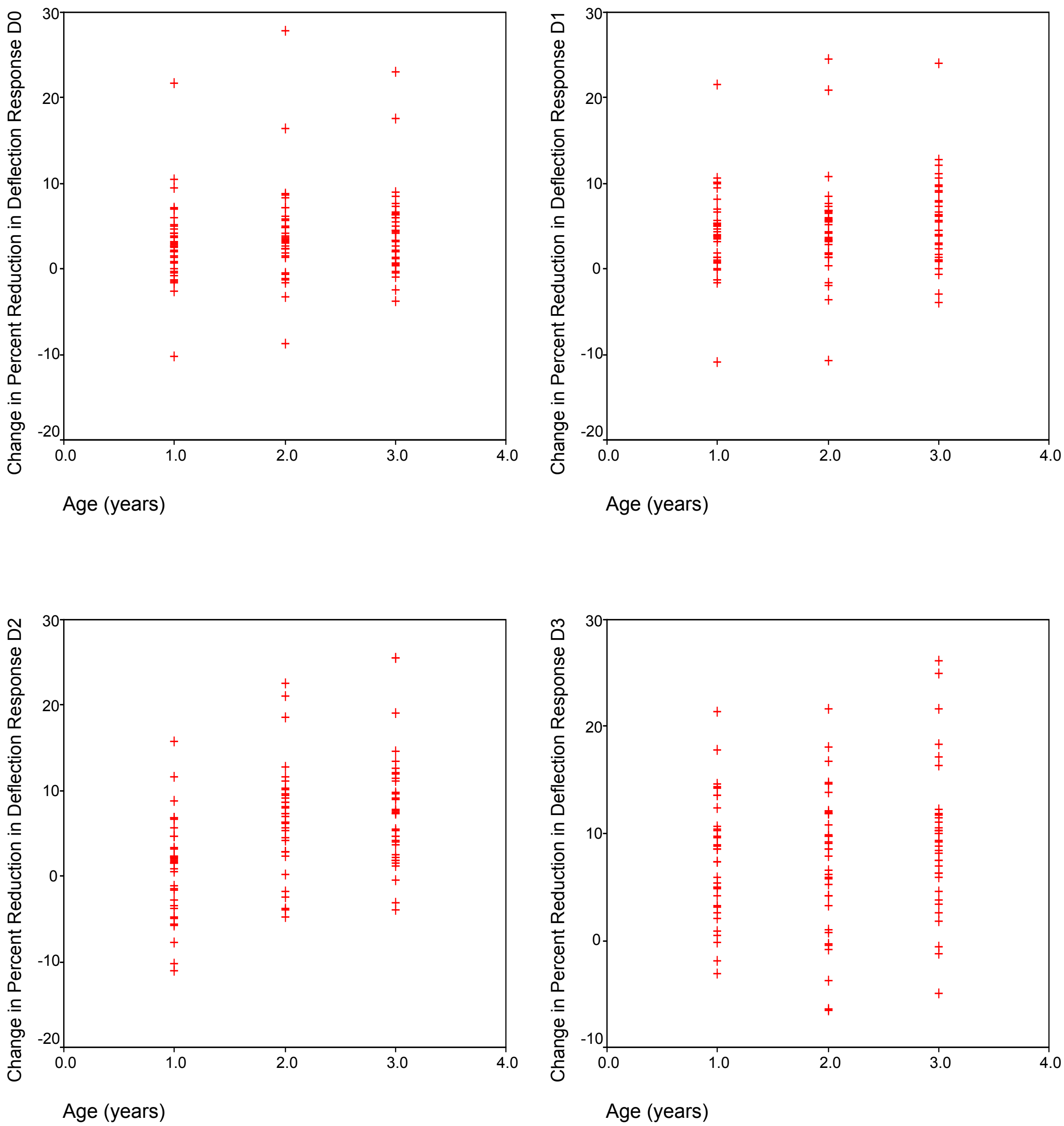
Plots of change in percent reduction in deflection responses D0, D1, D2, and D3 versus ACC surface preparation



Plots of change in percent reduction in deflection responses D0, D1, D2, and D3 versus synthetic fiber usage



Plots of change in percent reduction in deflection responses D0, D1, D2, and D3 versus age



Two-way factorial analysis of variance with interaction for change in percent reduction in deflection responses D0, D1, D2, and D3 by PCC thickness (T), joint spacing (JS) with age (AGE)

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D0	Covariates	AGE	39.375	1	39.375	1.985	.162
	Main Effects	(Combined)	960.003	5	192.001	9.681	.000
		T	566.616	2	283.308	14.285	.000
		JS	409.820	3	136.607	6.888	.000
	Model		999.378	6	166.563	8.398	.000
	Residual		1943.652	98	19.833		
	Total		2943.030	104	28.298		

a. D0 by T, JS with AGE

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D1	Covariates	AGE	32.504	1	32.504	1.355	.247
	Main Effects	(Combined)	731.904	5	146.381	6.101	.000
		T	339.251	2	169.625	7.070	.001
		JS	222.402	3	74.134	3.090	.031
	Model		764.408	6	127.401	5.310	.000
	Residual		2351.313	98	23.993		
	Total		3115.721	104	29.959		

a. D1 by T, JS with AGE

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D2	Covariates	AGE	794.983	1	794.983	24.557	.000
	Main Effects	(Combined)	1014.739	5	202.948	6.269	.000
		T	522.495	2	261.247	8.070	.001
		JS	218.005	3	72.668	2.245	.088
	Model		1809.722	6	301.620	9.317	.000
	Residual		3172.588	98	32.373		
	Total		4982.309	104	47.907		

a. D2 by T, JS with AGE

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

ANOVA[a,b,c]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D3	Covariates	AGE	50.916	1	50.916	1.704	.195
	Main Effects	(Combined)	1235.974	5	247.195	8.273	.000
		T	143.126	2	71.563	2.395	.096
		JS	919.003	3	306.334	10.252	.000
	Model		1286.890	6	214.482	7.178	.000
	Residual		2928.192	98	29.880		
	Total		4215.081	104	40.530		

a. D3 by T, JS with AGE

b. All effects entered simultaneously

c. Due to empty cells or a singular matrix, higher order interactions have been suppressed.

Two-way factorial analysis of variance with interaction for change in percent reduction in deflection responses D0, D1, D2, and D3 by PCC thickness (T), ACC surface preparation (SP) with age (AGE)

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D0	Covariates	AGE	39.375	1	39.375	2.093	.151
	Main Effects	(Combined)	1020.166	4	255.042	13.554	.000
		T	869.826	2	434.913	23.113	.000
		SP	251.589	2	125.794	6.685	.002
	2-Way Interactions	T * SP	345.546	4	86.387	4.591	.002
	Model		1155.467	9	128.385	6.823	.000
	Residual		1787.563	95	18.816		
	Total		2943.030	104	28.298		

a. D0 by T, SP with AGE

b. All effects entered simultaneously

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D1	Covariates	AGE	32.504	1	32.504	1.705	.195
	Main Effects	(Combined)	1052.093	4	263.023	13.801	.000
		T	796.883	2	398.442	20.906	.000
		SP	301.318	2	150.659	7.905	.001
	2-Way Interactions	T * SP	530.151	4	132.538	6.954	.000
	Model		1305.157	9	145.017	7.609	.000
	Residual		1810.564	95	19.059		
	Total		3115.721	104	29.959		

a. D1 by T, SP with AGE

b. All effects entered simultaneously

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D2	Covariates	AGE	794.983	1	794.983	26.937	.000
	Main Effects	(Combined)	1221.334	4	305.334	10.346	.000
		T	1022.740	2	511.370	17.327	.000
		SP	248.405	2	124.202	4.208	.018
	2-Way Interactions	T * SP	350.876	4	87.719	2.972	.023
	Model		2178.619	9	242.069	8.202	.000
	Residual		2803.690	95	29.513		
	Total		4982.309	104	47.907		

a. D2 by T, SP with AGE

b. All effects entered simultaneously

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D3	Covariates	AGE	50.916	1	50.916	1.423	.236
	Main Effects	(Combined)	453.533	4	113.383	3.168	.017
		T	424.182	2	212.091	5.927	.004
		SP	51.368	2	25.684	.718	.490
	2-Way Interactions	T * SP	410.931	4	102.733	2.871	.027
	Model		815.393	9	90.599	2.532	.012
	Residual		3399.688	95	35.786		
	Total		4215.081	104	40.530		

a. D3 by T, SP with AGE

b. All effects entered simultaneously

Two-way factorial analysis of variance with interaction for change in percent reduction in deflection responses D0, D1, D2, and D3 by PCC thickness (T), synthetic fiber usage (FU) with age (AGE)

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D0	Covariates	AGE	39.375	1	39.375	1.680	.198
	Main Effects	(Combined)	431.298	3	143.766	6.135	.001
		T	245.819	2	122.909	5.245	.007
		FU	42.157	1	42.157	1.799	.183
	2-Way Interactions	T * FU	30.123	2	15.062	.643	.528
	Model		646.619	6	107.770	4.599	.000
	Residual		2296.411	98	23.433		
	Total		2943.030	104	28.298		

a. D0 by T, FU with AGE

b. All effects entered simultaneously

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D1	Covariates	AGE	32.504	1	32.504	1.282	.260
	Main Effects	(Combined)	479.186	3	159.729	6.298	.001
		T	203.108	2	101.554	4.004	.021
		FU	80.696	1	80.696	3.182	.078
	2-Way Interactions	T * FU	26.207	2	13.103	.517	.598
	Model		630.360	6	105.060	4.143	.001
	Residual		2485.361	98	25.361		
	Total		3115.721	104	29.959		

a. D1 by T, FU with AGE

b. All effects entered simultaneously

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D2	Covariates	AGE	794.983	1	794.983	23.302	.000
	Main Effects	(Combined)	723.754	3	241.251	7.071	.000
		T	446.133	2	223.066	6.538	.002
		FU	40.003	1	40.003	1.173	.282
	2-Way Interactions	T * FU	11.016	2	5.508	.161	.851
	Model		1638.916	6	273.153	8.007	.000
	Residual		3343.393	98	34.116		
	Total		4982.309	104	47.907		

a. D2 by T, FU with AGE

b. All effects entered simultaneously

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
D3	Covariates	AGE	50.916	1	50.916	1.411	.238
	Main Effects	(Combined)	437.379	3	145.793	4.041	.009
		T	169.431	2	84.715	2.348	.101
		FU	123.260	1	123.260	3.416	.068
	2-Way Interactions	T * FU	165.589	2	82.794	2.295	.106
	Model		679.131	6	113.189	3.137	.007
	Residual		3535.950	98	36.081		
	Total		4215.081	104	40.530		

a. D3 by T, FU with AGE

b. All effects entered simultaneously

One-way analysis of variance with post HOC tests for change in percent reduction in deflection responses D0, D1, D2, and D3 by PCC thickness (T)

Multiple Comparisons

Dependent Variable		(I) T	(J) T	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
D0	Bonferroni	.00	1.00	5.0995*	1.176	.000	2.2364	7.9625
			2.00	5.0311*	1.197	.000	2.1167	7.9456
		1.00	.00	-5.0995*	1.176	.000	-7.9625	-2.2364
			2.00	-6.84E-02	1.119	1.000	-2.7932	2.6565
		2.00	.00	-5.0311*	1.197	.000	-7.9456	-2.1167
			1.00	6.838E-02	1.119	1.000	-2.6565	2.7932
	Tamhane	.00	1.00	5.0995*	1.176	.005	1.3335	8.8655
			2.00	5.0311*	1.197	.006	1.2243	8.8380
		1.00	.00	-5.0995*	1.176	.005	-8.8655	-1.3335
			2.00	-6.84E-02	1.119	.999	-1.6953	1.5585
		2.00	.00	-5.0311*	1.197	.006	-8.8380	-1.2243
			1.00	6.838E-02	1.119	.999	-1.5585	1.6953
D1	Bonferroni	.00	1.00	4.2123*	1.228	.003	1.2243	7.2003
			2.00	5.3506*	1.250	.000	2.3089	8.3922
		1.00	.00	-4.2123*	1.228	.003	-7.2003	-1.2243
			2.00	1.1382	1.168	.997	-1.7055	3.9820
		2.00	.00	-5.3506*	1.250	.000	-8.3922	-2.3089
			1.00	-1.1382	1.168	.997	-3.9820	1.7055
	Tamhane	.00	1.00	4.2123*	1.228	.028	.3754	8.0492
			2.00	5.3506*	1.250	.004	1.5202	9.1809
		1.00	.00	-4.2123*	1.228	.028	-8.0492	-.3754
			2.00	1.1382	1.168	.375	-.7493	3.0258
		2.00	.00	-5.3506*	1.250	.004	-9.1809	-1.5202
			1.00	-1.1382	1.168	.375	-3.0258	.7493
D2	Bonferroni	.00	1.00	5.4864*	1.556	.002	1.6998	9.2730
			2.00	6.5800*	1.584	.000	2.7254	10.4346
		1.00	.00	-5.4864*	1.556	.002	-9.2730	-1.6998
			2.00	1.0936	1.481	1.000	-2.5102	4.6974
		2.00	.00	-6.5800*	1.584	.000	-10.4346	-2.7254
			1.00	-1.0936	1.481	1.000	-4.6974	2.5102
	Tamhane	.00	1.00	5.4864*	1.556	.010	1.0791	9.8937
			2.00	6.5800*	1.584	.002	2.1952	10.9648
		1.00	.00	-5.4864*	1.556	.010	-9.8937	-1.0791
			2.00	1.0936	1.481	.762	-1.9367	4.1239
		2.00	.00	-6.5800*	1.584	.002	-10.9648	-2.1952
			1.00	-1.0936	1.481	.762	-4.1239	1.9367
D3	Bonferroni	.00	1.00	3.8831*	1.501	.033	.2288	7.5373
			2.00	3.8044*	1.528	.043	8.459E-02	7.5243
		1.00	.00	-3.8831*	1.501	.033	-7.5373	-.2288
			2.00	-7.86E-02	1.429	1.000	-3.5565	3.3992
		2.00	.00	-3.8044*	1.528	.043	-7.5243	-8.46E-02
			1.00	7.863E-02	1.429	1.000	-3.3992	3.5565
	Tamhane	.00	1.00	3.8831*	1.501	.044	8.409E-02	7.6821
			2.00	3.8044	1.528	.082	-.3498	7.9587
		1.00	.00	-3.8831*	1.501	.044	-7.6821	-8.41E-02
			2.00	-7.86E-02	1.429	1.000	-3.3617	3.2044
		2.00	.00	-3.8044	1.528	.082	-7.9587	.3498
			1.00	7.863E-02	1.429	1.000	-3.2044	3.3617

*. The mean difference is significant at the .05 level.

One-way analysis of variance with post HOC tests for change in percent reduction in deflection responses D0, D1, D2, and D3 by joint spacing (JS)

Multiple Comparisons

Depender Variable		(I) JS	(J) JS	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
D0	Bonferror	.00	1.00	-3.5167	1.450	.103	-7.4200	.3867
			2.00	1.5792	1.348	1.000	-2.0483	5.2066
			3.00	.8125	1.450	1.000	-3.0908	4.7158
		1.00	.00	3.5167	1.450	.103	-.3867	7.4200
			2.00	5.0958*	1.348	.002	1.4684	8.7233
			3.00	4.3292*	1.450	.021	.4258	8.2325
		2.00	.00	-1.5792	1.348	1.000	-5.2066	2.0483
			1.00	-5.0958*	1.348	.002	-8.7233	-1.4684
			3.00	-.7667	1.348	1.000	-4.3941	2.8608
		3.00	.00	-.8125	1.450	1.000	-4.7158	3.0908
			1.00	-4.3292*	1.450	.021	-8.2325	-.4258
			2.00	.7667	1.348	1.000	-2.8608	4.3941
	Tamhane	.00	1.00	-3.5167	1.450	.356	-8.7551	1.7218
			2.00	1.5792	1.348	.747	-1.8258	4.9842
			3.00	.8125	1.450	.987	-2.6460	4.2710
		1.00	.00	3.5167	1.450	.356	-1.7218	8.7551
			2.00	5.0958*	1.348	.028	.4063	9.7853
			3.00	4.3292	1.450	.087	-.3949	9.0533
		2.00	.00	-1.5792	1.348	.747	-4.9842	1.8258
			1.00	-5.0958*	1.348	.028	-9.7853	-.4063
			3.00	-.7667	1.348	.938	-3.0903	1.5569
		3.00	.00	-.8125	1.450	.987	-4.2710	2.6460
			1.00	-4.3292	1.450	.087	-9.0533	.3949
			2.00	.7667	1.348	.938	-1.5569	3.0903
D1	Bonferror	.00	1.00	-1.8917	1.499	1.000	-5.9256	2.1422
			2.00	3.0754	1.393	.177	-.6734	6.8242
			3.00	2.0375	1.499	1.000	-1.9964	6.0714
		1.00	.00	1.8917	1.499	1.000	-2.1422	5.9256
			2.00	4.9670*	1.393	.003	1.2182	8.7158
			3.00	3.9292	1.499	.061	-.1047	7.9631
		2.00	.00	-3.0754	1.393	.177	-6.8242	.6734
			1.00	-4.9670*	1.393	.003	-8.7158	-1.2182
			3.00	-1.0379	1.393	1.000	-4.7867	2.7109
		3.00	.00	-2.0375	1.499	1.000	-6.0714	1.9964
			1.00	-3.9292	1.499	.061	-7.9631	.1047
			2.00	1.0379	1.393	1.000	-2.7109	4.7867
	Tamhane	.00	1.00	-1.8917	1.499	.912	-7.2068	3.4235
			2.00	3.0754	1.393	.224	-.9797	7.1305
			3.00	2.0375	1.499	.691	-2.0927	6.1677
		1.00	.00	1.8917	1.499	.912	-3.4235	7.2068
			2.00	4.9670*	1.393	.018	.6256	9.3084
			3.00	3.9292	1.499	.103	-.4809	8.3392
		2.00	.00	-3.0754	1.393	.224	-7.1305	.9797
			1.00	-4.9670*	1.393	.018	-9.3084	-.6256
			3.00	-1.0379	1.393	.843	-3.5616	1.4859
		3.00	.00	-2.0375	1.499	.691	-6.1677	2.0927
			1.00	-3.9292	1.499	.103	-8.3392	.4809
			2.00	1.0379	1.393	.843	-1.4859	3.5616

*. The mean difference is significant at the .05 level.

Multiple Comparisons

Depender Variable		(I) JS	(J) JS	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
D2	Bonferror	.00	1.00	-.2417	1.925	1.000	-5.4216	4.9383
			2.00	4.8455*	1.789	.048	164E-02	9.6593
			3.00	2.6083	1.925	1.000	-2.5716	7.7883
		1.00	.00	.2417	1.925	1.000	-4.9383	5.4216
			2.00	5.0871*	1.789	.032	.2733	9.9009
			3.00	2.8500	1.925	.851	-2.3299	8.0299
		2.00	.00	-4.8455*	1.789	.048	-9.6593	.16E-02
			1.00	-5.0871*	1.789	.032	-9.9009	-.2733
			3.00	-2.2371	1.789	1.000	-7.0509	2.5767
		3.00	.00	-2.6083	1.925	1.000	-7.7883	2.5716
			1.00	-2.8500	1.925	.851	-8.0299	2.3299
			2.00	2.2371	1.789	1.000	-2.5767	7.0509
	Tamhane	.00	1.00	-.2417	1.925	1.000	-6.9887	6.5054
			2.00	4.8455*	1.789	.024	.4483	9.2426
			3.00	2.6083	1.925	.567	-2.0565	7.2731
		1.00	.00	.2417	1.925	1.000	-6.5054	6.9887
			2.00	5.0871	1.789	.145	-1.0180	11.1922
			3.00	2.8500	1.925	.763	-3.4314	9.1314
		2.00	.00	-4.8455*	1.789	.024	-9.2426	-.4483
			1.00	-5.0871	1.789	.145	-11.1922	1.0180
			3.00	-2.2371	1.789	.409	-5.7151	1.2409
		3.00	.00	-2.6083	1.925	.567	-7.2731	2.0565
			1.00	-2.8500	1.925	.763	-9.1314	3.4314
			2.00	2.2371	1.789	.409	-1.2409	5.7151
D3	Bonferror	.00	1.00	-3.7750	1.605	.124	-8.0945	.5445
			2.00	4.9318*	1.492	.008	.9177	8.9460
			3.00	083E-02	1.605	1.000	-4.2486	4.3903
		1.00	.00	3.7750	1.605	.124	-.5445	8.0945
			2.00	8.7068*	1.492	.000	4.6927	12.7210
			3.00	3.8458	1.605	.110	-.4736	8.1653
		2.00	.00	-4.9318*	1.492	.008	-8.9460	-.9177
			1.00	-8.7068*	1.492	.000	-12.7210	-4.6927
			3.00	-4.8610*	1.492	.009	-8.8752	-.8468
		3.00	.00	.08E-02	1.605	1.000	-4.3903	4.2486
			1.00	-3.8458	1.605	.110	-8.1653	.4736
			2.00	4.8610*	1.492	.009	.8468	8.8752
	Tamhane	.00	1.00	-3.7750	1.605	.215	-8.6819	1.1319
			2.00	4.9318*	1.492	.003	1.3385	8.5251
			3.00	083E-02	1.605	1.000	-4.1354	4.2770
		1.00	.00	3.7750	1.605	.215	-1.1319	8.6819
			2.00	8.7068*	1.492	.000	4.1134	13.3002
			3.00	3.8458	1.605	.226	-1.2055	8.8971
		2.00	.00	-4.9318*	1.492	.003	-8.5251	-1.3385
			1.00	-8.7068*	1.492	.000	-13.3002	-4.1134
			3.00	-4.8610*	1.492	.006	-8.6710	-1.0510
		3.00	.00	.08E-02	1.605	1.000	-4.2770	4.1354
			1.00	-3.8458	1.605	.226	-8.8971	1.2055
			2.00	4.8610*	1.492	.006	1.0510	8.6710

*. The mean difference is significant at the .05 level.

One-way analysis of variance with post HOC tests for change in percent reduction in deflection responses D0, D1, D2, and D3 by ACC surface preparation (SP)

Multiple Comparisons

Dependent Variable		(I) SP	(J) SP	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
D0	Bonferroni	.00	1.00	-.7016	1.247	1.000	-3.7376	2.3343
			2.00	-2.4016	1.247	.171	-5.4376	.6343
		1.00	.00	.7016	1.247	1.000	-2.3343	3.7376
			2.00	-1.7000	1.298	.580	-4.8599	1.4599
		2.00	.00	2.4016	1.247	.171	-.6343	5.4376
			1.00	1.7000	1.298	.580	-1.4599	4.8599
	Tamhane	.00	1.00	-.7016	1.247	.880	-3.2733	1.8700
			2.00	-2.4016	1.247	.254	-5.8563	1.0530
		1.00	.00	.7016	1.247	.880	-1.8700	3.2733
			2.00	-1.7000	1.298	.498	-4.9688	1.5688
		2.00	.00	2.4016	1.247	.254	-1.0530	5.8563
			1.00	1.7000	1.298	.498	-1.5688	4.9688
D1	Bonferroni	.00	1.00	-1.6625	1.269	.580	-4.7523	1.4274
			2.00	-3.1443*	1.269	.045	-6.2341	-5.45E-02
		1.00	.00	1.6625	1.269	.580	-1.4274	4.7523
			2.00	-1.4818	1.321	.794	-4.6978	1.7342
		2.00	.00	3.1443*	1.269	.045	5.447E-02	6.2341
			1.00	1.4818	1.321	.794	-1.7342	4.6978
	Tamhane	.00	1.00	-1.6625	1.269	.416	-4.5557	1.2308
			2.00	-3.1443	1.269	.062	-6.4065	.1179
		1.00	.00	1.6625	1.269	.416	-1.2308	4.5557
			2.00	-1.4818	1.321	.634	-4.8505	1.8868
		2.00	.00	3.1443	1.269	.062	-.1179	6.4065
			1.00	1.4818	1.321	.634	-1.8868	4.8505
D2	Bonferroni	.00	1.00	-2.4902	1.622	.383	-6.4371	1.4567
			2.00	-2.9932	1.622	.203	-6.9402	.9537
		1.00	.00	2.4902	1.622	.383	-1.4567	6.4371
			2.00	-.5030	1.688	1.000	-4.6111	3.6051
		2.00	.00	2.9932	1.622	.203	-.9537	6.9402
			1.00	.5030	1.688	1.000	-3.6051	4.6111
	Tamhane	.00	1.00	-2.4902	1.622	.389	-6.6976	1.7172
			2.00	-2.9932	1.622	.140	-6.6462	.6597
		1.00	.00	2.4902	1.622	.389	-1.7172	6.6976
			2.00	-.5030	1.688	.989	-4.8025	3.7965
		2.00	.00	2.9932	1.622	.140	-.6597	6.6462
			1.00	.5030	1.688	.989	-3.7965	4.8025
D3	Bonferroni	.00	1.00	-.3641	1.519	1.000	-4.0609	3.3327
			2.00	-.7308	1.519	1.000	-4.4276	2.9660
		1.00	.00	.3641	1.519	1.000	-3.3327	4.0609
			2.00	-.3667	1.581	1.000	-4.2144	3.4811
		2.00	.00	.7308	1.519	1.000	-2.9660	4.4276
			1.00	.3667	1.581	1.000	-3.4811	4.2144
	Tamhane	.00	1.00	-.3641	1.519	.995	-4.5424	3.8142
			2.00	-.7308	1.519	.926	-3.9560	2.4944
		1.00	.00	.3641	1.519	.995	-3.8142	4.5424
			2.00	-.3667	1.581	.994	-4.2213	3.4880
		2.00	.00	.7308	1.519	.926	-2.4944	3.9560
			1.00	.3667	1.581	.994	-3.4880	4.2213

*. The mean difference is significant at the .05 level.

Two-sample T test for change in percent reduction in deflection responses D0, D1, D2, and D3 by synthetic fiber usage (FU)

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Mean	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
D0	Equal variances assumed	4.189	.043	-2.218	103	.029	-2.2844	1.0298	-4.3268	-.2421
	Equal variances not assumed			-2.412	92.593	.018	-2.2844	.9470	-4.1650	-.4039
D1	Equal variances assumed	4.063	.046	-2.815	103	.006	-2.9417	1.0452	-5.0145	-.8688
	Equal variances not assumed			-3.035	96.135	.003	-2.9417	.9692	-4.8655	-1.0178
D2	Equal variances assumed	4.649	.033	-2.182	103	.031	-2.9256	1.3409	-5.5849	-.2662
	Equal variances not assumed			-2.308	101.608	.023	-2.9256	1.2676	-5.4399	-.4112
D3	Equal variances assumed	.315	.576	-2.630	103	.010	-3.2122	1.2212	-5.6341	-.7903
	Equal variances not assumed			-2.687	100.918	.008	-3.2122	1.1957	-5.5841	-.8403

APPENDIX E. DIRECT SHEAR STRENGTH STATISTICAL ANALYSIS

Two-way factorial analysis of variance with interaction for direct shear strength (SHEAR) by joint spacing (JS), ACC surface preparation (SP), and age (AGE)

ANOVA[a,b]

			Unique Method				
			Sum of Squares	df	Mean Square	F	Sig.
SHEAR	Main Effects	(Combined)	45157.980	4	11289.495	7.821	.000
		JS	2921.878	1	2921.878	2.024	.160
		SP	43832.800	2	21916.400	15.184	.000
		AGE	790.895	1	790.895	.548	.462
	2-Way Interactions	(Combined)	42153.605	5	8430.721	5.841	.000
		JS * SP	30877.750	2	15438.875	10.696	.000
		JS * AGE	2648.939	1	2648.939	1.835	.180
		SP * AGE	7045.603	2	3522.802	2.441	.095
	Model		87606.309	9	9734.034	6.744	.000
	Residual		90933.776	63	1443.393		
	Total		178540.1	72	2479.723		

a. SHEAR by JS, SP, AGE

b. All effects entered simultaneously

One-way analysis of variance with post HOC tests for direct shear strength (SHEAR) by ACC surface preparation (SP)

Multiple Comparisons

Dependent Variable: SHEAR

						95% Confidence Interval	
	(I) SP	(J) SP	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Bonferroni	.00	1.00	44.7944*	12.981	.003	12.9530	76.6358
		2.00	49.7768*	12.552	.001	18.9876	80.5660
	1.00	.00	-44.7944*	12.981	.003	-76.6358	-12.9530
		2.00	4.9824	13.100	1.000	-27.1496	37.1144
	2.00	.00	-49.7768*	12.552	.001	-80.5660	-18.9876
		1.00	-4.9824	13.100	1.000	-37.1144	27.1496
Tamhane	.00	1.00	44.7944*	12.981	.012	8.2035	81.3853
		2.00	49.7768*	12.552	.001	19.0562	80.4973
	1.00	.00	-44.7944*	12.981	.012	-81.3853	-8.2035
		2.00	4.9824	13.100	.960	-23.0001	32.9649
	2.00	.00	-49.7768*	12.552	.001	-80.4973	-19.0562
		1.00	-4.9824	13.100	.960	-32.9649	23.0001

*. The mean difference is significant at the .05 level.

REFERENCES

1 Hart, John. "Evaluation of Bonding Between Ultra-thin Portland Cement Concrete Overlays and Asphalt Cement Concrete." Thesis. Ames: Iowa State University, 2000.

2. Silfwerbrand, John. "Whitetoppings - Swedish Field Tests and Recommendations." Sixth International Purdue Conference on Concrete Pavement Design and Materials for High Performance Vol. 2. 18-21 Nov. 1997. Indianapolis: Purdue University, 1997.

3. Risser, Robert J. et al. "Ultra-thin Concrete Overlays on Existing Asphalt Pavement." Fifth International Conference on Concrete Pavement Design and Rehabilitation. 20-22 Apr. 1993. West Lafayette: Purdue University, 1993.

4. Highland, J.D. and R.I. Dideriksen. Soil Survey Report. Washington: U.S. Government Press, 1967.

5. Anderson, Donald A. and Theodore L. Welp. An Engineering Report on the Soils, Geology, Terrain and Climate of Iowa. Ames: Iowa State Commission, 1960.

6. Heyer, Melinda and Vernon J. Marks. Construction Report for Iowa Department of Transportation (Report No. HR-559). Ames: Federal Highway Administration, 1995.

7 Cable, James K. et al. "Thin Bonded Overlay Evaluation." Construction Report for Iowa Department of Transportation (Report No. HR-559). Ames: Iowa State University, 1999.