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Evaluation of Dowel Bar Retrofits for Local Road Pavements

February 2008

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IHRB Project TR-520

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FINAL REPORT

IOWA STATE UNIVERSITY
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16. Abstract

As truck traffic on Iowa secondary roads has increased, engineers have moved to concrete pavements of greater depths. Early designs included thickened edge pavements and depths of seven inches or greater. The designs typically did not have load transfer devices installed in the transverse joints and relied on aggregate interlock for this purpose. In some cases, aggregate interlock was not adequate to deal with the soils and traffic conditions and faulting of the joints has begun to appear.

Engineers are now faced with the need to install or retrofit load transfer in the joints to preserve the pavements. Questions associated with this decision range from the type of dowel material to dowel diameter, spacing, number of bars, placement method, and construction techniques to be used to assure reduction or elimination of faulting. Buena Vista County constructed a dowel bar retrofit project on one mile of road. The plan called for addition of the dowels (2, 3, or 4) in the outer wheel path only and surface grinding in lieu of asphalt overlay.

The project included the application of elliptical- and round-shaped dowels in a rehabilitation project. Dowel material types included conventional epoxy-coated steel and fiber-reinforced polymer. This work involved the determination of relative costs in materials to be used in this type of work and performance of fiber-reinforced polymer (FRP) and elliptical-shaped steel dowels in the retrofit work. The results indicate good performance from each of the bar configurations and use the results of ride and deflection testing over the research period to project the benefits that can be gained from each configuration vs. the anticipated construction costs. The reader is cautioned that this project could not relate the number of dowels required to the level of anticipated truck traffic for other roads that might be considered.

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INTRODUCTION

Background

Most of the portland cement concrete (PCC) pavements in Iowa were originally built to depths of 6–7 inches that were not suitable for the addition of load transfer devices. Traffic volumes, specifically truck traffic volumes, have increased on local roads. Designs have changed in depth and cross section to allow for the consideration of load transfer device addition. Many of these routes were built to provide access to industrial areas or major grain terminals.

Buena Vista County is one of the counties that built a PCC pavement—eight inches in depth, 24-feet wide, with transverse joint spacings of twenty feet—in 1988 for the purpose of serving an industrial site on the east edge of Storm Lake. This particular section of road is one mile in length. Recent profile data collection indicated that this road is experiencing faulting to the point of needing some type of load transfer restoration measure. Dowel bar retrofitting and diamond surface grinding provide one of the best and most cost-effective measures to remove faulting and extend the service life of the pavement.

Much work has been done in other states on the application of dowel bar retrofits in the wheel paths to restore adequate load transfer in the transverse joints. Nebraska and South Dakota have conducted extensive dowel bar/surface grinding projects on their interstate systems. In the past, Iowa has used dowel bar retrofits on Interstate 80 in eastern Iowa, and the city of Des Moines has used this technique on a portion of 63rd Street as part of a demonstration project. Both Iowa projects were a success and extended the life of these pavements.

Past Iowa research by Iowa State University, the ISU Department of Civil, Construction, and Environmental Engineering, and ISU Center for Transportation Research and Education has centered on the evaluation of dowel bar shapes, sizes, and materials in state and local pavements. Examples include the evaluation of fiber-reinforced polymer (FRP), stainless steel and epoxy-coated bars, spacing on U.S. 65 near Des Moines, and evaluation of elliptical-shaped FRP and epoxy-coated bars in three sizes and multiple spacing on Iowa 330 between Des Moines and Marshalltown. A project in Union County has evaluated the potential for using epoxy-coated dowels in only the outer wheel path on rural and urban settings. Each of the projects has included lab and field testing by Dr. Max Porter and Dr. James K. Cable of Iowa State University.

Problem Statement

As truck traffic on Iowa secondary roads has increased, engineers have moved to concrete pavements of greater depths. Early designs included thickened edge pavements and depths of seven inches or greater. The designs typically did not have load transfer devices installed in the transverse joints and relied on aggregate interlock for this purpose. In some cases, aggregate interlock was not adequate to deal with the soils and traffic conditions, and faulting of the joints has begun to appear.

Engineers are now faced with the need to install or retrofit load transfer in the joints to preserve the pavements. Questions associated with this decision range from the type of dowel material to dowel diameter, spacing, number of bars, placement method, and construction techniques to be used to assure reduction or elimination of faulting.

Buena Vista County was interested in constructing a dowel bar retrofit project on one mile of road. The plan called for addition of the dowels in the outer wheel path only and surface grinding in lieu of asphalt overlay.

The Iowa State University team of Cable and Porter was interested in moving to the next step in the application of elliptical-shaped dowels in a rehabilitation project. This work involved the determination of relative costs in materials to be used in this type of work and performance of FRP and elliptical-shaped steel dowels in the retrofit work.

This project provided a way for Buena Vista County, Iowa State University, and the Iowa Highway Research Board (IHRB) to evaluate dowel retrofit materials, placement, costs, and performance for application in local road pavements.

Objectives

1. Evaluate the feasibility of using elliptical or round dowels to retrofit an eight-inch deep local road pavement as part of a retrofit/grind rehabilitation project.
2. Evaluate the impact of applying two, three, or four dowels in only the outer wheel path in a local pavement on pavement performance.
3. Evaluate the impact of using FRP or steel dowels in the retrofit of the test pavement on long-term performance.
4. Determine the relative cost of elliptical-shaped dowels (FRP and steel) for the retrofit project.

Research Approach

With the assistance of Ames Engineering and Braun Intertec Inc., the research team measured the profile of the outer wheel path in each direction and selected deflection and structural evaluation tests of sample joints and slabs in both directions in the test pavement. Profile of deflection and faulting measurements were conducted four times during the research period. A visual distress survey was conducted to determine the overall condition of the test pavement.

The research team laid out a series of subsections in the one mile test section to include the variables of dowel material type and number of bars per joint. Test segments included conventional round steel dowels and elliptical steel and FRP dowels. A total of 36 test sections in each direction of travel were used for this work. Selected bars in three of the test segments were instrumented for strain evaluation. The team purchased the number of bars from American Highway Technologies and Hughes Bros. Inc. to complete the work.

The Buena Vista County staff developed a construction project to retrofit the dowels in the joints and grind the surface of the test pavement. The contract included items for the preparation and the installation of dowels in each of the transverse joints in the pavement.

The research team provided the dowel bar plan and dowels to the contractor and the county for the installation in the test pavement. This plan included bars of each type that were instrumented to provide strain information after construction. The team assisted the contractor in the installation of the instrumented dowels.

The Buena Vista County staff administered the contract for retrofitting the dowels diamond and grinding the surface of the test pavement.

Visual distress surveys were conducted at the same time as the falling weight deflectometer (FWD) and profile testing.

The joint fault testing was conducted by ISU faculty and research assistants. The fault meters were produced by the Federal Highway Administration (FHWA) and have an accuracy of 0.04 inches. Faulting measurements were taken 18 inches from each edge of the pavement in the northbound and southbound lanes. Faulting data were acquired at every joint along the retrofit pavement. The data were then broken down by bar material type, as well as the number of bars used in each joint. These sections can be seen in Table 1 of the report. Most of the sections had 30 test joints within them.

The FWD testing was conducted by Braun Intertec Inc. Data were collected in both the northbound and southbound lanes, once before project construction and three times after the retrofit was complete. Deflection data were collected at three joints in each of the 36 test sections along the retrofit pavement. Each deflection test of three joints correlated to a particular type and number of dowel bar. These section breakdowns can be seen in Table 1 of the report. Data were collected at distances of 0, 8, 12, 18, 24, 36, and 60 inches from the center of load impact. The load tests recorded by the machine were in the 6,000, 9,000, and 12,000 pound vicinities. The analysis of the data, as it relates to load transfer, only requires the 0- and 12-inch readings in the 9,000 pound test load vicinity. This was the only data used for the purpose of this report.

The profile testing was conducted by Ames Engineering. The data were collected in both wheel paths and both directions on the one mile section of roadway at four different time periods. The raw data collected by Ames Engineering were evaluated with ProVAL 2.7 computer software. International Roughness Index (IRI) values were extracted from

ProVAL 2.7 to analyze the effects of diamond grinding and dowel bar retrofits on pavement profile.

With the assistance of Buena Vista County, the research team conducted load transfer strain measurements in each of the dowel types during summer and winter conditions in the first year after construction and again at the end of years two and four.

CONSTRUCTION PLANS AND SPECIFICATIONS

The location of the project is shown in Figure 1.

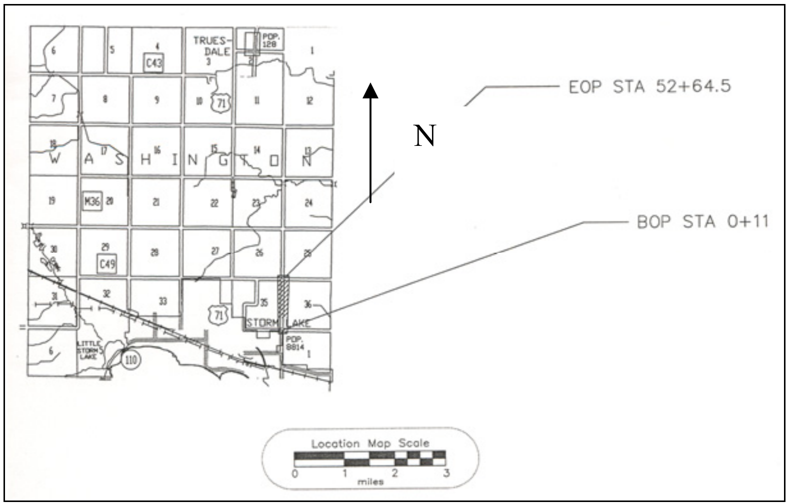

Figure 1. Project site map

The following tables show which material types and numbers of dowel bars were used to retrofit the project. Table 1 illustrates which joints received which type of bar and how many bars were put in that joint.

Table 1. Buena Vista County dowel bar retrofit test sections layout

Section joint	Sub-section joint	Material	# Joints	Bars/lane	Total bars
0 (BOP)		--------	1	--------	--------
1-30	1-10	FRP	10	4	80
	11-20	FRP	10	4	80
	21-30	FRP	10	4	80
	Section TOTAL	**FRP**	**30**	**4**	**240**
31-60	31-40	FRP	10	3	60
	41-50	FRP	10	3	60
	51-60	FRP	10	3	60
	Section TOTAL	**FRP**	**30**	**3**	**180**
61-90	61-70	FRP	10	2	40
	71-80	FRP	10	2	40
	81-90	FRP	10	2	40
	Section TOTAL	**FRP**	**30**	**2**	**120**
91-117	91-99	Steel round	9	2	36

Section joint	Sub-section joint	Material	# Joints	Bars/lane	Total bars
	100-108	Steel round	9	2	36
	109-117	Steel round	9	2	36
	Section TOTAL	**Steel round**	**27**	**2**	**108**
118-147	118-127	Med. elliptical	10	2	40
	128-137	Med. elliptical	10	2	40
	138-147	Med. elliptical	10	2	40
	Section TOTAL	**Med. elliptical**	**30**	**2**	**120**
148-177	148-157	Heavy elliptical	10	2	40
	158-167	Heavy elliptical	10	2	40
	168-177	Heavy elliptical	10	2	40
	Section TOTAL	**Heavy elliptical**	**30**	**2**	**120**
178-204	178-186	Steel round	9	3	54
	187-195	Steel round	9	3	54
	196-204	Steel round	9	3	54
	Section TOTAL	**Steel round**	**27**	**3**	**162**
205-234	205-214	Med. elliptical	10	3	60
	215-224	Med. elliptical	10	3	60
	225-234	Med. elliptical	10	3	60
	Section TOTAL	**Med. elliptical**	**30**	**3**	**180**
235-264	235-244	Heavy elliptical	10	3	60
	245-254	Heavy elliptical	10	3	60
	254-264	Heavy elliptical	10	3	60
	Section TOTAL	**Heavy elliptical**	**30**	**3**	**180**
265-280	265-269	Steel round	5	4	40
	270-274	Steel round	5	4	40
	275-280	Steel round	6	4	48
	Section TOTAL	**Steel round**	**16**	**4**	**128**
281-310	281-290	Med. elliptical	10	4	80
	291-300	Med. elliptical	10	4	80
	301-310	Med. elliptical	10	4	80
	Section TOTAL	**Med. elliptical**	**30**	**4**	**240**
311-340	311-320	Heavy elliptical	10	4	80
	321-330	Heavy elliptical	10	4	80
	331-340	Heavy elliptical	10	4	80
	Section TOTAL	**Heavy elliptical**	**30**	**4**	**240**
341 (EOP)		--------	1	--------	--------

The numbers of dowel bars required for the entire project are listed in Table 2.

Table 2. Dowel bars required

Bar type	Number required[*]
FRP elliptical	540 — 2.3” x 1.3” x 18”
Steel round	398 — 1.5” x 18”
Medium elliptical	540 — 1.7” x 1.1” x 18”
Heavy elliptical	540 — 2.0” x 1.3” x 18”
Total bars	2018

[*] Totals do not account for bars used to establish load transfer across active cracks. Crack repair to use the same bar type and spacing as in the adjacent joints.

Field Construction

The project began construction on Monday, October 18, 2004. Traffic was detoured around the project by Buena Vista County in order to allow the contractor total access to the project.

Diamond Grinding

Typically diamond grinding of the finished dowel retrofit project is used to remove excess grout over the dowels, remove joint faulting, and maximize surface ride quality. It is usually the final step in the retrofit project and done under traffic. In this case, the closed roadway and dowel placement in only one wheel path allowed the contractor to do grinding and retrofitting simultaneously and to reduce road closure construction time.

The contractor intended to start diamond grinding at the centerline and work towards the outside edge. This approach allowed the slot sawing machine to work on the outside edge at the same time. The diamond grinding machine was set up to cut four-foot strips in one pass, making three passes to complete a 12-foot-wide lane (shown in Figure A.1). The machine started at the south end of the project in the southbound lane and proceeded north to the end of the project. Typically, the contractor started at the outside edge and worked toward the centerline, but in order to speed up the project, the contractor started at the centerline and worked towards the outside edge. This sequence allowed for the sawing and patching of the slots to proceed at the same time as the diamond grinding.

At the request of the county engineer, it was decided not to diamond grind through the rumble strips. The rumble strip area was reviewed after one pass was completed by the diamond grinding machine and approved for the process of leaving the rumble strip in place.

The diamond grinding machine returned by way of the northbound lane to finish the first four-foot pass next to the centerline. After completing this pass, the machine then continued on to diamond grind the area between joints 61 and 177. This process was done with the second pass on the northbound and southbound lanes.

Slot Cutting

The process started at the south end of the project at joint 31 in the northbound lane. The joints on the project were numbered from south to north as joints 1–341. The three-slot pattern was cut first (Figure A.2).

The slot sawing machine was set up to cut the slots at the prescribed width of 3.25 inches, with one side set up to cut two slots at a time and the other side set up to cut three slots at a time to accommodate the elliptical FRP bars. The contractor intended to cut the two outside slots first in all the two- and four-slot areas to accommodate the placement of the instrumented bars by the ISU research team.

The suggestion, and subsequent approval, was given to move the outside slot from the plan dimension of 12 (plan dimension) to 18 inches from the outside edge of the pavement. Because the project was only slotting of the outside edge, this reduced the chance of a breakout at the edge. Bushing was done on all slots from joints 91–209 in the northbound lane to remove debris and allow for easier placement of dowel bars.

After the slots were cut, there was excess material left by the upward motion of the slot-cutting saw. This material was removed by a jackhammer with a flat hammer on the end, called bushing (Figure A.3).

A slot length of 33–34 inches did not allow enough room to get a finger under the end of the steel bar (Figure A.4). If the slots had been cut 35–36 inches long, then no bushing would have been required.

After bushing, sandblasting, and air blasting the slots, the bars were placed in the slots. All elliptical bars came with chairs that were 3.25 inches wide to lock the bars in the slot. The standard 1.5-inch steel round bars came with a standard chair that was designed to lock bars into a normal 2.5-inch slot. Liquid nail compound was used to glue the chairs, of the 1.5-inch steel round bars, to the clean concrete so that the bars could remain straight during the patching process (Figure A.5).

Four bars were checked at random (Table 3) for tolerance from the top of the pavement to the top of the bars. All measurements were within the industry standard of a quarter inch tolerance.

Table 3. Random bar tolerances

Joint number	Bar type	North end (in.)	Middle (in.)	South end (in.)
33	FRP	3 ¾	3 ¾	3 ⅞
92	Steel round	2 ⅞	3	3 ⅛
147	Medium elliptical	3 ½	3 ⅝	3 ⅝
148	Heavy elliptical	3 ¼	3 ⅜	3 ⅜

The three elliptical-shaped bar shapes have the following dimensions. FRP measured two and one-quarter inches in the horizontal direction and one and one-quarter inches in the vertical direction. The heavy elliptical steel bar measured two inches in the horizontal direction and one and three-eighth inches in the vertical direction. The medium elliptical steel bar measured one and five-eighth inches in the horizontal direction and one and one-eighth inches in the vertical direction. The one and one-half-inch round steel bar was the fourth bar type used on this project.

Before placement of the bars, a sheetrock plaster compound was used to seal the existing crack at the bottom of the joint and on the sidewalls (Figure A.6). This material was readily available from the housing industry and did an excellent job preventing the patching mix from being vibrated into the existing joint or crack. The concrete patching material was a mix designed by the contractor using a Five Star Highway Patch Cement. During construction, the concrete mix was tested by an outside agency to ensure that the target value of 4,500 psi compressive strength was achieved in 24 hours. Preliminary tests failed, but the tests conducted during the construction of the project all exceeded the target value.

After reviewing the finished product, it was noticed that the joint reformer material did not stay centered in the joint on the steel retrofit bars. Normally, the crew would chip out the concrete between the joint reformer and the joint and then fill the area with joint sealer material. This project had no sealing, so the spalls will show up after traffic and snowplows work on the roadway. There are similar spalls in other areas of the existing pavement joints (Figure A.7).

The location of these problem spalls are between joints 91 and 209 in the northbound lane. The fiber-reinforced bars had the joint reformer material designed to be at least one and one-half inches below the top of the pavement, which would reduce the chance of spalls as long as the joints were sawed as soon as possible.

Installation of Strain Gages

After reviewing the profile index taken prior to construction, it was decided to place the instrumented bars in the southbound lane in the two-slot pattern, as requested by Porter. The profile index in the southbound lane outside wheel path was 26 in/mi and the profile index in the northbound lane outside wheel path was 16 in/mi before grinding. The profile index in both inside wheel paths was approximately 12 in/mi.

Instrumented bars were placed in the southbound lane at joints 61, 101, and 128. Joint 61 was a FRP, and it was embedded four inches from the top of the pavement to the top of the bar before diamond grinding. Joint 101 was a standard 1.5-inch round bar and it was embedded 3.5 inches below the pavement surface before diamond grinding. Joint 128 was a medium elliptical bar and it was embedded 4 1/8 inches below the pavement surface before diamond grinding. An example of the instrumented bars can be seen in Figure A.8.

For the placement of the three instrumented bars, a pipe was bored under the pavement to carry the wires out to the foreslope. The boring machine could only bore a four-inch hole and the pipes were only two inches in diameter, leaving a void around the pipe. To correct this void, two options were presented. The first option was to use a backhoe to excavate a two-foot-wide trench and water blast a two-inch trench under the pavement to facilitate the placement of the pipe. The second option was to use the water blaster to excavate a narrow 2–4-inch trench out to the foreslope deep enough only to allow the pipe to be placed under the pavement (Figure A.9). The second option was selected as the method to use and gravel from the county yard was used as backfill in the trench. The slots were then removed and the bars with the wires were placed in the slots.

The patching crews continued to sandblast and clean the remaining joints in the southbound lane from joint 251 to the south end of the project. Great care was taken by the crews at joints 61, 101, and 128 in the southbound lane. These joints contained the instrumented bars for future load testing by Iowa State University. The wires were placed inside a rubber hose, cut to allow entry of the wires, and the bars were placed inside a feed sack and sealed with duct tape. This allowed the sandblasting crew to adequately clean the slots around wires. The sheetrock joint compound was used to seal the holes drilled for the wires through the bottom of the pavement. A profilograph was run with a final ride after construction approximately two inches per mile.

The construction went smoothly and efficiently, with no major construction problems. Contractor and inspector cooperation was essential to good performance of the finished product. Each of the dowel materials and shapes presented no problems in installation. The use of local aggregates created an almost invisible installation. Diamond grinding of the finished surface will ensure an improved ride and basis for extended performance.

Data Analysis

Visual Distress Surveys

There were no new distresses resulting from the retrofit construction. There were a few transverse cracked slabs that were present before the dowel bar retrofit. These cracks were monitored throughout the study and found to not have an effect on the results of the study.

Faulting

Faulting data were collected over each joint along the retrofit pavement as explained earlier in the "Research Approach" section of the report. The raw faulting data collected by the handheld faulting meters is available upon request. This data were summarized and can be found below in Tables 4, 5, 6, and 7. These tables show a maximum, minimum, and average faulting of the pavement where each particular dowel was inserted. Table 4 shows a summary of the faulting survey taken before construction. Tables 5, 6, and 7 show summaries of the three faulting surveys taken after construction.

Table 4. Storm Lake faulting averages for 9/27/2004

Material	No. bars	Southbound lane (in.)			Northbound lane (in.)		
		Maximum	Minimum	Average	Maximum	Minimum	Average
FRP	4	0.40	0.12	0.25	0.24	-0.06	0.14
FRP	3	0.37	-0.06	0.20	0.19	0.00	0.09
FRP	2	0.37	0.04	0.16	0.31	-0.07	0.09
Stl. Rd.	2	0.31	0.04	0.24	0.13	-0.04	0.13
Med. Ell.	2	0.25	0.01	0.13	0.16	-0.11	0.06
Heavy Ell.	2	0.36	0.03	0.19	0.26	-0.04	0.11
Stl. Rd.	3	0.27	0.12	0.20	0.18	0.04	0.09
Med. Ell.	3	0.31	0.04	0.13	0.24	-0.02	0.07
Heavy Ell.	3	0.32	0.03	0.13	0.26	-0.09	0.07
Stl. Rd.	4	0.22	0.06	0.14	0.12	-0.02	0.07
Med. Ell.	4	0.25	0.05	0.15	0.22	0.02	0.11
Heavy Ell.	4	0.43	0.06	0.19	0.75	-0.04	0.17

Table 5. Storm Lake faulting averages for 11/18/2004

Material	No. bars	Southbound lane (in.)			Northbound lane (in.)		
		Maximum	Minimum	Average	Maximum	Minimum	Average
FRP	4	0.09	-0.02	0.02	0.05	-0.03	0.01
FRP	3	0.08	-0.02	0.03	0.06	-0.06	0.01
FRP	2	0.23	-0.20	0.02	0.04	-0.07	0.00
Stl. Rd.	2	0.07	-0.02	0.02	0.05	-0.02	0.01
Med. Ell.	2	0.07	-0.03	0.02	0.07	-0.02	0.02
Heavy Ell.	2	0.07	-0.02	0.02	0.07	-0.03	0.03
Stl. Rd.	3	0.06	-0.02	0.02	0.07	-0.03	0.02
Med. Ell.	3	0.10	-0.06	0.04	0.05	-0.03	0.01
Heavy Ell.	3	0.10	-0.04	0.02	0.20	-0.06	0.02
Stl. Rd.	4	0.07	-0.03	0.03	0.04	-0.02	0.00
Med. Ell.	4	0.08	-0.02	0.03	0.07	-0.02	0.02
Heavy Ell.	4	0.06	-0.02	0.02	0.06	-0.02	0.02

Table 6. Storm Lake faulting averages for 7/26/2006

Material	No. bars	Southbound lane (in.)			Northbound lane (in.)		
		Maximum	Minimum	Average	Maximum	Minimum	Average
FRP	4	0.09	0.00	0.06	0.09	0.03	0.04
FRP	3	0.12	0.03	0.06	0.09	0.03	0.04
FRP	2	0.09	-0.02	0.06	0.08	0.03	0.05
Stl. Rd.	2	0.09	0.04	0.07	0.09	0.03	0.06
Med. Ell.	2	0.09	0.03	0.07	0.09	0.03	0.06
Heavy Ell.	2	0.11	0.04	0.07	0.09	0.03	0.06
Stl. Rd.	3	0.08	0.03	0.05	0.08	0.03	0.06
Med. Ell.	3	0.09	-0.02	0.06	0.09	0.03	0.05
Heavy Ell.	3	0.09	0.03	0.06	0.12	0.03	0.05
Stl. Rd.	4	0.09	0.03	0.06	0.15	0.03	0.06
Med. Ell.	4	0.09	0.03	0.05	0.09	-0.06	0.04
Heavy Ell.	4	0.08	0.03	0.05	0.09	0.03	0.05

Table 7. Storm Lake faulting averages for 5/30/2007

Material	No. bars	Southbound lane (in.)			Northbound lane (in.)		
		Maximum	Minimum	Average	Maximum	Minimum	Average
FRP	4	0.07	0.00	0.02	0.05	-0.06	0.02
FRP	3	0.08	-0.04	0.02	0.04	0.00	0.02
FRP	2	0.05	-0.04	0.02	0.05	0.00	0.02
Stl. Rd.	2	0.07	0.01	0.03	0.06	0.00	0.03
Med. Ell.	2	0.06	0.00	0.03	0.05	0.00	0.02
Heavy Ell.	2	0.08	0.00	0.04	0.06	0.00	0.02
Stl. Rd.	3	0.06	0.00	0.02	0.05	0.00	0.02
Med. Ell.	3	0.06	0.00	0.03	0.06	0.00	0.02
Heavy ELL	3	0.05	0.00	0.02	0.06	0.00	0.02
Stl. Rd.	4	0.06	0.00	0.02	0.07	0.00	0.02
Med. Ell.	4	0.05	0.00	0.02	0.06	0.00	0.02
Heavy Ell.	4	0.06	0.00	0.02	0.08	0.00	0.02

The thought originally occurred that the percentage of reduction in the initial faulting because of diamond grinding would be a good evaluation of the effectiveness of diamond grinding. However, there does not appear to be any correlation between initial faulting and the effectiveness of the diamond grinder. Figure 2 shows, if anything, diamond grinding better reduces faulting in the sections with higher initial faulting rather than the sections with lower initial faulting. For this reason, the data seems to suggest that diamond grinding reduces the faulting to a particular value rather than a percentage of the original faulting. However, diamond grinding on pavements of much higher initial faulting than this project may not yield the same values as this project. Nevertheless, the conclusion can be made that any similar concrete pavements with initial faulting less than 0.19 inches can be reduced to a value of roughly 0.019 inches. At this particular stage of the dowel bar retrofit there are no bars in the pavement. Therefore, an important note is that the dowel type and number are of no particular relevance in Figure 2 except to help label the sections for post-retrofit comparisons. Figure 3 shows the overall average before diamond grinding is about 0.138 inches and the average after is approximately 0.02 inches.

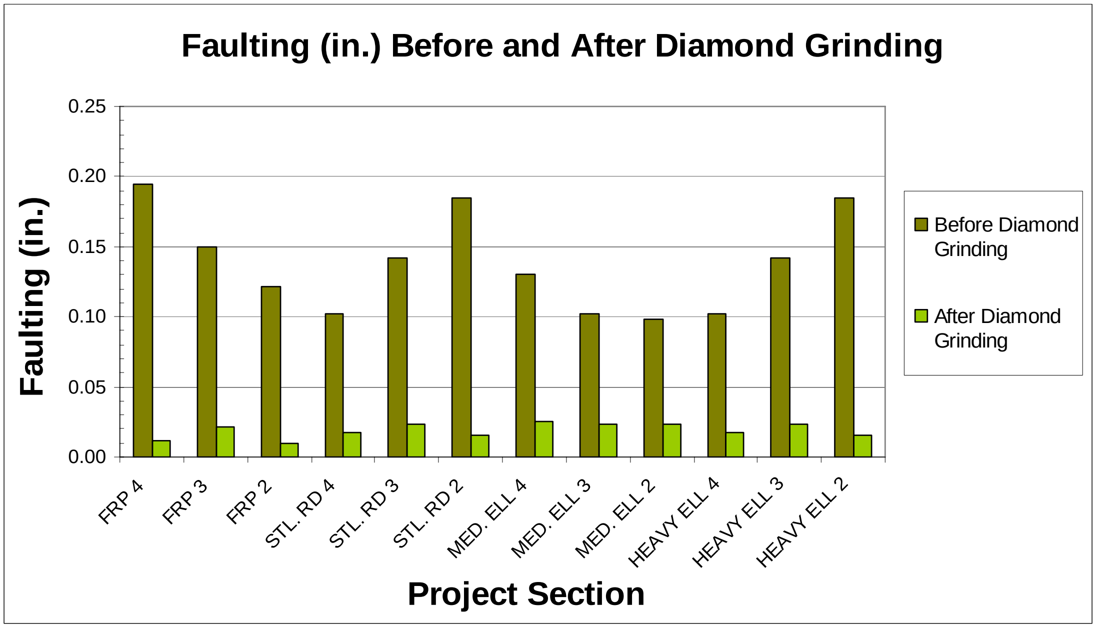

Figure 2. Faulting before and after diamond grinding

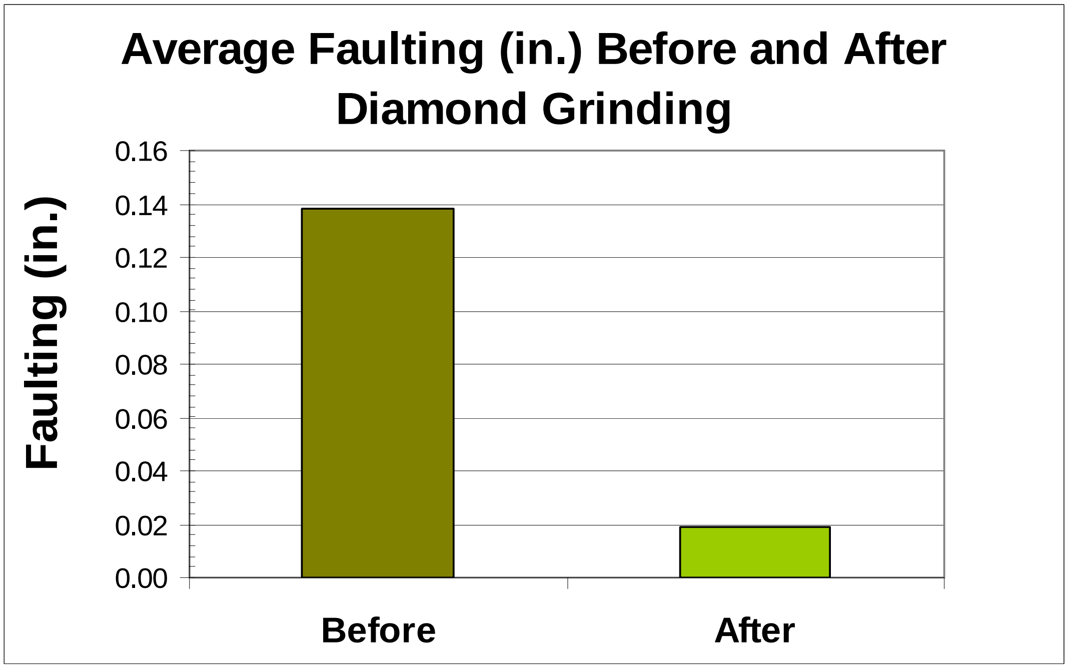

Figure 3. Average faulting before and after diamond grinding

To analyze dowel bar performance, the least change in faulting over the testing period was determined to indicate the most successful joints. The average faulting over the project life is found in Figures 4 and 5. Figure 4 compares standard round dowel bars with FRP dowel bars. Figure 5 compares standard round dowels with elliptical dowel bars. In the figures all dowel sections were assumed to have the same initial faulting of

0.019 inches, which was the average faulting achieved through diamond grinding. This is to show the performance of each type over time. The faulting decrease from 2006 to 2007 can be attributed to effects of weather, season, and pavement temperature differences. Regardless of the decrease in faulting from 2006 to 2007, the graphs still show there is no significant difference in faulting based on dowel material or shape. Hence the conclusion is that all four dowel bar types have equal performance in faulting. Also important to note is that the average faulting values over the study period were lower than the noticeable faulting tolerance of drivers.

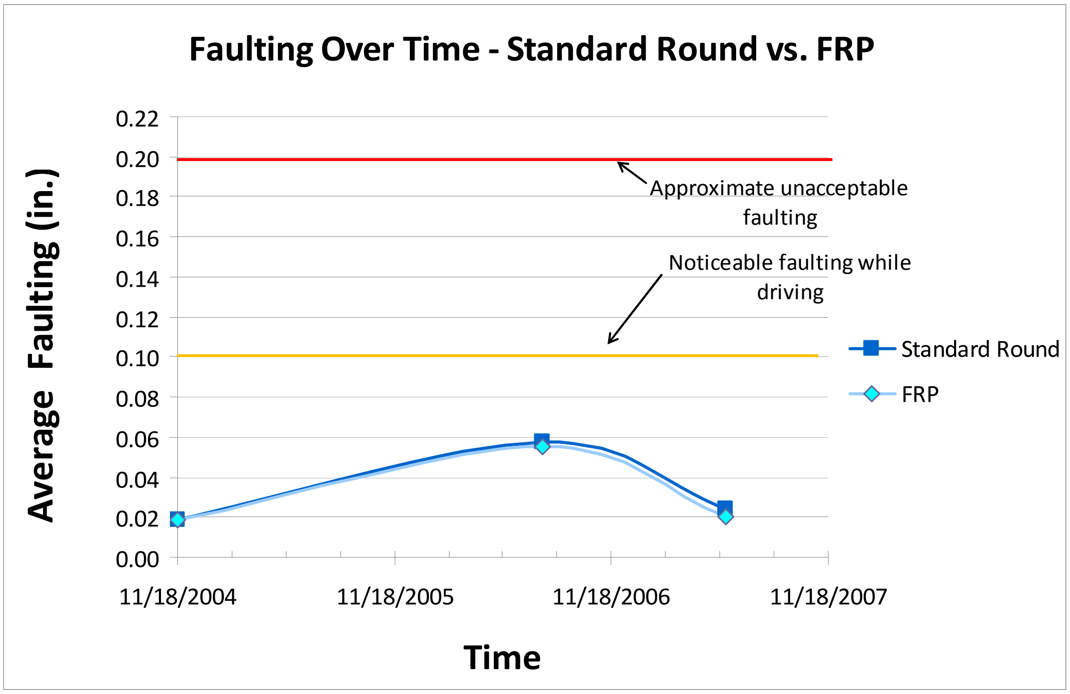

Figure 4. Faulting over time – standard round vs. FRP

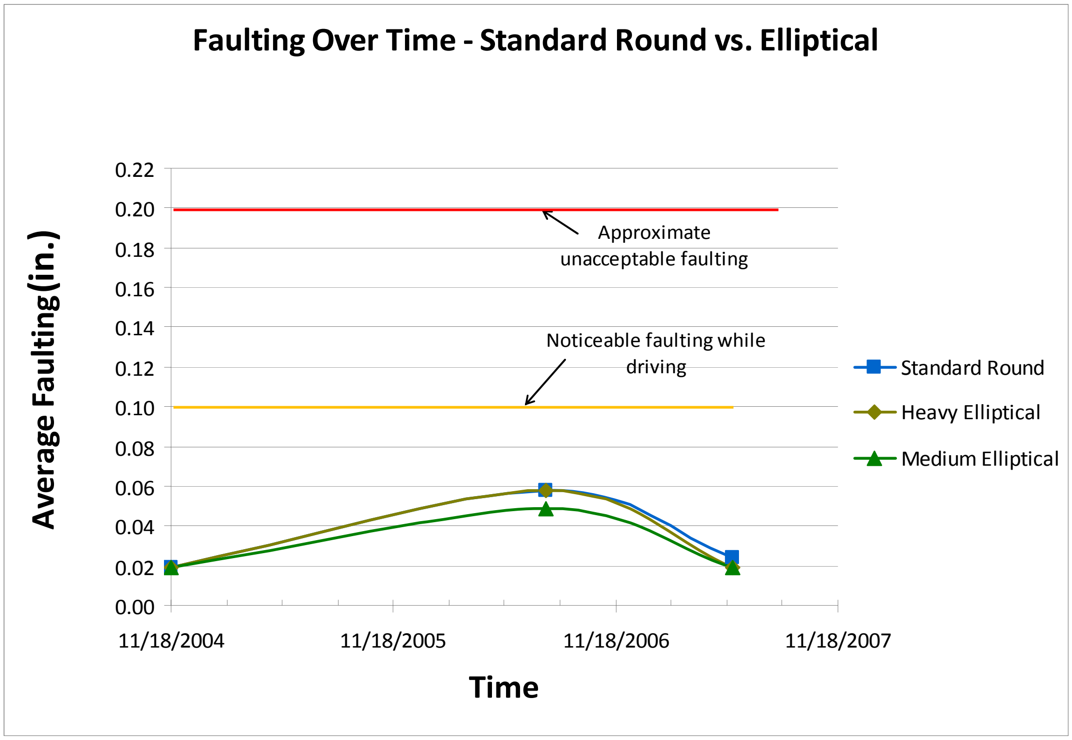

Figure 5. Faulting over time – standard round vs. elliptical

Deflection Testing (FWD)

The FWD was used to measure the amount of deflection induced by a measured load in the vicinity of 9,000 pounds. The deflection was measured as the load was induced at different distances from the joint. The deflections over the joint and 12 inches from the joint were standardized to a 9,000 pound load. The load transfer across the joint was calculated using these two deflections. The equation can be seen below.

$$LTE = 100 * (D3/D1) * (9000\ lb/La) \qquad (1)$$

Where:

LTE = load transfer efficiency (%)
D3 = deflection reading 12 inches from the applied load (in)
D1 = deflection reading 0 inches or at the center of the applied load (in)
La = actual load applied (lb)

Each section in the study consisted of approximately 30 joints. These 30 joints were broken down into three subsections; thus, there are approximately 10 joints per subsection. Within each subsection, deflection measurements from three individual joints were averaged to provide one representative deflection value and calculated load transfer value for each subsection. A complete set of before and after construction deflections data are available upon request.

Before construction, in September 2004, an overall average of all the joint sections showed that 41.5% of the load was being transferred across the joints. After construction, in November 2004, the overall load transfer became 85.7 percent. The load transfer from the final data set taken in July 2007 came to 92.4 percent. This data suggests that the load transfer in a pavement increases from approximately 40% to at least 80% or 85% when a dowel retrofit is introduced into an eight-inch-deep non-doweled pavement. This data also suggests that the load transfer is maintained at an acceptable level over the research period. Figure 6 shows the immediate load transfer change after the dowel retrofit.

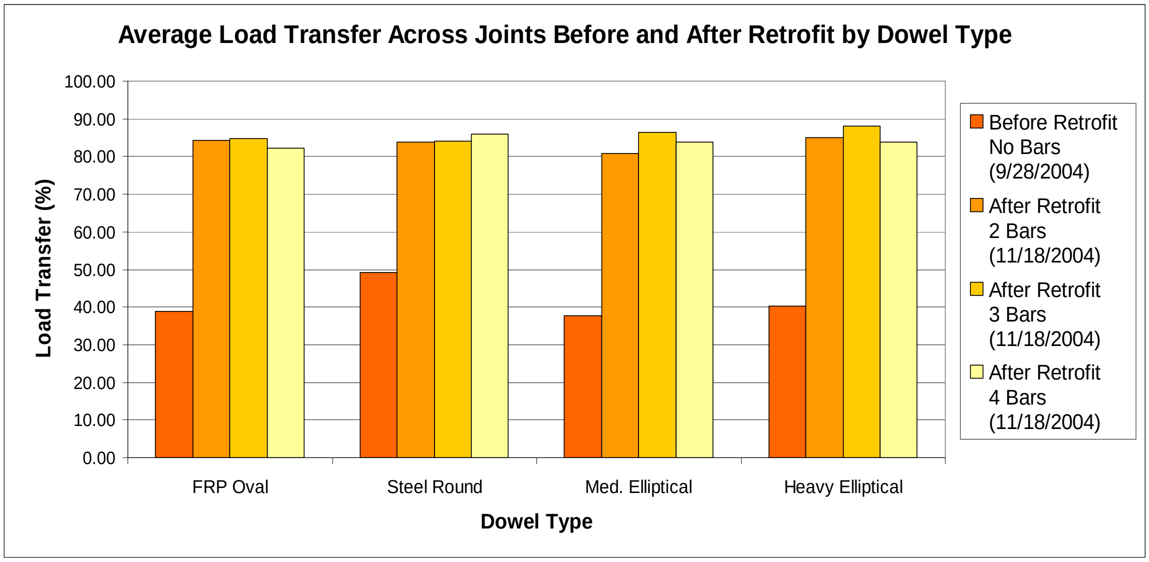

Figure 6. Overall average joint load transfer before and after dowel retrofit

Figures 7 and 8 show the joint load transfer for the northbound and southbound lanes over the project life. The part of the graph that is substantially lower correlates to the load transfer of the pavement before any dowel bars were inserted into the pavement. The graphs of the load transfer after the dowel bars were instigated show that the load transfer remains in the 85–95% range regardless of where it is on the project.

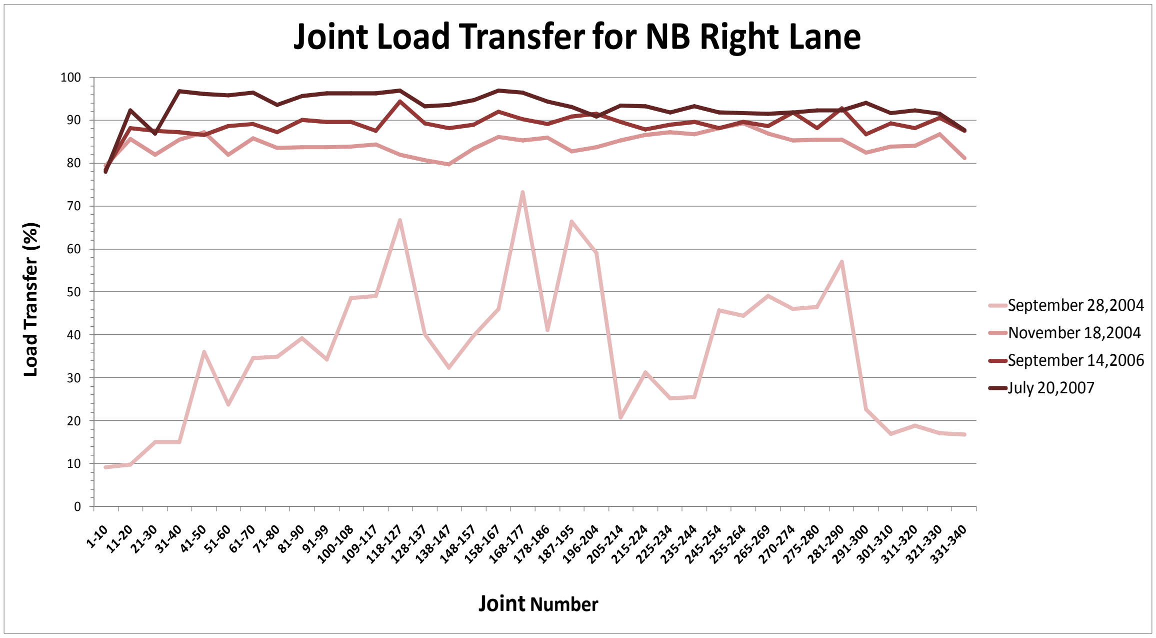

Figure 7. Joint load transfer values, northbound right lane

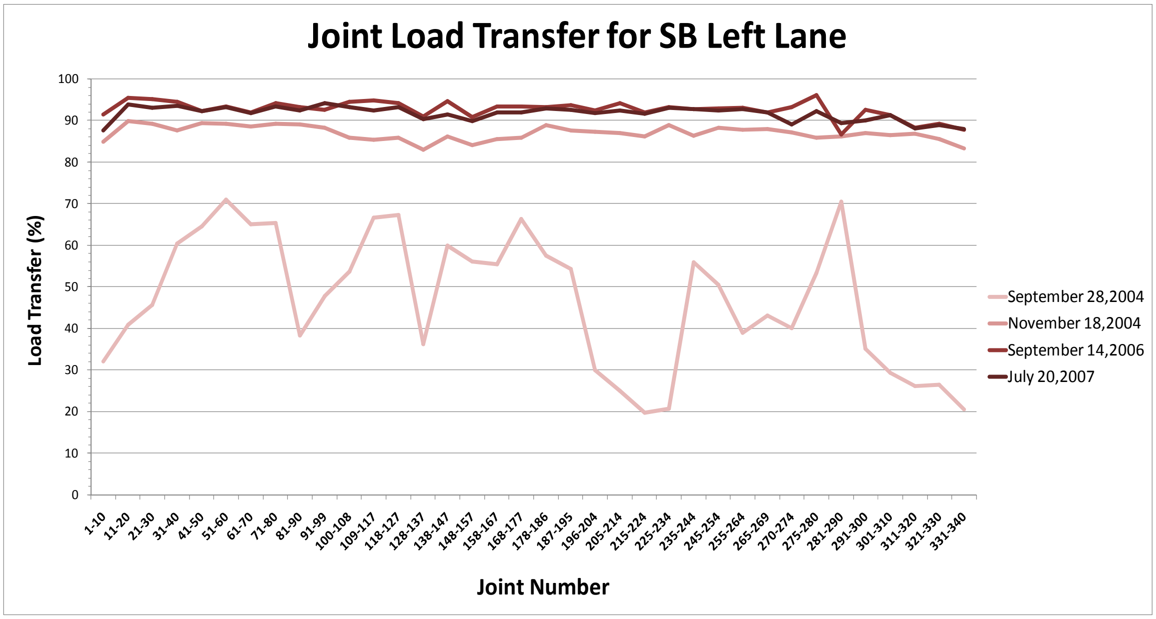

Figure 8. Joint load transfer values, southbound left lane

The results of the load transfer across joints are found in Table 8. This data shows the average load transfer at the end of the data collection period is in the range of 90–95 percent. In the right column, the table shows that the number of dowel bars used does not affect load transfer over time. Finally, the bottom row of Table 8 indicates all the dowel bars performed equally over time.

Table 8. Storm Lake load transfer 7/20/2007 summary

# Bars	FRP	Stl. Rd.	Med. Ell.	Heavy Ell.	Avg.
2	95.2%	96.2%	94.6%	96.0%	← 95.5%
3	96.2%	92.7%	92.8%	92.2%	← 93.5%
4	85.7%	91.8%	92.7%	90.4%	← 90.2%
Avg.	92.3%	93.6%	93.3%	92.9%	

Profile Testing

For this project, the profile was recorded once prior to the design of the project. It was then recorded once before and three times after construction. The profile was recorded electronically. It was taken in each wheel path in the direction of travel. The profile data were used and analyzed by ProVAL 2.7 software. This program computes an IRI value, which is a quantitative measure of the roughness of the pavement. There are other methods for measuring the roughness of a pavement, but for this particular project the IRI value was used. A larger IRI value correlates to a rougher pavement. In the past, IRI values in the range of 150–170 in/mi have been indicators of noticeable roughness by road users. This range of values will be used as a reference for acceptable and unacceptable pavement roughness. A complete set of profile data is available upon request.

The data collected were used to quantify the effectiveness of diamond grinding and to determine which type and quantity of dowel bar best maintains the pavement's smoothness. As with faulting, it was originally thought that the percentage of reduction in the initial IRI because of diamond grinding would be a good evaluation of the effectiveness of diamond grinding. However, there does not appear to be any correlation between initial IRI and the effectiveness of the diamond grinder, as seen in Figures A.10 and A.11. These graphs seem to suggest that diamond grinding reduces the IRI to a particular value, just as it did with faulting. Even so, Figure A.11 shows that it is possible to diamond grind a pavement with an IRI as high as 330 down to 105 in/mi (this can be seen in the first 150-foot section). Figure 9 shows that diamond grinding is effective at producing a post-grinding IRI value around 80 when the average initial IRI is between 170 and 230 in/mi.

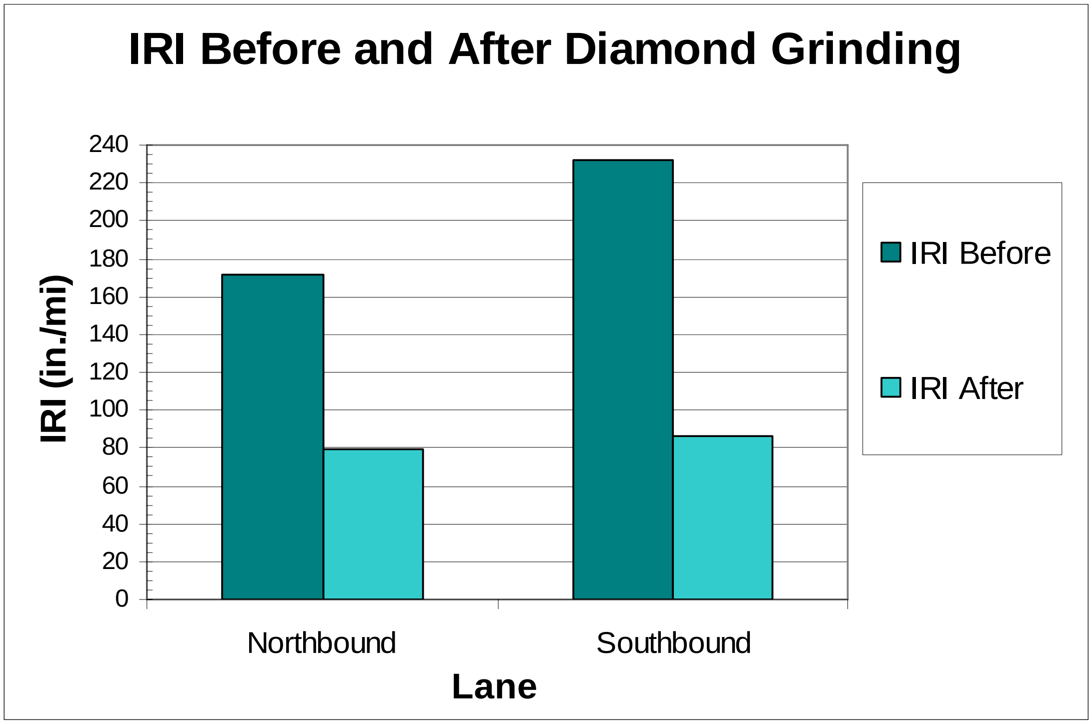

Figure 9. IRI before and after diamond grinding

Figures 10 and 11 show the IRI over time for the northbound and southbound lanes, respectively. In the figures the IRI is much higher in September 2004. This marks the IRI of the pavement before the diamond grinding had taken place. The November 2004 IRI data drops significantly, which indicates the IRI after diamond grinding. The IRI then gradually goes up, showing general wear of the pavement over time.

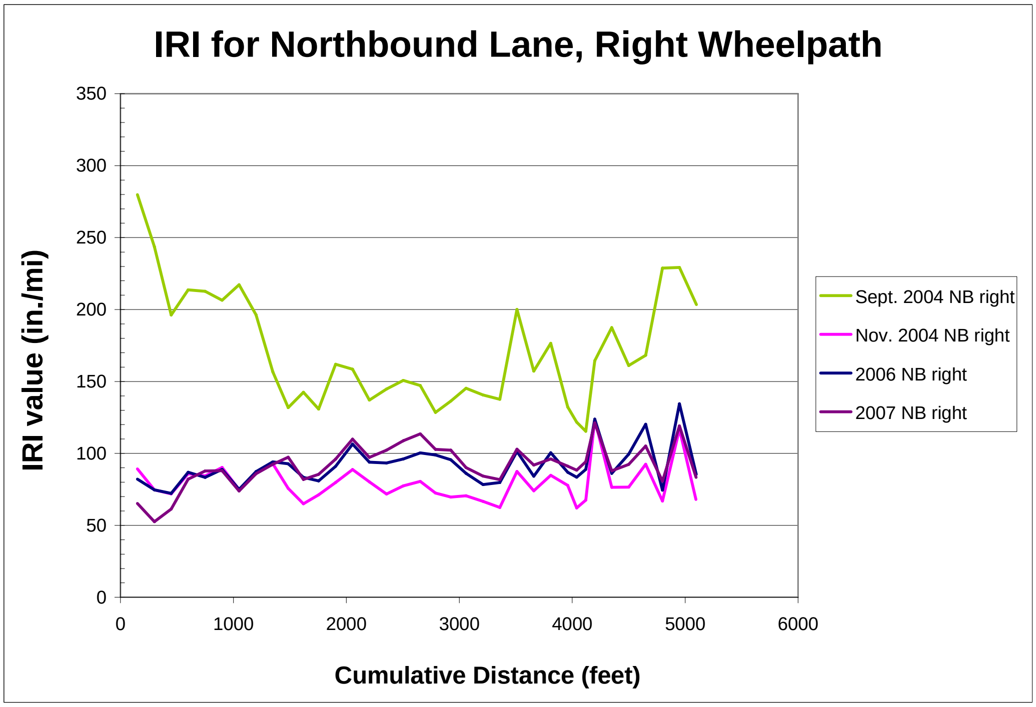

Figure 10. IRI for northbound right wheel path

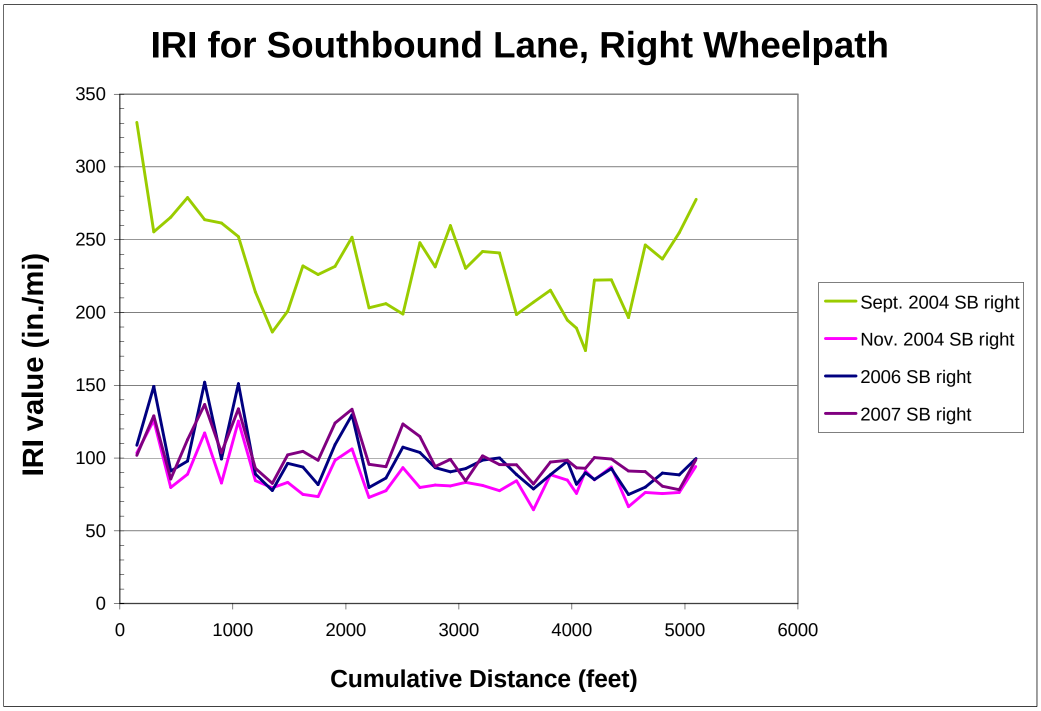

Figure 11. IRI for southbound right wheel path

The IRI information can also be used to determine which type and quantity of dowel bar best maintains the pavement’s smoothness.

Because the starting IRI values were not the same after diamond grinding, an analysis of the profile data based on a change in IRI was necessary for each dowel configuration and not just on the IRI value itself. So, even though the IRI value of a particular bar may be much higher than others, this does not mean it performs less in terms of maintaining the pavement profile. Table 9 contains the change in IRI over time and is broken down by material type and number of bars. Worth acknowledging is an inconsistency in the data that occurred in the FRP dowels with four bars per joint. The IRI value actually turned out to be smoother than the pavement just after diamond grinding. This appears to be a potential error in the machine or with the data collection. This detail is the reason that the average value for the July 17, 2007, not being included in the average calculation, FRP data were taken from the two and three bars data. The four bars section was excluded from the average. Note that the IRI values for November 2004 were considered as a base value to create the same starting point in order to monitor the change of IRI over time. Also, the change in IRI per year values were calculated by taking the most recent IRI values (2007) and dividing them by the number of years since the initial diamond grinding. This was not true for the FRP four bars change in IRI per year. Because the July 2007 data were out of place, the change in IRI per year value was calculated by taking the September 2006 IRI value and dividing it by the number of years passed since the initial diamond grinding.

The data suggests that FRP performs a minimum of 25% better in terms of IRI performance compared with round or elliptical steel bars. This was not entirely the conclusion for heavy elliptical steel with four bars. However, Table 9 shows that the IRI decreased from the 2006 to the 2007 data. It is unlikely that the IRI decreased over the year, so the data comparison from the FRP and heavy elliptical cannot be considered significant.

Table 9. Change in IRI over time by bar type and number of bars

Bar type									
# Bars	**FRP**				**# Bars**	**Steel round**			
	11/18/04	**9/14/06**	**7/16/07**	**Δ IRI / year**		**11/18/04**	**9/14/06**	**7/16/07**	**Δ IRI / year**
2	0	5.2	3.1*	2.8**	2	0	14.2	21.0	7.9
3	0	9.8	10.3	3.9	3	0	16.5	19.1	7.2
4	0	5.6	-8.2*	3.0**	4	0	8.0	14.2	5.3
Avg.	0.0	6.9	6.7	3.2	Avg.	0.0	12.9	18.1	6.8
# Bars	**Medium elliptical**				**# Bars**	**Heavy elliptical**			
	11/18/04	**9/14/06**	**7/16/07**	**Δ IRI / year**		**11/18/04**	**9/14/06**	**7/16/07**	**Δ IRI / year**
2	0	14.0	21.7	8.1	2	0	17.8	29.4	11.0
3	0	14.5	16.9	6.4	3	0	10.4	13.8	5.2
4	0	11.9	14.0	5.3	4	0	12.4*	7.2	2.7
Avg.	0.0	13.5	17.5	6.6	Avg.	0.0	13.5	16.8	6.3

NOTE: * indicates a number that appears to be out of place
** indicates a Δ IRI / year value calculated using 2006 IRI data

The data does indicate that the changes in IRI for steel round and medium elliptical bars perform equally well in all configurations. Also, the four bar combinations in each of the steel dowel configurations yield the best IRI performance.

Figure 12 shows the average change in IRI by dowel type over time. The figure is not intended to be used for quantitative measure, but to compare how the different dowels perform relative to the other dowel types. In Figure 12, FRP performs significantly better than the other bars for maintaining a lower IRI value over time. This means that using FRP dowel retrofits will maintain a smoother ride than standard round or elliptical steel dowels, according to this research data. The dashed line in the graph is a better representation of the FRP data if the irregularities are removed. This still indicates that FRP bars maintain IRI better than the other dowel bars tested.

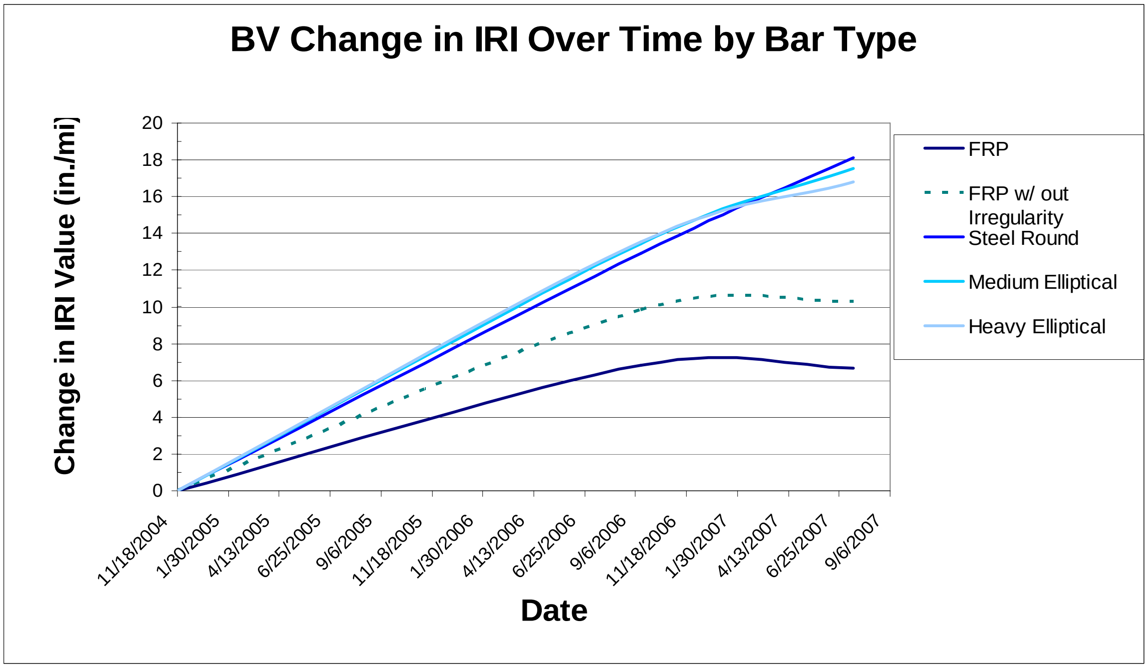

Figure 12. Change in IRI over time by bar type

Figure 13 shows the average change in IRI per year by the number of dowels used in the joint. Excluding FRP bars, Figure 13 shows that using two bars will give a higher IRI value and thus a rougher pavement over time than using three and four bars. FRP bars performed in an unexpected manner. The use of two bars yielded better results than using three or four bars according to this research data.

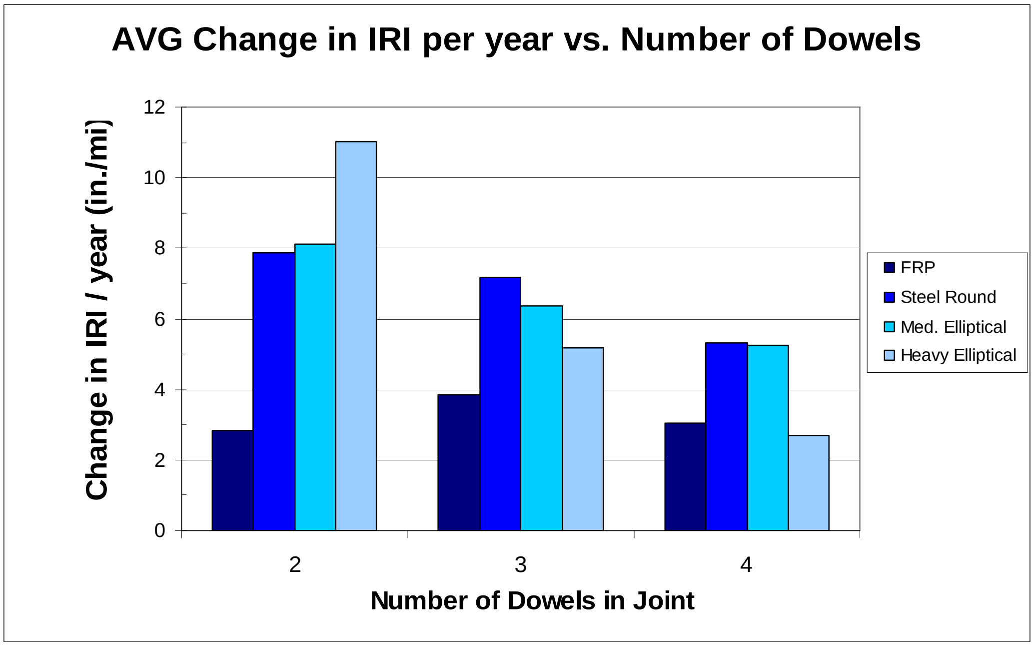

Figure 13. Change in IRI per year vs. number of dowels used

The quantitative value used to compare the number of bars used in each joint is expressed as an average change in IRI per year. The change in IRI per year was used to determine the average pavement life extension caused by the dowel retrofit in terms of road smoothness. The change in IRI data collected during this study was graphed versus time starting at a value of 80 (approximate value attained after grinding). A linear trendline was assigned to each data set. These trendlines were then extended until they passed the maximum acceptable IRI values of 150 and 170 in/mi. These numbers were mentioned earlier as the acceptable road user tolerances for roughness. These points signify the useful life of the retrofit based on IRI. The graphical representation of the data can be found in Figures 14 and 15. These graphs are based on a linear interpolation of the data collected in this report. The linear relationship between time and change in IRI is unknown, but the IRI values from the collected data were used to predict long term IRI maintainability. Also important to note is that all interpolations were based on a linear regression of three data points except for the FRP dowels and heavy elliptical sections with four bars. Earlier, Table 9 showed that there appeared to be irregularities in the FRP data. For this reason, data from November 2004 and September 2006 were used to do a straight line regression for two and four FRP bars. The data for three FRP bars appeared to be regular, so all three data points were used for its linear regression. The heavy elliptical data with four bars per section also seemed to have a small inconsistency with the September 2006 data. For this reason, data from November 2004 and July 2007 were used to do a straight line regression for four heavy elliptical bars.

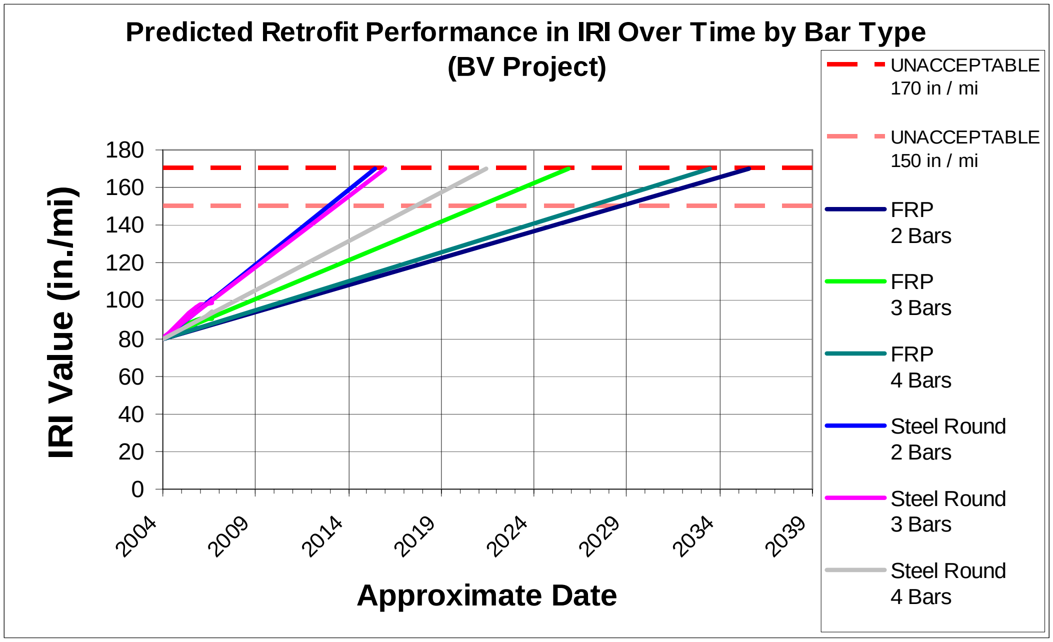

Figure 14. Predicted IRI over time (FRP & steel round)

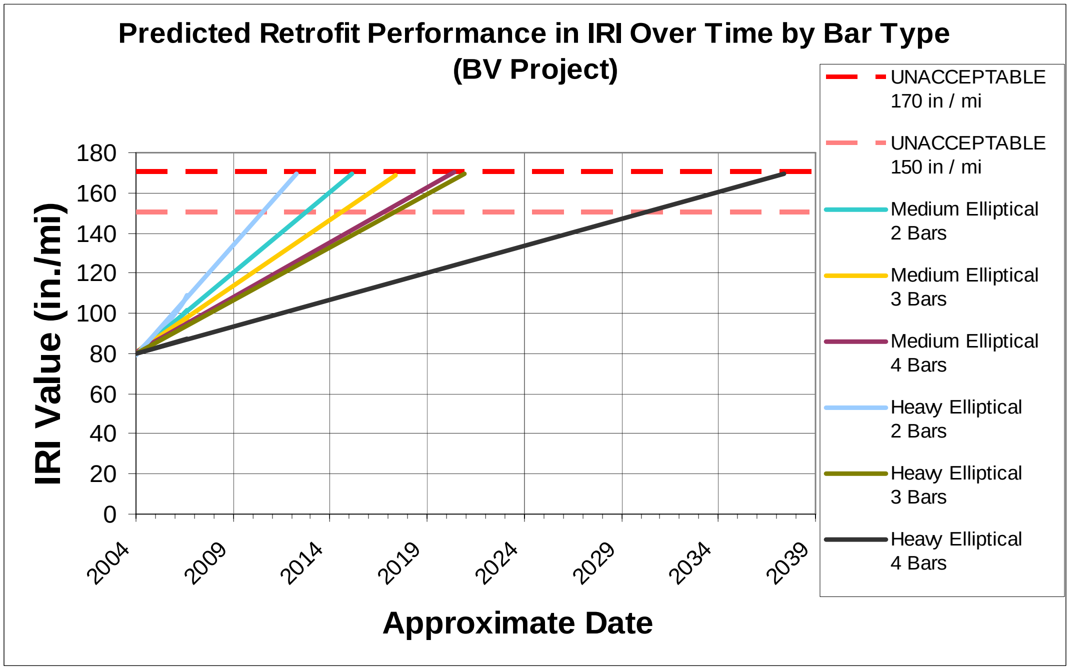

Figure 15. Predicted IRI over time (medium & heavy elliptical steel)

The summary of the results from the graphs are found in Table 10.

Table 10. Pavement life extension for road profile due to dowel retrofit

Bar type & number	Pavement life extension (years)
Heavy elliptical 4	26–33
FRP 2	25–32 *
FRP 4	23–29
FRP 3	17–22
Steel round 4	13–17
Heavy elliptical 3	13–17
Medium elliptical 4	13–16
Medium elliptical 3	11–13
Steel round 2	9–12
Steel round 3	9–12
Medium elliptical 2	8–11
Heavy elliptical 2	7–8

NOTE: * indicates a number that has intuitively inconsistent data

Strain Testing

Strain gages are utilized to determine the behavior of a dowel along the length of the dowel instead of determining deflection specifically at the joint. This utilization is performed by applying multiple strain gages to a sample set of dowels and applying a known load to the joint.

For this project, five strain gages were applied on the bottom of each dowel: one gage at the center of the dowel, two gages two inches from the center of the dowel, and two gages four inches from the center of the dowel. Five gages were applied, each to one round steel dowel, one medium elliptical steel dowel, and one elliptical FRP dowel.

The load application consisted of driving a loaded truck (see Figure A.12) over the gaged dowel joint (see Figure A.13) at walking speed while strain data were being obtained. The truck was used to roll over the joint three times for each gaged dowel. The truck axle loads varied each testing occasion and had the following ranges:

- Front axle: 12–16 kips
- Rear tandem axle: 24–38 kips

Approximately 6–9 kips were applied directly over the dowel by each axle (one-half of the total load per axle). Strain measurements were recorded and saved to a data file as the truck rolled over the joint. Strain gage readings and graphs for each of the dowel types on four different test dates are available upon request. Gages 1, 2, 3, 4, and 5 are -4, -2, 0, 2,and 4 inches from the center of the dowel, respectively. There are three spikes in the strain graphs that represent the three truck axles as they crossed the joint (the front axle passed first).

Figures A.14 through A.16 show the plots of strain versus location along the dowel. The strain values used are the maximum recorded strain, most of which occurred as a result of the front axle rolling over the joint.

The plots in Figures A.14 through A.16 consistently show that the strains were much greater for the November 2004 tests than for the April 2005, July 2006, and May 2007 tests. The strains from the April 2005 and May 2007 tests were greater than for the July 2006 tests. For the November 2004 tests the (medium or large) elliptical steel dowel had the smallest strains, the elliptical FRP had the largest strains, and the round steel had strain values in between. The elliptical FRP dowels had a lower flexural rigidity than either of the steel bars, due to a smaller modulus of elasticity, so the larger strains were expected. Considering the difference in the elastic modulus of the FRP and steel dowels, the strain magnitude in the FRP is very close to that of the steel dowels.

The strains for the April 2005 testing were comparable among the three dowel types, with the elliptical FRP dowel having slightly larger strains than the steel dowels. The strains for the July 2006 testing showed similar strains between the round and medium elliptical steel dowels and larger strains for the elliptical FRP dowels. The strains for 2007 showed FRP dowels and medium elliptical steel dowels to be in the same range of strain with smaller strains produced in the round dowels.

The November 2004 testing shows that the elliptically shaped steel dowel provided better flexural resistance than the other two dowels. Despite the fact that the elliptical dowels are placed in weak-axis bending, the increased bearing surface of the elliptical shape provided between the dowel and the concrete helped reduce stresses in the dowel.

A noticeable disparity in the data is that the strain-reading values consistently changed from test date to test date. This could have been because of many factors, including variations in subgrade conditions, concrete temperature (and, therefore, joint binding), and strain gage decay. For the most part, the strain gages became more “noisy” (unable to maintain a stable reading for a constant load) and some gages gave readings that were suspiciously low. However, the final set of data in 2007 appeared to have no “noise” as strain readings were in the same range as the spring 2005 readings.

The data from the April 2005, July 2006, and May 2007 strain measurements show that the three dowel types—round steel, medium elliptical steel, and elliptical FRP—performed similarly in terms of flexural reaction, although medium elliptical steel performed best for November 2004 testing. The elliptical dowels performed well at reducing stresses despite being subject to weak-axis bending. The FRP dowel also performed well considering it had a significantly lower flexural rigidity than the steel dowels. While all three dowels performed as required, continued testing of elliptical dowels at various spacing may be beneficial to determine if there is a more effective use of material than the standard round dowels. In addition, FRP should be considered where corrosion is a concern and in situations where it may be more cost-effective.

Cost Analysis

To determine whether or not the dowel bar retrofit should be implemented, cost needs to be taken into account. The approximate fixed cost to prepare, install, and finish the retrofit of the pavement (excluding dowel costs) is summarized in Table 11 below.

Table 11. Installation cost per mile by number of bars per lane

2 Bars	3 Bars	4 Bars
$85,400	$104,500	$123,500

The cost of using a particular dowel and the number of dowels per lane is summarized in Table 12. The FRP bars are much more expensive than the other dowel types. Therefore, FRP bars need to perform in such a way as to justify the extra expenses incurred upon installation.

Table 12. Total dowel cost (one-mile pavement) vs. type and number used

Dowel type	Material cost / unit	Total # used in both lanes			Total dowel cost by # used (two lanes)		
		2 Bars / lane	3 Bars / lane	4 Bars / lane	2 Bars / lane	3 Bars / lane	4 Bars / lane
FRP	$12.00	1360	2040	2720	$16,300	$24,500	$32,600
Stl. Rd	$4.58	1360	2040	2720	$6,200	$9,300	$12,500
Med. Ell	$4.43	1360	2040	2720	$6,000	$9,000	$12,000
Heavy Ell	$4.83	1360	2040	2720	$6,600	$9,900	$13,100

Note: Cost includes bar, chairs, and joint spacer

Table 13 below shows the total cost of installation along with material costs.

Table 13. Total dowel & installation cost (one-mile pavement)

Dowel Type	Total installation cost (two lanes)		
	2 Bars/lane	3 Bars/lane	4 Bars/lane
FRP	$101,700	$128,900	$156,100
Stl. Rd	$91,700	$113,800	$136,000
Med. Ell	$91,500	$113,500	$135,600
Heavy Ell	$92,000	$114,300	$136,600

CONCLUSIONS

- The construction report confirms the feasibility of using elliptical or round dowels to retrofit an eight-inch local road concrete pavement as part of a retrofit/grind rehabilitation project.
- Faulting was reduced to approximately 0.019 inches because of diamond grinding.
- IRI was reduced to 80 in/mi because of diamond grinding.
- All dowel types tested performed equally at controlling faulting.
- Two, three, and four dowels all performed equally for faulting.
- All bar material types performed equally in load transfer development.
- Two, three, and four dowel configurations performed equally for load transfer across joints.
- FRP dowels attained higher performance in terms of pavement IRI vs. steel dowels.
- Using more dowels increased IRI performance.
- FRP strain values were higher than steel strain values, but all combinations performed in an acceptable range.
- Increasing the number of dowels increases the performance life of the pavement.

RECOMMENDATIONS

After a careful analysis of the dowel bar retrofit sections, the conclusion was made that FRP bars maintain a better IRI. However, this comes at a higher cost. Which retrofit would best suit the needs of a particular project would be up to the individuals involved in making retrofit decisions. Table 14 summarizes the cost to life extension due to each type of retrofit. Table 14 data indicate that 7–20 years extended life can be obtained through addition of 2–4 steel dowels in the outside wheel path and surface diamond grinding. However, this life extension does not account for the extension due to the reduced corrosion benefits of the FRP dowels. If corrosion is considered to be an issue, then FRP should be considered.

Table 14. Summary of life extension to cost (one-mile pavement)

Bar type/#	Cost/mile	Pavement life extension (years)
Heavy elliptical 4	$136,600	26–33
FRP 2	$101,700	25–32 *
FRP 4	$156,100	23–29
FRP 3	$128,900	17–22
Steel round 4	$136,000	13–17
Heavy elliptical 3	$114,300	13–17
Med. elliptical 4	$135,600	13–16
Med. elliptical 3	$113,500	11–13
Steel round 2	$91,700	9–12
Steel round 3	$113,800	9–12
Med. elliptical 2	$91,500	8–11
Heavy elliptical 2	$92,000	7–8

NOTE: * indicates a number that has intuitively inconsistent data

APPENDIX A

Figure A.1. Surface grinder

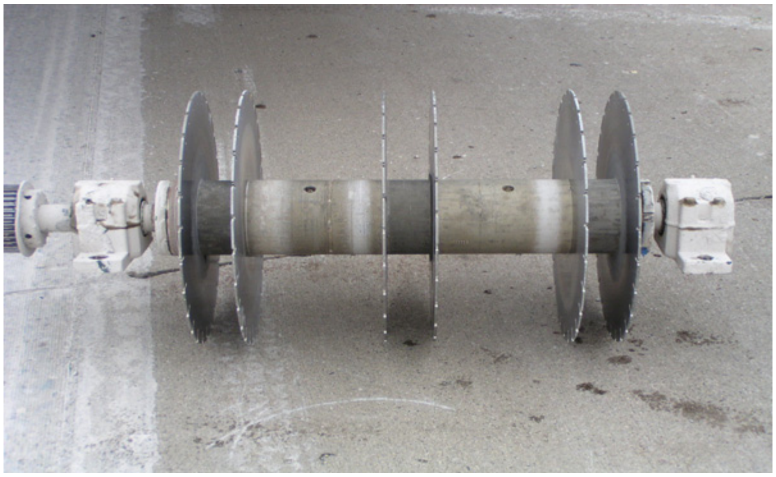

Figure A.2. Slot cutter head

Figure A.3. Slot material removal

Figure A.4. Proper slot length

Figure A.5. Dowel chair anchoring

Figure A.6. Plaster crack sealing

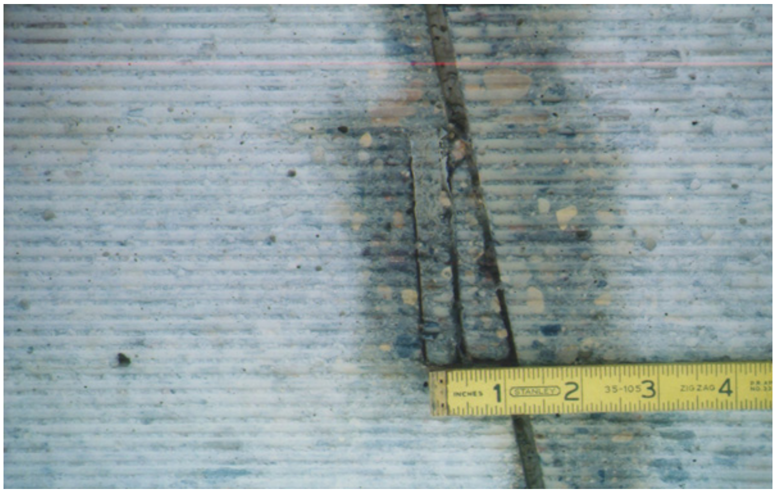

Figure A.7. Spall protection

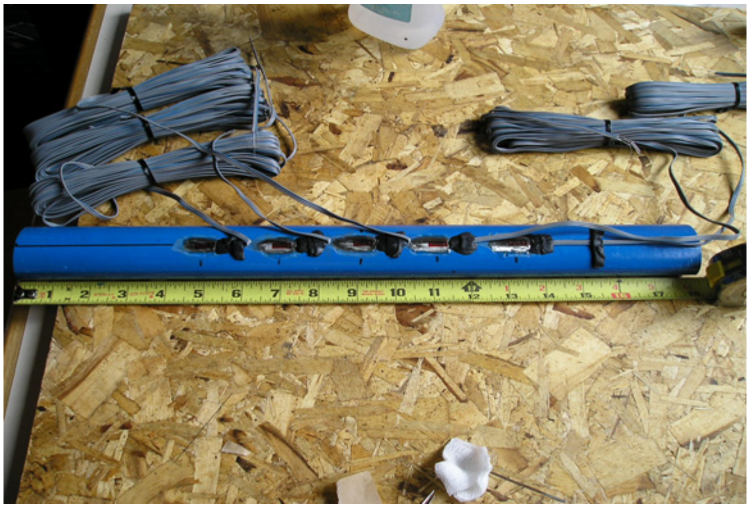

Figure A.8. Dowel instrumentation

Figure A.9. Instrumentation trench jetting

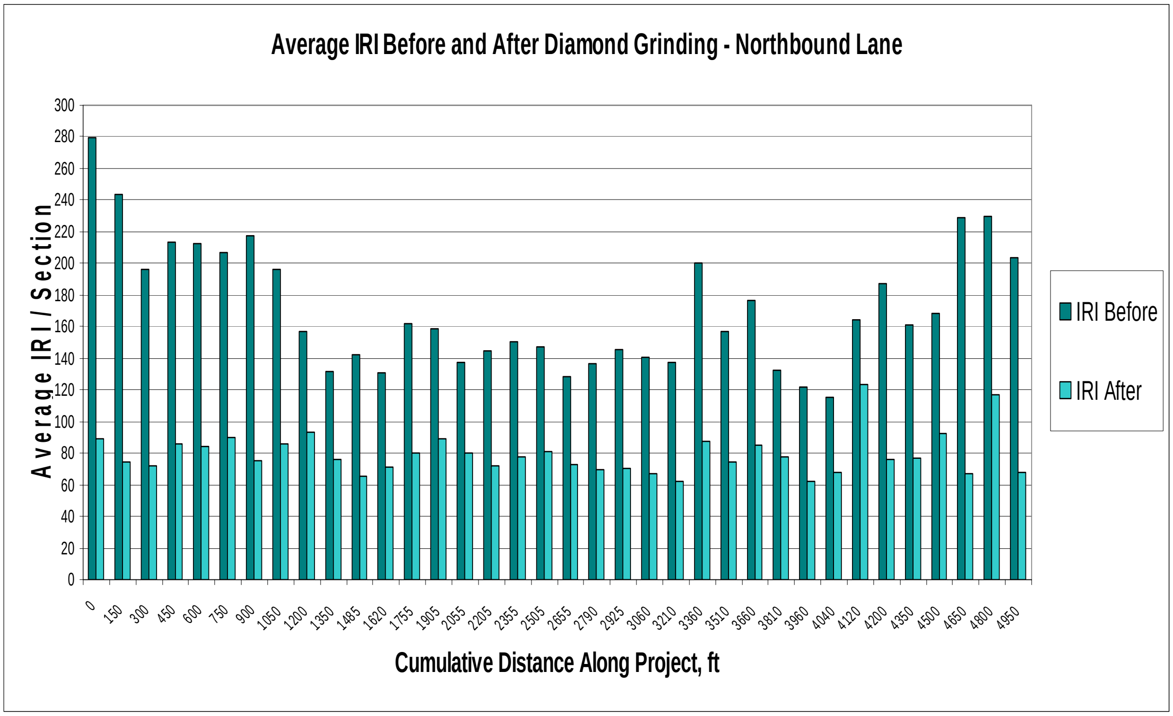

Figure A.10. Avg. IRI before and after diamond grinding – NB lane right wheel path

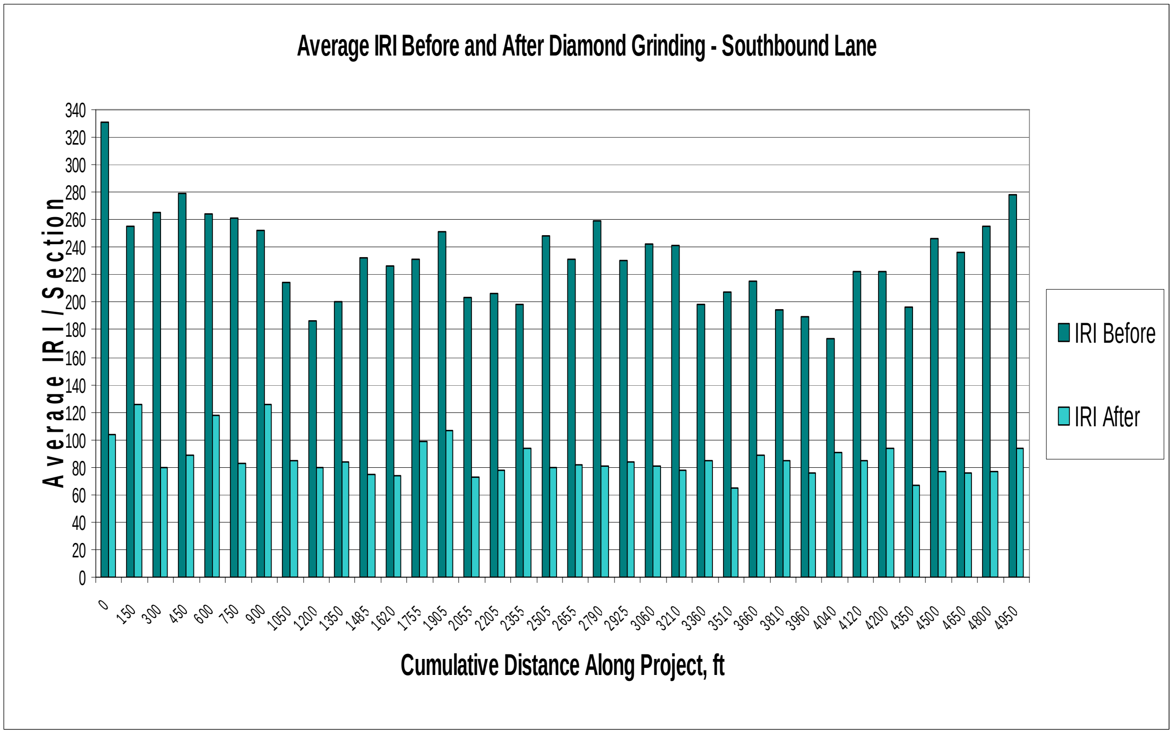

Figure A.11. Avg. IRI before and after diamond grinding – SB lane right wheel path

Figure A.12. Loaded truck for strain testing

Figure A.13. Truck driving over doweled joint (retrofit trenches outlined)

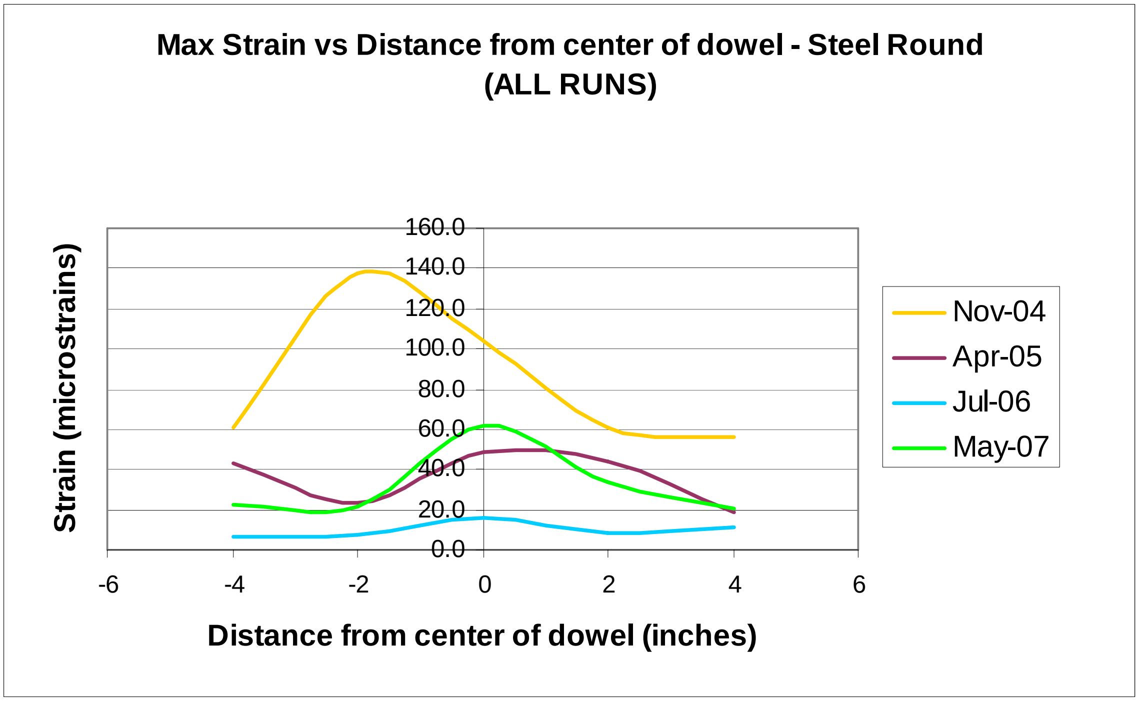

Figure A.14. Plot of max strain vs. distance from center of dowel — steel round

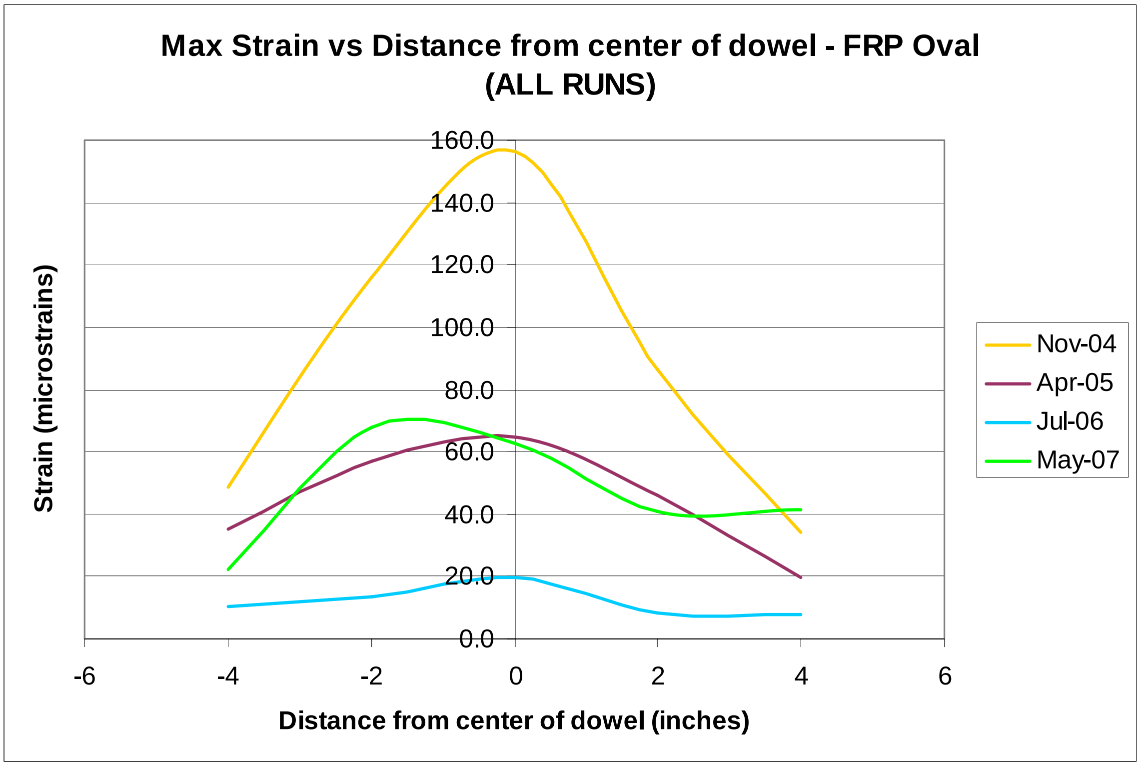

Figure A.15. Plot of max strain vs. distance from center of dowel — FRP oval

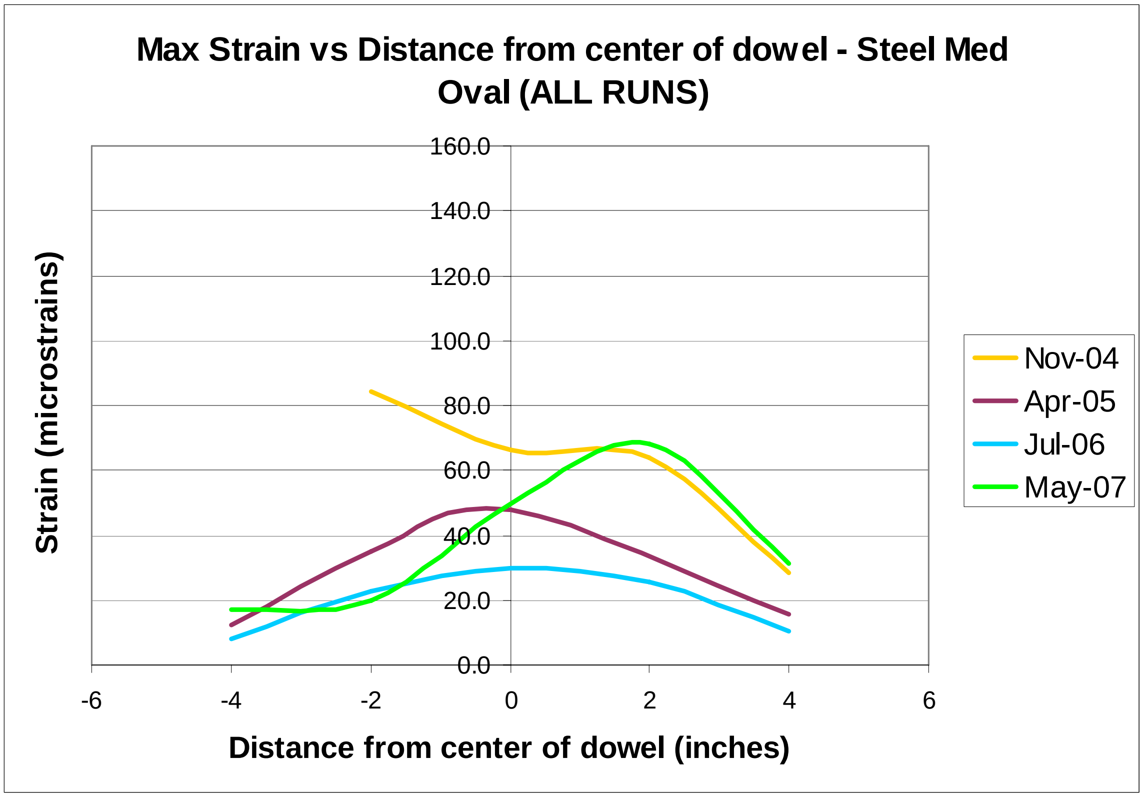

Figure A.16. Plot of max strain vs. distance from center of dowel — steel med. oval