Glass Fiber Reinforced Polymer Dowel Bar Evaluation

WA-RD 795.1

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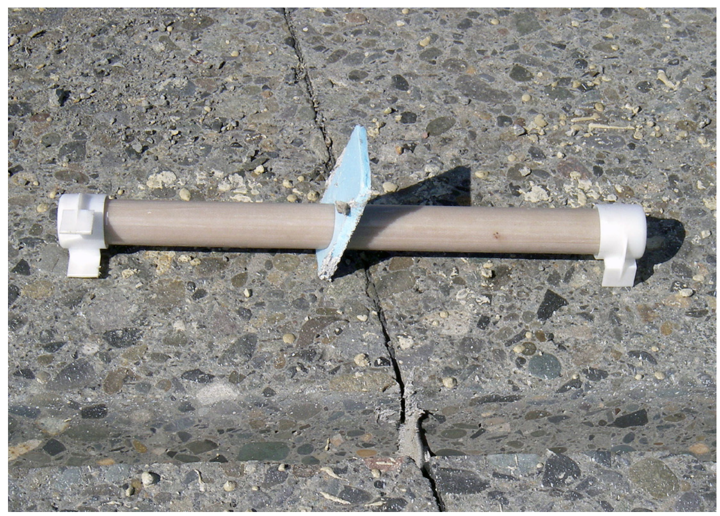
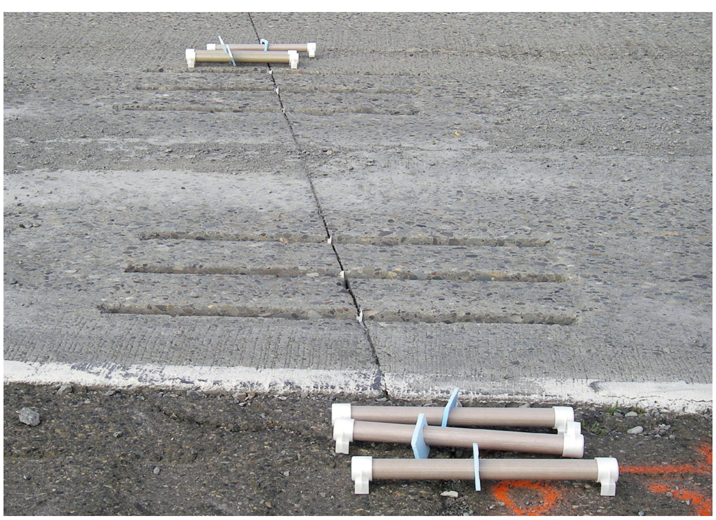


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Experimental Feature Project

Post-Construction Report
Experimental Feature 10-04

Glass Fiber Reinforced Polymer Dowel Bar Evaluation

I-5, Contract 7753, SR 532 Vic. to Starbird Rd Vic. – PCCP Rehab.

I-82, Contract 8028, Yakima River Br Vic. to Granger – Dowel Bar Retrofit and Concrete Rehab.

I-82, Contract 8068, Grandview to Prosser - Dowel Bar Retrofit and Concrete Rehab.

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16. ABSTRACT

Glass Fiber Reinforced Polymer (GFRP) dowel bars were installed on one new construction project and two dowel bar retrofit projects to evaluate the performance of this type of dowel bar in comparison to steel dowel bars installed on the same contracts. The primary data collection site (I-82, Yakima River Br. Vic. to Granger) included 67 joints retrofit with GFRP dowels and an equal number of epoxy coated doweled joints that serve as the control section.

Falling weight deflectometer (FWD) testing will be used to evaluate the load transfer efficiency (LTE) of the two types of dowel bars. Periodic coring of the concrete at the joints is also planned to examine the condition of the GFRP and epoxy coated dowels.

Post-installation FWD testing of the primary data site revealed that the average LTE of the joints retrofit with epoxy coated dowel was higher than the joints retrofit with the GFRP dowels and that the difference was statistically significant. Pre-installation FWD testing showed no difference in the LTE of the joints in the areas where the GFRP and epoxy coated dowels were installed.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Introduction

WSDOT designs concrete pavements to have a 50-year or more pavement life. In order to achieve this performance, every component of the pavement structure must be able to achieve this 50+ year life. WSDOT has demonstrated that the concrete pavements constructed in the late 1950's to early 1960's without doweled joints were only able to obtain a 50-year or more pavement life by retrofitting the joints with dowel bars to eliminate future faulting and diamond grinding to eliminate faulting. As a result of this, all new concrete pavements constructed since 1992 have required steel dowel bars at each transverse joint.

The use of dowel bars does not necessarily ensure that a 50-year performance life will be obtained. WSDOT and several other states have observed that the corrosion of epoxy coated dowel bars occurs within 15 to 20 years. Therefore, it is desirable to obtain and use dowel bars that have the ability to resist corrosion. WSDOT only allows dowel bars that have proven to be highly resistant to corrosion to be used in the construction of new pavements. The types of dowel bars currently allowed are solid stainless steel, stainless steel clad, stainless steel tubes with epoxy coated inserts, high chromium steel (MMFX) or zinc clad steel dowel bars. Epoxy coated steel bars are not allowed for use in new concrete pavements due to their inadequate resistance to corrosion due to small holes in the epoxy coatings or damage that often occurs during handling of the bars during the construction process. However, epoxy coated dowel bars are allowed for dowel bar retrofit (DBR) and panel replacement applications because these are fixes that we expect to be in place for no more than 20 years. Fiber reinforced polymer (FRP) and glass fiber reinforced polymer (GFRP) dowel bars are not currently allowed except as part of an experimental feature.

Literature Search

Fiber reinforced polymer (FRP) and glass fiber reinforced polymer (GFRP) dowel bars appear to be a promising alternative to conventional metal bars because of their non-corrosive properties. FRP and GFRP consist of a binder, a strong reinforcing element, and inert materials. The binders can be either a resin or polymer material such as polyester, vinyl ester or epoxy.

The reinforcing material can be fiberglass, carbon fiber, or graphite fiber. The inert filler material can be calcium carbonate, clay, or hydrated alumina. The bars are made through a process called protrusion, in which the reinforcing elements are pulled through a bath of the binder and then through a die, where the resin is cured (Snyder 2011).

FRP is a generic term for fiber reinforced polymer and can include carbon, glass, Kevlar, basalt and other materials as reinforcing elements. GFRP is a specific term and refers to glass fiber reinforced polymer. The glass content does not make the dowel more or less susceptible to corrosion; however, the glass type and resin type do have an impact on the corrosion resistance. The glass content has a positive effect on the mechanical properties (modulus, shear resistance, etc.) of the bars (Personal Communication, Ashley McWatters).

Field Installations

The Ohio Department of Transportation installed several FRP dowel bars in 1983 on both an interstate and state route. The bars were extracted and tested after 15 years of service and found to be virtually unaffected by traffic loading and exposure to the environment (Vijay, et.al. 2009).

In 1997, FRP dowel bars were installed on a bypass route near Des Moines, IA. The dowels were installed on 12 and 8 inch centers in skewed joints spaced 20 feet apart. The FRP dowel bars have performed well to date. Illinois, Iowa, Kansas, Minnesota, Ohio, Wisconsin, and Manitoba have also installed FRP dowels on an experimental basis (Vijay, et al. 2009).

Sigma DG Corporation, distributor of MateenDowel™, reported in November of 2010 that the largest use of GFRP dowels was conducted by the Idaho Transportation Department (ITD). The ITD project used 64,500 dowels 1.5” x 18” in a 10 inch thick concrete pavement. The dowels were spaced 12 inches center to center. The project, on I-84 in Boise, used a dowel bar inserter. The contract required the Contractor to uncover 10 percent of the bars on the first night of paving to ensure they meet ITD requirements. The percentage was reduced by ITD after proof of the consistency of alignment was verified. Sigma DG reported that not one of the bars was out of alignment or not at the proper depth (McWatters 2010).

Combined Laboratory and Field Evaluations

Brown and Bartholomew employed scale model tests to compare the performance of FRP dowels made of vinyl ester resins with steel dowels. They recommended an approximately 20-30 percent increase in dowel diameter to maintain maximum deflections, concrete bearing stress, and load transfer percentages at the same levels with joints containing steel dowels (Brown and Bartholomew 1993).

A study conducted by the University of Manitoba, Canada used GFRP dowels in both laboratory and field installations. They found that the diameter of the GFRP dowels needed to be 20-30 percent larger than steel dowels to produce equivalent load transfer efficiencies (Shalaby and Murison 2001).

Full scale model tests and field installations were used by Eddie et al. to determine joint effectiveness of GFRP dowel bars. They found that the load transfer efficiencies of the GFRP dowels were in the range of 86-100 percent on a weak subgrade, and 90-97 percent on a stiff subgrade. The American Concrete Paving Association (ACPA) criterion for successful joint load transfer is 75 percent (Eddie et al. 2001).

A study by Porter and other researchers at Iowa State University used GFRP dowels in plain jointed concrete pavements. They concluded that 1.5-inch diameter GFRP dowels spaced on 12-inch centers were inadequate in transferring load for the anticipated life of the pavement, but that reducing the spacing to 6-inch centers provided adequate load transfer (Porter et al 2001). A subsequent field installation study by Cable and Porter reported problems with the bars floating to the pavement surface when placed using a dowel bar inserter (Cable and Porter 2003).

West Virginia University completed an extensive laboratory and field evaluation of FRP dowel bars in 2009. The research showed that 1.5-inch diameter FRP dowels provided very good load transfer efficiencies up to and beyond 90 percent. Extensive field fatigue testing showed that the FRP dowels provided sufficient load transfer efficiency (LTE) after 5 million cycles of HS25 loading (25 ton semi-truck). Examination of the dowels subject to the 5 million load cycles revealed that they were in excellent condition with no visible damage, microcracks, or separation between the FRP dowels and surrounding concrete (Vijay et al. 2009).

Caltrans used GFRP in a dowel bar retrofit application which was tested with the heavy vehicle simulator (HVS). The GFRP dowels (1.5” x 18”) were placed four dowels per wheel path as were epoxy coated steel and grout filled hollow stainless steel tubes. One section of epoxy coated steel was retrofit with three dowels per wheel path. The HVS results showed that none of the dowel alternatives were substantially damaged by heavy HVS loading and that the slabs failed by fatigue cracking before the LTE dropped substantially. All of the dowel alternatives showed a slight increase in initial LTE with increasing HVS wheel load. All of the sections showed little or no decrease in LTE after HVS trafficking based on measurement under the 60 kN HVS wheel load at over 2 million repetitions. LTE was lower and deflections higher for the section with three epoxy coated dowels per wheel path. Coring of the pavement after all testing was completed showed that many of the GFRP dowels were installed higher than mid-slab with some of them very close to the top of the pavement (one core showed the GFRP dowel 2.4 inches above the mid-slab of the 8 inch thick slab). In spite of the misplacement of the GFRP dowels the HVS testing indicated that the dowels performed equal to the steel dowels with respect to LTE (Bian et al. 2006).

Synthesis Studies

FRP and GFRP dowels have the advantage of being lightweight, relatively inexpensive, noncorroding, and nonmagnetic. The reduced stiffness of these materials, however, is a disadvantage that results in higher bearing stresses and differential joint deflections as compared to steel dowels when all other factors are held constant (Cable and Porter 2003; Crovetti 1999).

FRP dowels have Young’s modulus values about 80 percent lower than that of carbon steel. The reduced stiffness makes the behavior of FRP and GRFP doweled joints more sensitive to the width of the joint and the stiffness of the underlying materials. As a result, much larger diameter dowels and/or much closer spacing of the dowels is required to produce the same bearing stresses and deflections that would be produced with any given size of round metal dowel. Field studies and laboratory tests have noted that in the use of FRP or GFRP dowels of comparable size and spacing to standard steel dowels in pavements results in higher deflections, lower initial LTE, and more rapid loss of LTE under repeated loads. Increasing the diameter of the FRP or GFRP dowels to address these problems may cause other problems such as slab cracking or delamination along the plane of the dowels at the joint. Because of these issues and the fact that the long-term performance of pavements construction using FRP/GFRP has not been established the use of these dowels should be approached with great caution (Snyder 2011).

Literature Summary

The literature review indicates contradictory conclusions on the LTE of 1.5-inch diameter FRP/GFRP dowels. Several studies conclude that the diameter of the FRP/GFRP dowels must be increased to match the deflection and bearing stresses of 1.5 inch diameter steel dowels or if 1.5 inch diameter FRP dowels are used the spacing needs to be reduced to 8 inches center to center. Other studies found that the 1.5 inch diameter FRP/GFRP dowels performed equivalent to 1.5 inch diameter steel dowels with very good LTE values and no signs of deterioration of the dowels. Sigma DG Corporation, distributor of MateenDowel™, points out that an FHWA study found GFRP dowels have lower environmentally induced bearing stresses caused by curing and curling of concrete which may be higher than dynamic stresses from traffic loading as these are sustained stresses on the concrete and dowel bar (FHWA 2006). GFRP is more efficient at distributing stresses induced by dynamic loading. Increasing bar diameter is the wrong approach in matching steel bars deflection and bearing stress parameters. A better solution is to decrease bar diameter and space them closer together to take advantage of the material properties unique to GFRP dowels (Vijay et al. 2009).

On the construction side, floating of the dowels when used in both DBR and new construction applications was noted in several studies. The project built by IDT, however, did not mention any problems with floating dowels.

Project Objectives

This project will evaluate the performance of MateenDowels™ GFRP dowel bars. The primary area of concern is the ability of the dowels to carry the loading resulting from large volumes of traffic and to carry these loads without significant deterioration. Other areas of concern are deterioration of the GFRP dowels as a consequence of exposure to the environment or deicing chemicals and issues such as floating of the dowels or misalignment during installation.

Study Design

Falling weight deflectometer (FWD) testing will be the primary evaluation tool used in this study as noted in the work plan (Appendix A). FWD testing will be performed periodically to measure load transfer efficiency (LTE) which is a measure of the ability of the bars to transfer loads from one slab to the next. To perform testing of transverse joint load transfer efficiency on rigid pavements, a weight of 9000 pounds is dropped approximately six inches from the joint, and the deflection at the sensors immediately on each side of the joint are compared as shown in Figure 1. The percentage LTE is simply: (D2/D1) x 100.

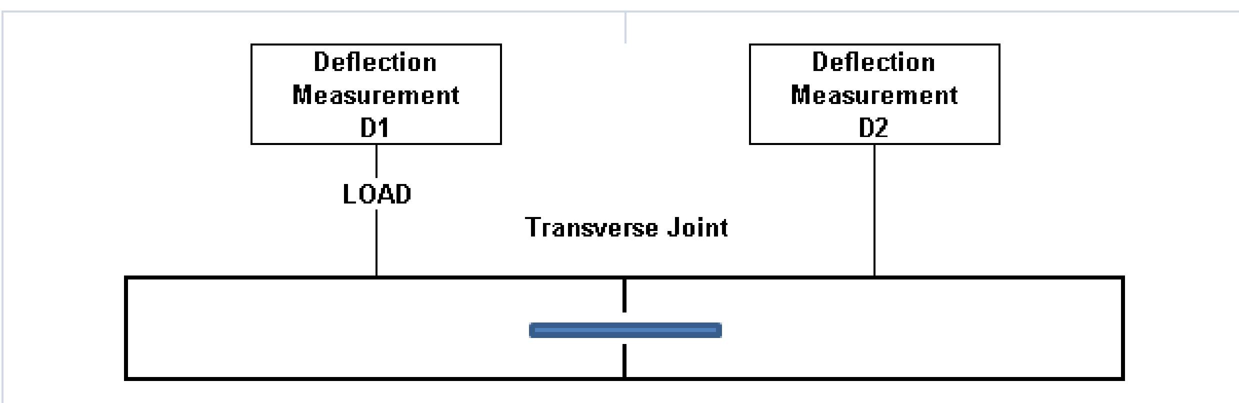

Figure 1. Diagram of load transfer efficiency testing.

Dowel Bar Composition

The GFRP dowels used in this study were manufactured by Pultron Composites, LTD with the trade name MateenDowels™. They are non-corrosive dowel bars composed of epoxy backboned vinyl ester resin and E-CR glass fibers, with glass content above 70%. Glass fibers are produced in a variety of chemical compositions based on their intended use. Some are able to withstand high temperatures, others are good electrical conductors, and still others are resistant to corrosive chemicals. The E-CR glass (CR = corrosion resistant) reinforcement is boron-free which makes it able to survive harsh environments such as hydrochloric acid. The properties of the GFRP dowels are listed in Table 1

Table 1. Properties of GFRP dowel bars used in this study. (Mateen-Bar^{TM} 2005)

Property	Value		Imperial	Standard
Tensile Strength	***Minimum****	**>1000MPa****	**145 ksi**	**ASTM D3916**
Modulus (tensile)	***Typical****	**54.5 GPa**	**7904 ksi**	**ASTM D3916**
	Minimum*	**>50 GPa**	**7250 ksi**	
Shear Strength (single sided)	***Typical***	**260 MPa**	**37.7 ksi**	**ASTM B769-94**
	Minimum	**230 MPa**	**33.4 ksi**	
Shear Strength (double sided)	***Typical***	**520 MPa**	**75.4 ksi**	**ASTM B769-94**
	Minimum	**460 MPa**	**66.7 ksi**	
Compressive Strength (longitudinal)	***Typical***	**690 MPa**	**100 ksi**	**ASTM D695**
	Minimum	**500 MPa**	**72.5 ksi**	
Moisture Absorption	***Typical***	**0.024%**		**BS2782 pt 4,**
				Method 430/
				ISO 62-1980
Thermal Conductivity	***Typical***	**0.25 W/mK-^{1}**		**ASTM C117**
Electrical Strength	***Typical***	**5-40 kVmm**		**DIN 53 481**
Volume Resistivity	***Typical***	**10^{10}Ω.m**		**DIN 53 482**
Dielectric Constant	***Typical***	**<5**		**DIN 53 483**
Magnetic Properties		**non-magnetic**		
Density	***Typical***	**1.9 – 2.1 g/cm^{3}**		

***Tensile strength and modulus are typically higher for smaller diameter bars.**
****Based on 20mm diameter.**

Projects

The three projects that used GFRP dowel bars are listed in Table 2. The third project, Yakima River Br Vic to Granger, is the primary subject of this investigation; however, FWD testing will be conducted on all three projects to monitor LTE. The location of the three projects is shown in Figure 2.

The project on I-5, SR 532 to Starbird Road rehabilitated a portion of I-5 by repaving the outside lane. The GFRP dowels were used in new construction on this particular project. Two baskets with 13 dowels in each basket were used in the 14-foot wide pavement for a total of 26 dowels (2 joints).

The dowel bar retrofit projects used six dowels per joint, three in each wheel path. The Grandview to Prosser project used 18 bars for three transverse joints. The Yakima River Bridge Vicinity to Granger project used a total of 402 GFRP bars (6 per joint) to retrofit 67 transverse joints.

Table 2. Project information.

Route Number	Contract No.	Project Title	Number of Dowels Installed
I-5	7753	SR 532 to Starbird Road – PCCP Rehab.	26
I-82	8068	Grandview to Prosser Dowel Bar Retrofit and Concrete Rehab.	18
I-82	8028	Yakima River Br. Vic. to Granger – Dowel Bar Retrofit and Concrete Rehab	402

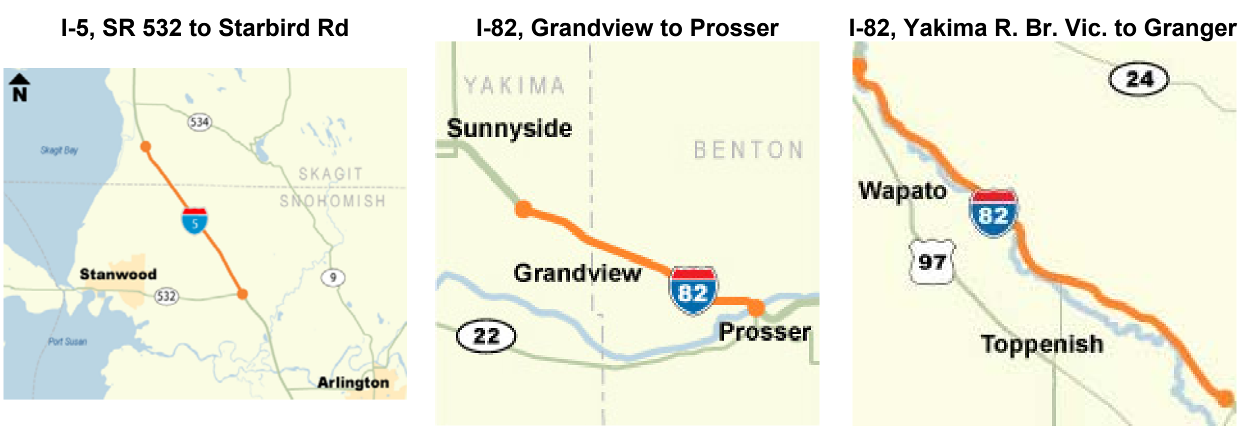

Figure 2. Vicinity maps for the three GFRP installations.

Construction

Standard construction practices were employed on all three projects as shown in the photos (Figures 3 through 13). MMFX dowel bars were used on the Starbird Road project as the control section. Epoxy coated dowel bars meeting ASTM A 934 (purple) were used on the two DBR projects. No construction problems were reported on the I-5 or the I-82, Grandview to Prosser projects.

The biggest problem on the I-82, Yakima River Bridge Vicinity to Granger job was movement of the foam insert away from the actual joint. A total of 29 of the 402 bars were removed due to this problem. The inspector also noted that the concrete patching material was sticking to the GFRP bars which did not happen with the epoxy coated bars. Author's note: the MateenDowels™ brochure states that a bond breaker is not required since the composite dowels are much slicker than steel. The Contractor's foremen also told the inspector that a number of the GFRP dowels that were removed had floated up and were out of vertical alignment possibly due to the vibration used to consolidate the patching material.

I-5, SR 532 to Starbird Rd

Figure 3. GFRP dowels used in new construction on I-5.

I-82, Grandview to Prosser

Figure 4. GFRP bar top, epoxy coated bar bottom.

Figure 5. GFRP dowels placed in slots.

Figure 6. Close-up of dowels in slots.

Figure 7. Close-up of GFRP dowel.

I-82, Yakima River Br Vic to Granger

Figure 8. GFRP dowels.

Figure 9. Dowels in slots.

Figure 10. End caps on GFRP dowels.

Figure 11. Slot filling.

Figure 12. Application of curing compound.

Figure 13. Finished installation prior to diamond grinding to remove faulting.

FWD Testing

FWD testing measures the LTE of the joints. Quoting from Pavement Interactive “this efficiency depends on several factors, including temperature (which affects joint opening), joint spacing, number and magnitude of load applications, foundation support, aggregate particle angularity, and the presence of mechanical load transfer devices.” The issues of major concern on these projects that will affect LTE will be pavement temperature at the time of testing and foundation support. Temperature at the time of testing will affect all of the sites, especially the I-82 sites that experience very high temperatures in the summer months. The foundation stiffness may be affected on the I-5 site due to extended periods of rainfall during the winter which may soften the subgrade. Moisture should not be an issue on the I-82 sites; therefore, the stiffness of the subgrade should remain relatively constant throughout the years. Since the LTE for each site will be analyzed independently from the other sites, the number and magnitude of load applications will be the same, the aggregate particle angularity will not change, and the presence of load transfer devices will be a constant.

I-5, SR 532 to Starbird Rd

The layout of the FWD testing sequence on the I-5 site is shown in Figure 14. GFRP dowels were used on only two transverse joints and MMFX dowels on the remainder of the section. The testing was done on May 12, 2010 with the pavement temperature at 60º F. Results are shown in Figure 15. Note that only the data from FWD test numbers at the pavement edge (0-16) are reported. Changes in LTE are most likely to appear first at the pavement edge rather than the center of the panel.

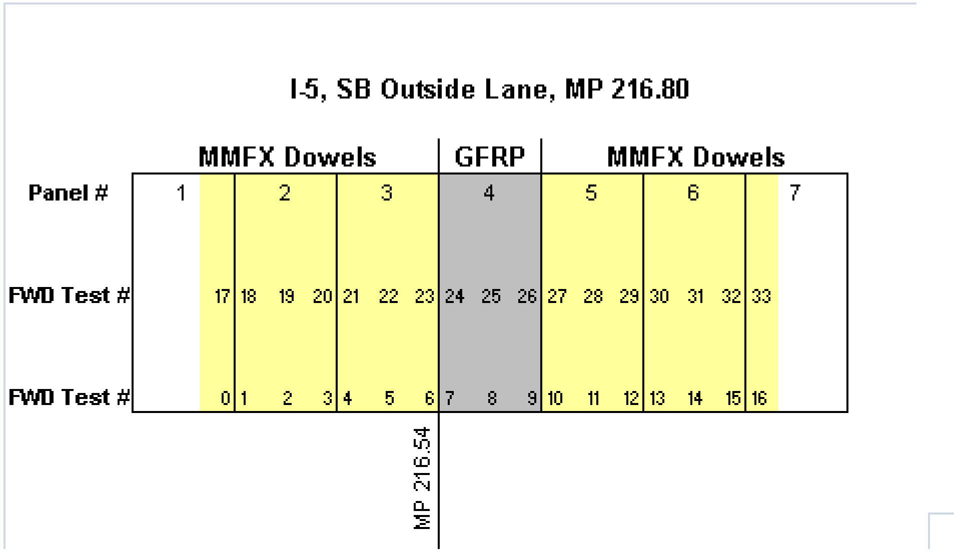

Figure 14. Plan map of I-5, SR 532 to Starbird Road test section showing location of FWD tests.

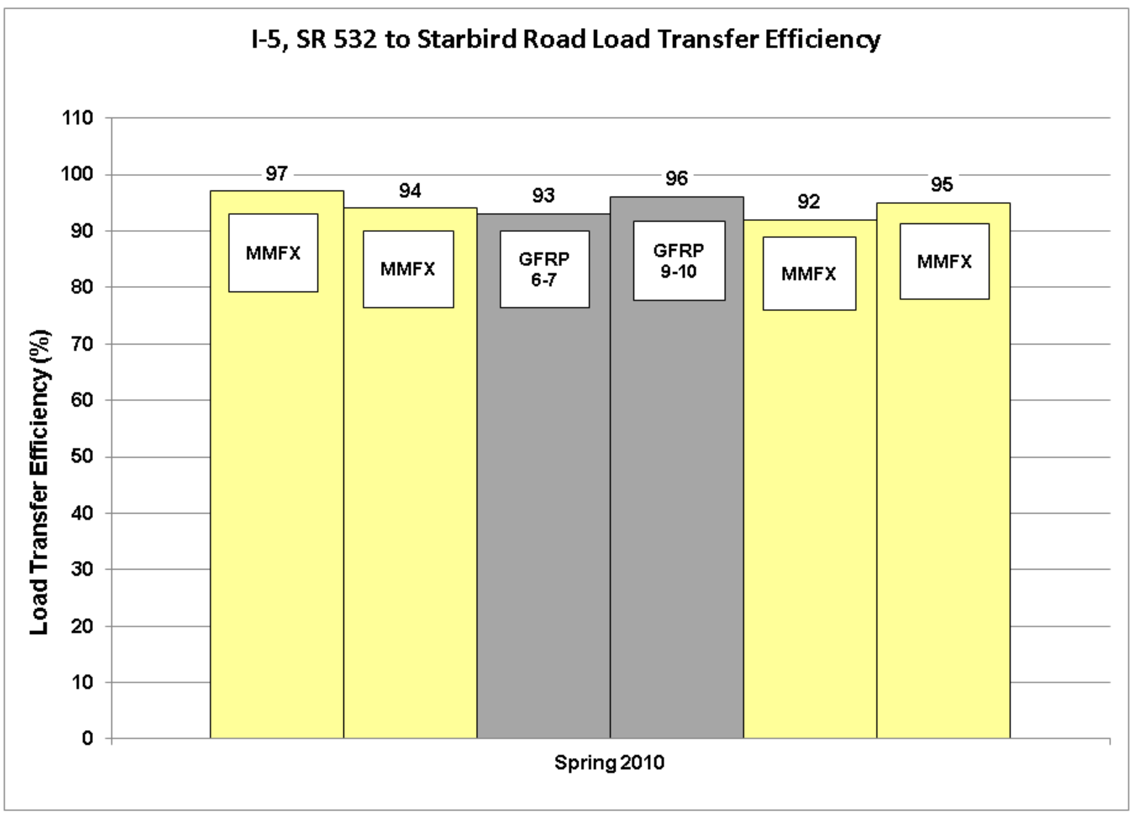

Figure 15. LTE for MMFX and GFRP dowel installed on I-5, SR 532 to Starbird Road.

The LTE's average 95 percent for both types of dowels which are high as would be expected for a new pavement. The LTE data does not indicate that the GFRP dowels are performing significantly different from the MMFX dowels.

I-82, Grandview to Prosser

The layout of the FWD testing sequence on the I-82, Grandview to Prosser project is shown in Figure 16. GFRP dowels were inserted into slots on Panels 6 and 7 with ASTM A 934 (purple) epoxy coated dowel bars used on the remainder of the project. The pavement temperature was 80° F at the time of the FWD testing on September 29, 2010. Results are shown in Figure 17. Note that only the FWD data from the pavement edge (0-31) are reported.

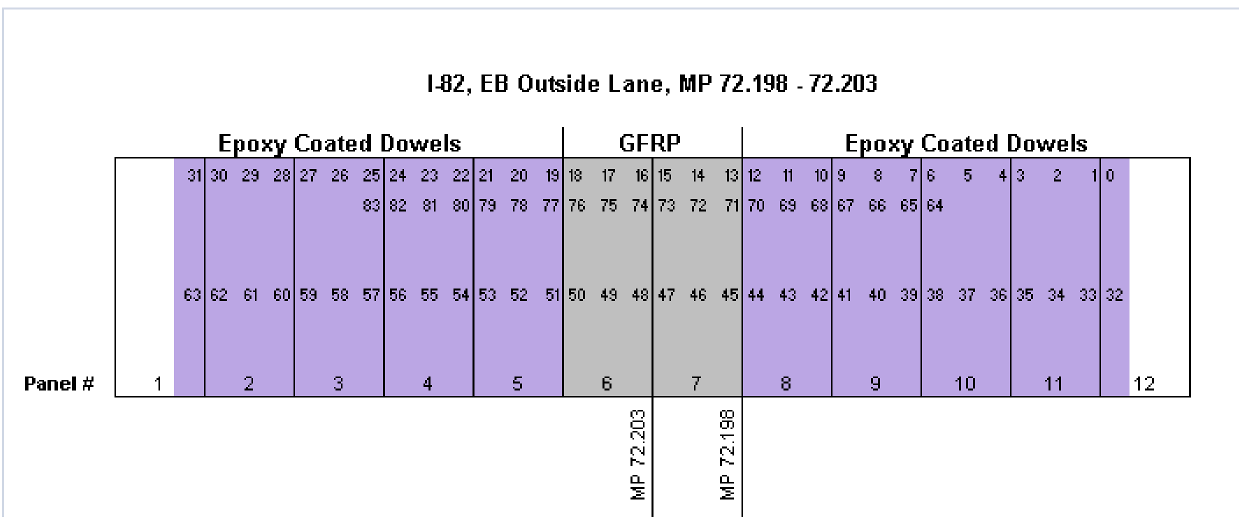

Figure 16. Plan map of I-82, Grandview to Prosser test section showing location of FWD tests.

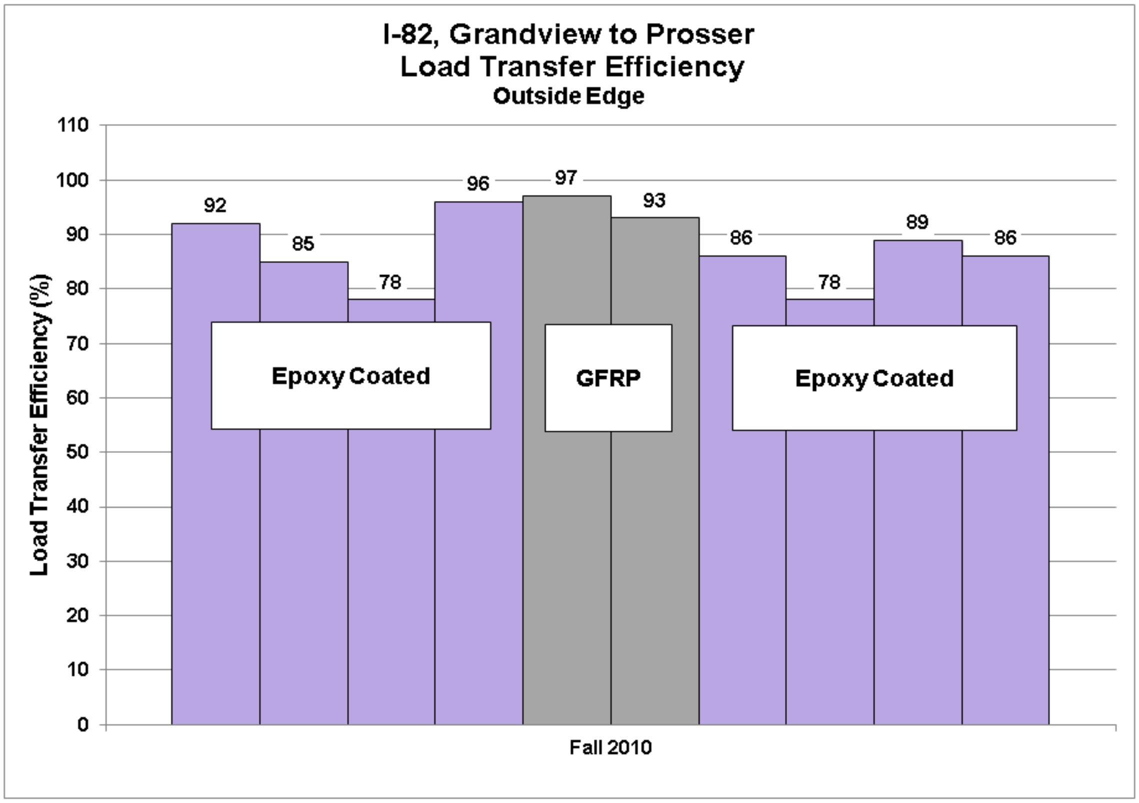

Figure 17. LTE for epoxy coated and GFRP dowels installed on I-82, Grandview to Prosser.

The LTE's are very high for both the epoxy coated and GFRP doweled joints. The LTE average for the epoxy coated dowels was 86 percent and for the GFRP dowels 95 percent which appears to be a significant difference, however, the sample size is so small that making any conclusions from a comparison would not be valid.

I-82, Yakima River Br Vic to Granger

The layout of the FWD testing of the installed dowel bars is shown in Figure 18. The GFRP bars were used on three test sections as shown in the gray color and ASTM A 934 (purple) epoxy coated dowel bars on three control sections as shown in purple. The FWD results for each joint are plotted in Figure 19. Testing was performed on March 28, 2012 when pavement temperatures between were 44° and 63° F.

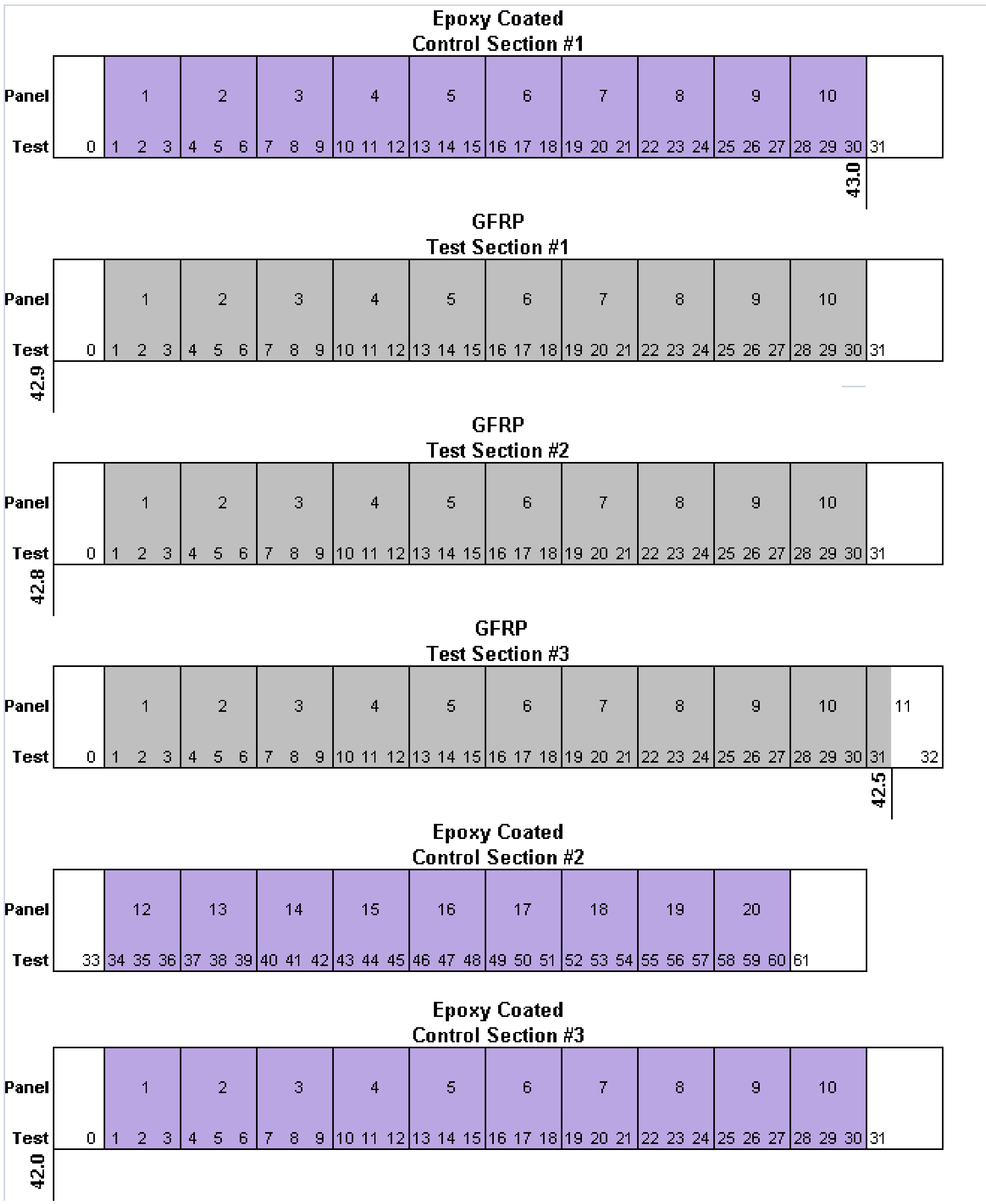

Figure 18. Post-installation FWD tests. Joints with epoxy coated bars are shown in purple, joints with GFRP bars are shown in gray.

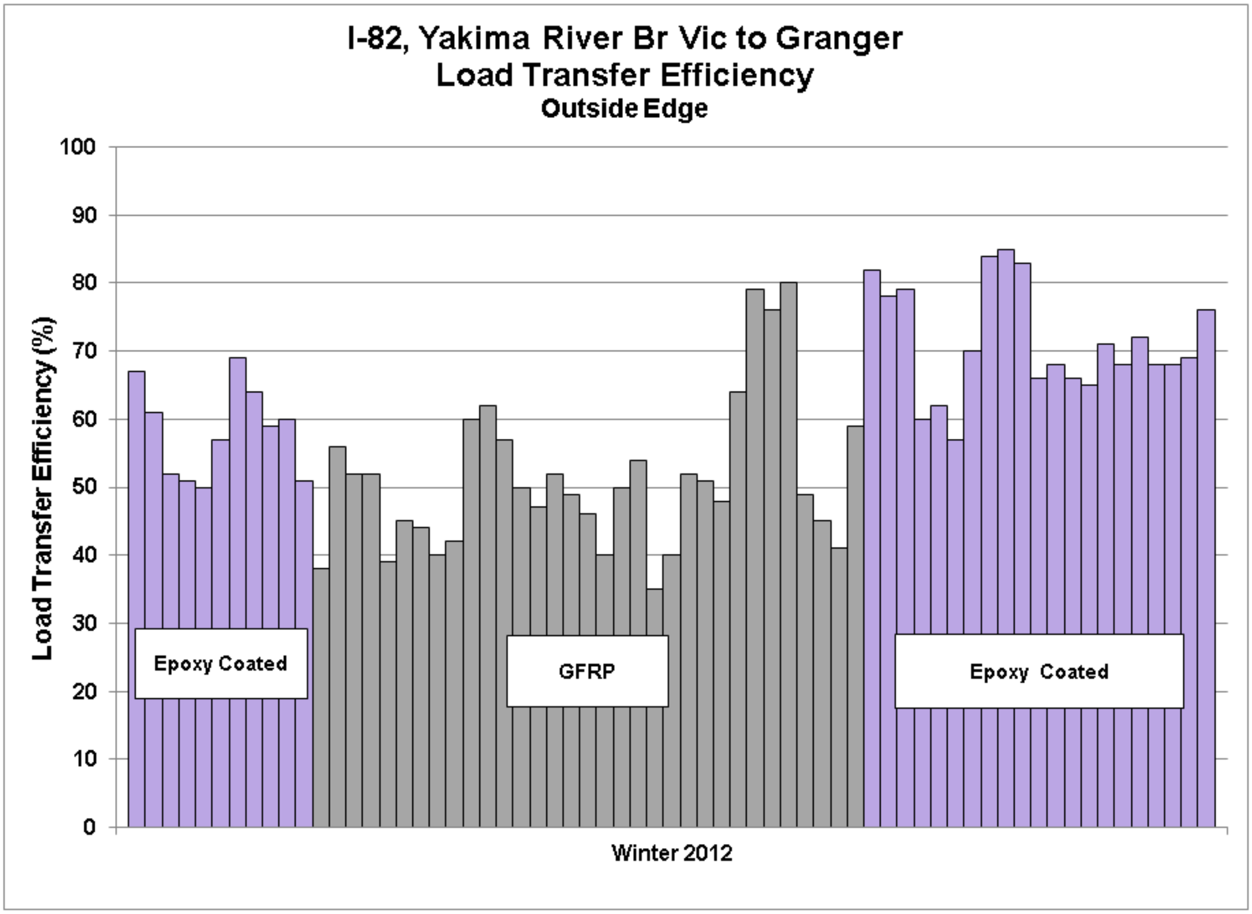

Figure 19. LTE for epoxy coated and GFRP dowel installed on I-82, Yakima River Bridge Vic. to Granger. Purple bars are for epoxy coated dowels, gray for GFRP dowels.

The average LTE of the GFRP dowels was 50 percent with a range of 35 to 80 percent and the average for the epoxy coated dowels was 67 percent with a range of 50 to 85 percent (Table 3). An analysis of the data revealed that there was a statistically significant difference between the mean value of the LTE's of the GFRP and epoxy coated dowels. This indicates that the epoxy coated dowels are currently outperforming the GFRP dowels with respect to load transfer efficiency. It is unclear at this time why LTE's for the GFRP dowels are lower than the epoxy coated dowels, but if this trend continues it might indicate that the GRRP dowels are not suitable for retrofit applications or that perhaps additional smaller diameter dowels spaced closer together is a better choice, as recommended in some of the literature.

Table 3. Comparison of LTE following retrofitting.

LTE for GFRP Joints (%)	LTE for Epoxy Coated Joints (%)
80	85
79	84
76	83
64	82
62	79
60	78
59	76
57	72
56	71
54	70
52	69
52	69
52	68
52	68
51	68
50	68
50	67
49	66
49	66
48	65
47	64
46	62
45	61
45	60
44	60
42	59
41	57
40	57
40	52
40	51
39	51
38	50
35	
Average = 50%	Average = 67%
Range 35 – 80%	Range 50 – 85%
Mean = 0.668	Mean = 0.510
Standard Deviation = 0.098	Standard Deviation = 0.112

A small sample of the joints where the GFRP and epoxy coated dowels would be installed was testing prior to construction (Table 4). Figure 20 shows the layout of the pre-installation tests. The panels shown in darker purple and darker gray are the joints that were tested on May 17, 2011 with pavement temperatures between 60 and 80° F.

The differences in the temperature of the pavement at the time of the pre-installation testing (60 to 80°F) versus the post-installation testing (44 to 63ºF) does not allow for a direct comparison of the pre and post-installation data. However, an analysis of the pre-installation LTE's indicated that there was no statistically significant difference between the mean values of the joints where the GFRP dowels were installed versus the joints which received retrofitting with the epoxy coated dowels. This indicates that the joints for both types of dowels were in relatively the same condition prior to retrofitting and negates the possibility that the pre-installation condition of the joints influenced the previously noted difference in post-installation LTE results.

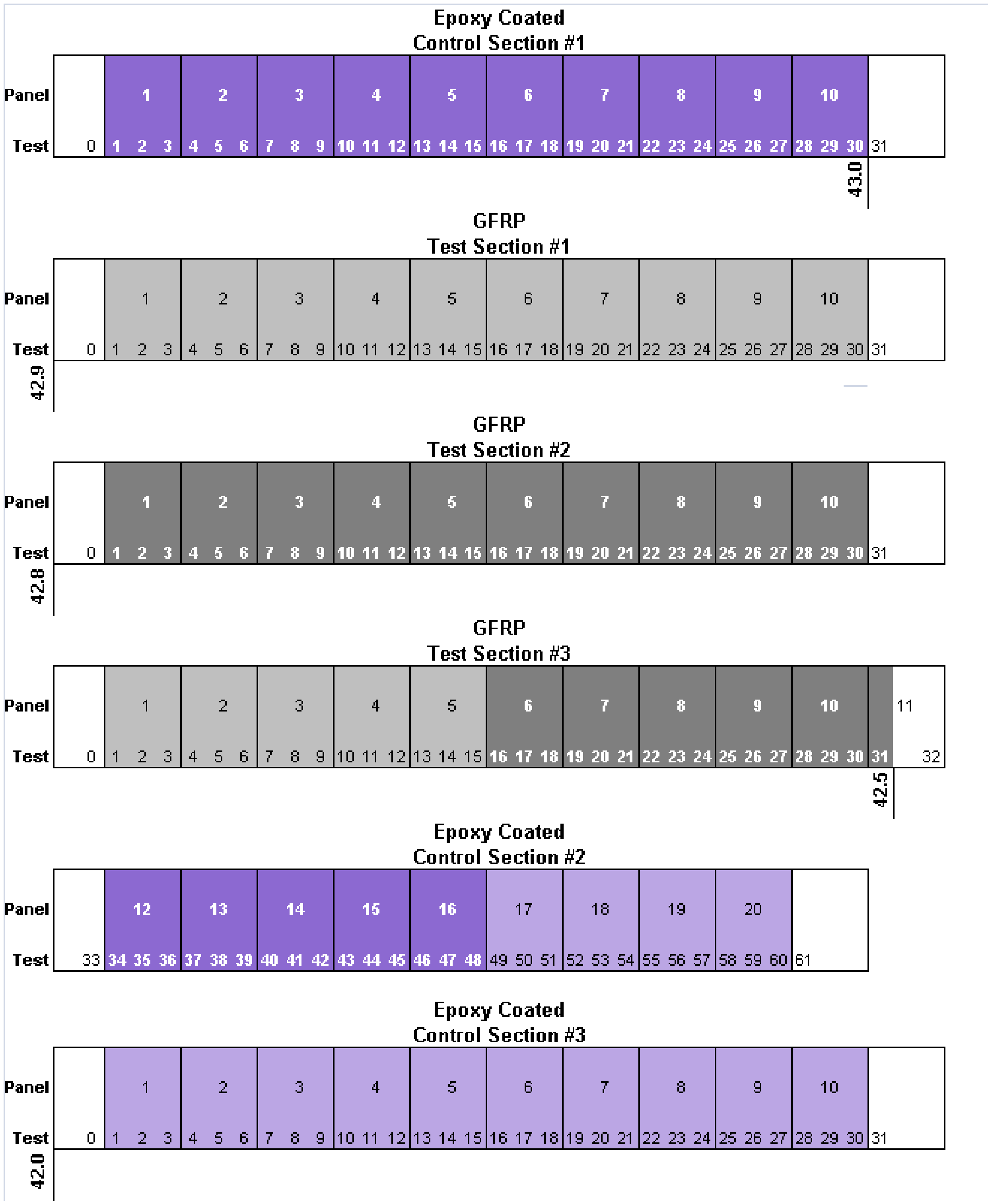

Figure 20. Location of pre-installation FWD tests.

Table 4. Comparison of mean LTE for joints prior to construction.	
LTE for GFRP Joints (%)	LTE for Epoxy Coated Joints (%)
83	89
78	63
73	63
69	61
61	60
59	57
59	57
57	57
57	55
55	53
53	52
47	52
46	52
45	49
45	48
43	47
39	
Mean = 0.572	Mean = 0.570
Standard Deviation = 0.099	Standard Deviation = 0.127

LTE Data Summary

A summary of the LTE data from each of the projects is shown in Table 5. Note that the I-5 project was new construction and the other two were dowel bar retrofits of existing pavement. The I-82, Yakima River Bridge Vic project is unique in that there is FWD data available prior to the installation of any dowel bars. There is no such data available for the other dowel bar retrofit project on I-82 and obviously no way to get such data on a new construction project.

Table 5. Summary of LTE data from projects.				
Project	**Test Date**	**Dowel Type**	**Pavement Temperature (ºF)**	**Average LTE (%)**
I-5, SR 532 to Starbird Rd.	5/12/2010	MMFX	60	95
		GFRP		95
I-82, Grandview to Prosser	9/29/2010	Epoxy Coated	80	86
		GFRP		95
I-82, Yakima R. B. Vic. to Granger	3/28/2012	Epoxy Coated	44-63	67
		GFRP		50

The average LTE were identical for both types of dowels on the I-5 project. The small sample size does not allow for in-depth statistical analysis. The LTE data for the I-82, Grandview to Prosser project indicated that the GFRP dowels were performing better than the epoxy coated dowels. Again the small sample size does not warrant extensive analysis at this time. Future data may show trends that may prove to be significant.

An analysis of the pre-construction FWD testing on the Yakima River Bridge Vicinity to Granger project indicated that there was no difference in the LTE of the existing joints between the areas retrofit with epoxy coated dowels versus the areas retrofit with the GFRP dowels. The initial measurement of the LTE's of the retrofit joints indicated that there was a statistically significant difference in the performance of the epoxy coated versus the GFRP dowels.

Summary of Observations

The following observations were made concerning the installation and performance of the GFRP dowel bars in the three trial installations:

- No installation problems were noted in the two smaller trial projects on I-5 and I-82.
- Floating of some bars was noted in the larger Yakima River Bridge Vicinity to Granger project.
- Movement of the foam insert and sticking of the concrete to the dowels were problems noted in the Yakima River Bridge Vicinity to Granger project.

- The load transfer efficiencies of the GFRP dowels and MMFX and epoxy coated dowels were very close in the two smaller projects.
- The load transfer efficiencies of the GFRP dowels were statistically lower than the LTE's of the epoxy coated dowels in the Yakima River Bridge Vicinity to Granger project. (Pre-installation testing did not note any difference in the LTE's of the joints where the GRFP and epoxy coated dowels were to be installed).

Future Research

As indicated previously, the three sections with GFRP dowels will be monitored using the FWD to measure any deterioration of the load transfer efficiency of the joints. The joints at the location of the dowels will be cored periodically to determine the condition of the both the epoxy coated and the GFRP dowels as they are exposed to traffic, the environment and deicing chemicals.

References

Bian, Y., Harvey, J., and Ali, A. 2006. "Construction and Test Results on Dowel Bar Retrofit HVS Test Sections 556FD, 557FD, 558FD and 559FD: State Route 14, Los Angeles County at Palmdale," University of California Pavement Research Center UC Davis and Berkeley, UCPRC-RR-2006-02, March 2006.

Brown, V.L. and Bartholomew, C.L. 1993. "FRP Dowel Bars in Reinforced Concrete Pavements," Proceedings of the International Symposium on FRP Reinforcement for Concrete Structures, ACI.

Cable, J.K., and Porter, M.L. 2003. "Demonstration and Field Evaluation of Alternative Portland Cement Concrete Reinforcement Materials," Final Report, Iowa DOT Project HR-1069, Iowa Department of Transportation, Ames, Iowa, June 2003.

Crovetti, J.A. 1999. "Cost-Effective Concrete Pavement Cross-Sections." Report No. WI/SPR 12-99. Wisconsin Department of Transportation. Madison, WI.

Eddie, D., Shalaby, A., and Rizkalla, S. 2001. "Glass Fiber-Reinforced Polymer Dowels for Concrete Pavements," American Concrete Institute Structural Journal, Vol. 98, No. 2.

FHWA 2006. ”High Performance Concrete Pavements – Project Summary,” Office of Infrastructure, Office of Pavement Technology, Washington, DC., FHWA-IF-06-031, February 2006.

Mateen-Bar™ 2005. ”The Ultimate Reinforcement for Concrete in Challenging Applications,” Pultron Composites Ltd., New Zealand.

McWatters, Ashley. 2010. “Putting It All Together,” Sigma DB Corporation, Vancouver Washington, November 19, 2010.

Pavement Interactive. 2007. “Load Transfer,” Publish Date: August 15, 2007.

Porter, M.L., Guinn, Jr., R.J., Lundy, A.L., Davis, D.D., and Rhner, J.G. 2001. “Investigation of Glass Fiber Composite Dowel Bars for Highway Pavement Slabs,” Project No. TR-408, Iowa State University.

Shalaby, A., and Murison, S. 2001 “Using Fiber-Reinforced Polymer Load Transfer Devices in Jointed Concrete Pavements,” 7th International Conference on Concrete Pavements – Orlando, FL, September 9-13, 2001.

Snyder, M., 2011. “Guide to Dowel Load Transfer Systems for Jointed Concrete Roadway Pavements,” Institute for Transportation, Iowa State University, Ames, IA., September 2011.

Vijay, P.V., GangaRao, H.V.S., and Li, H. 2009. “Design and Evaluation of Jointed Plain Concrete Pavement with Fiber Reinforced Polymer Dowels,” FHWA-HRT-06-106, Office of Research and Technical Services, Federal Highway Administration, Mclean, VA., September 2009.

Appendix A

Experimental Feature Work Plan

Washington State Department of Transportation

WORK PLAN

Mateen Fiber Reinforced Polymer Dowel Bars

I-82
Yakima River Bridge to Granger Dowel Bar Retrofit and Concrete Rehab
Milepost 38.62 to Milepost 57.87

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Introduction

In order to achieve the long-term pavement performance life of a concrete pavement, there is an ever-increasing need to ensure that each of the materials in the concrete pavement structure is adequately designed such that a 50-year or more pavement life can be obtained. WSDOT has demonstrated that the concrete pavements constructed in the late 1950's to early 1960's are able to obtain a 50-year or more pavement life as long as joint faulting can be overcome and the effects of studded tire effects can be minimized. The studded tire issue is outside the scope of this study and will not be further discussed in this experimental feature. The ability to provide adequate joint design to minimize joint faulting is being addressed by including dowel bars (1-1/2 by 18") at each transverse (contraction or construction) joint.

However, the use of dowel bars both locally and nationally does not necessarily ensure that a 50-year performance life will be obtained. Several states have observed that the corrosion of epoxy coated dowel bars occurs within 15 to 20 years. Therefore, it is desirable to obtain and use dowel bars that have the ability to offset the effects of corrosion. WSDOT PCC pavements are designed to last 50 years, so it is critical that the dowel bars also survive, intact and functional, for this period.

The use of Mateen Fiber Reinforced Polymer (FRP) Dowel bars is recommended as a 1000 foot test section for dowel bar retrofit placement on this project. While the project does not encompass new PCCP construction the placement of Mateen dowels allows WSDOT to evaluate both the construction and performance aspects of this product.

Currently, Sigma Development Group is the only source for the Mateen dowel bars. A few brief facts on Mateen dowel bars[1] follows:

Mateen Dowels are non-corrosive dowel bars composed of epoxy backboned vinyl ester resin and ECR glass, with glass content above 70%. Using this matrix of materials provide for shear strength above 400kN, moisture absorption below 0.1%, and high glass transition temperature above 100 C.

Plan of Study

The purpose of this experimental feature is to use Mateen Fiber Reinforce Polymer Dowel bars within each dowel bar retrofit slot (6 per transverse joint) for a 1,000 foot test section. Approximately 67 transverse joints will be retrofitted.

Scope

This project will require the use of 400 dowel bars placed as part of this dowel bar retrofit project.

Construction Procedure

The use of this product does not require special construction techniques.

Layout

Dowel bars will be placed in the test section according to WSDOT Standard Specifications and Standard Plan 60.20-01.

Staffing

No additional staffing is required.

[1] Information obtained Sigma Development Group

Testing

The South Central Region will core periodically to determine the condition of dowel bars. No set schedule has been established. As a minimum, cores will be taken at 5-year cycles. Likely, cores will be taken for informational purposes 1 year and a needed after construction.

Reporting

Since the only difference in this experimental feature is the use of the FRP instead of epoxy coated dowel bars, immediate reporting is not necessary. Any construction experience will be noted and incorporated into Special Provisions, Standard Specifications and Standard Plans, as necessary. Following any future coring, results will be summarized and shared within WSDOT and the FHWA.

Cost Estimate

<u>CONSTRUCTION COSTS</u>

Description	Quantity	Unit Cost	Unit	Total Price
Mateen FRP Dowels	400	$8.00	Each	$3,200
Total				**$3,200**

<u>TESTING COSTS</u>

Periodic Coring: $1,500

<u>REPORT WRITING COSTS</u>

No additional report writing costs. Any costs are minimal.

TOTAL COST = $4,700