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Glass Fiber-Reinforced Polymer Dowels for Concrete Pavements

by Darren Eddie, Ahmed Shalaby, and Sami Rizkalla

Corrosion of steel dowels in concrete pavements reduces their useful service life and creates considerable maintenance and repair expenditures for concrete pavements. Glass fiber-reinforced polymer (GFRP) dowel bars are a possible maintenance-free alternative that will potentially reduce the overall life cycle cost of pavements, especially in corrosive environments. This paper describes the performance of GFRP dowel bars under static and cyclic loads. Dowels were used for a slab/joint model tested under laboratory conditions. The test variables included two different base support levels and two GFRP dowel types in addition to standard epoxy-coated steel dowels. GFRP dowels with a 38 mm diameter were used in this study to replace the 32 mm diameter epoxy-coated steel dowels. This paper also discusses the results of a field application in which three types of GFRP dowels were installed in a new concrete pavement highway in Winnipeg, Manitoba, Canada. The field performance of doweled joints has been verified under dynamic load testing.

Keywords: concrete; dowel; fiber; load transfer; pavement (concrete); polymer; transverse joint.

INTRODUCTION

Transverse joints are introduced in concrete pavements to relieve thermal stresses. A common practice is to use dowels across these joints to transfer the load across the joint and reduce the relative displacement under traffic loads at the joint location.^{1,2} Currently, smooth epoxy-coated steel dowels are placed across transverse joints to transfer traffic loads while allowing for in-plane slab movement caused by thermal expansion and contraction. Due to the nature of the loading, dowels transfer loads by bearing on the surrounding concrete.^{3,4} A loss of contact between the concrete and dowel results in dowel looseness and a reduction in the ability of the dowel to transfer loads that will trigger expensive and untimely maintenance to restore the load transfer.

Steel dowels currently used in concrete pavements may cause severe deterioration of the concrete due to the expansion of steel during the corrosion process. The deterioration usually results in faulting, spalling, or cracking of the concrete. Glass fiber-reinforced polymer (GFRP) dowels are a corrosion- and maintenance-free alternative that can potentially extend the service life of concrete pavements.

GFRP dowel bars have an exceptionally high tensile strength in the direction of the fibers and a relatively low strength in the perpendicular direction. Previous research^{5,6} demonstrated the feasibility of using round GFRP dowels by using laboratory scale models. To study the behavior of GFRP dowels and compare their behavior to conventional epoxy-coated steel dowels, an experimental program was conducted at the University of Manitoba. Twelve full-scale models, each consisting of two slabs and a doweled joint, were tested. Each joint included two dowels of either GFRP or conventional epoxy-coated steel. The slab/joint system

was placed on a simulated base layer that provided two levels of stiffness.

The specimens were tested under static and cyclic loading conditions using a servohydraulic loading system. Nine slabs were tested to determine the joint effectiveness under static loads, while the remaining three slabs were tested under cyclic loading to investigate long-term effects.

RESEARCH SIGNIFICANCE

This paper presents laboratory and field results on the performance of GFRP dowel bars used in transverse joints of concrete pavements. The study included static and cyclic laboratory testing in addition to field testing using the falling weight deflectometer. Three types of GFRP were tested in addition to epoxy-coated steel. The paper provides information on load transfer in pavements and the feasibility of using GFRP in this application.

JOINT EFFECTIVENESS AND DESIGN ASPECTS

The American Concrete Pavement Association (ACPA)^{7,8} uses joint effectiveness to measure the performance of joints. Joint effectiveness is based on the measured deflections of the loaded and unloaded sides of the joint as given in Eq. (1). A joint is considered to be 100% effective if the deflections on both sides of the joint are equal, or 0% effective if the unloaded side is experiencing no deflection at any load level. ACPA recommends that a pavement joint is considered adequate if the effectiveness is 75% or greater.

$$E = \frac{2d_u}{d_l + d_u} \times 100 \quad (1)$$

where E is the joint effectiveness, d_u is the deflection of the unloaded slab, and d_l is the deflection of the loaded slab.

The three design elements for dowels are spacing, length, and diameter. Due to the flexibility of the subgrade, the load is not transferred by a single dowel but rather under a group action.⁹ The proportion of load transferred by individual dowels in a group is a function of the proximity of the dowel to the applied load and the stiffness of the slab and base support. It is generally accepted that 1/2 of the tire load will be transferred through this action. Because dowels are usually placed at 300 mm center-to-center spacing, the maximum expected tire load is in the range of 30 kN per dowel (or 60 kN

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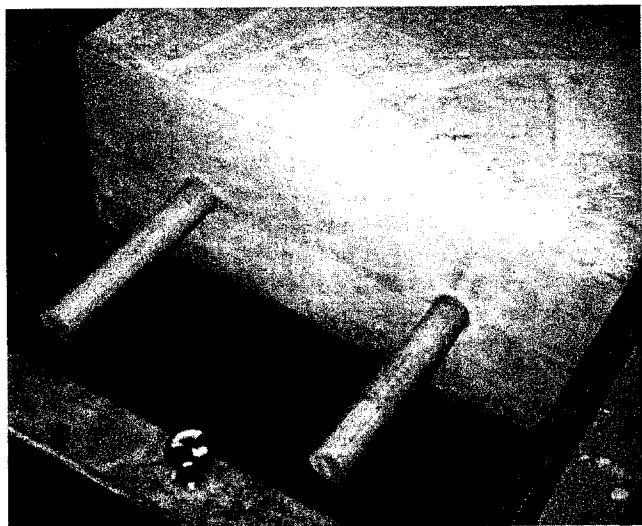


Fig. 1—Construction joint prior to casting of adjacent slab.

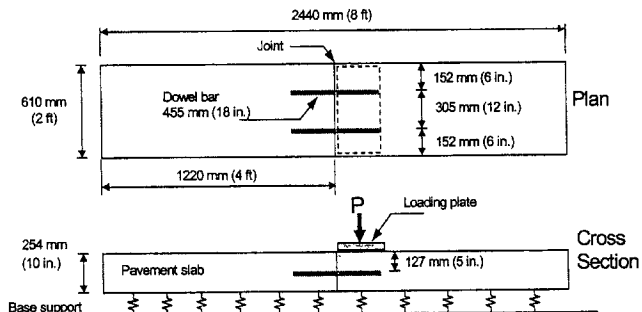


Fig. 2—Laboratory test configuration showing two concrete slabs and doweled joint.

per joint for the slab/joint system used in this experimental program) without dynamic effects or dowel group action.

EXPERIMENTAL PROGRAM

The laboratory testing consisted of manufacturing and loading 12 jointed pavement slabs. All slabs were cast with a butted joint and each test specimen contained two dowel bars, as shown in Fig. 1. Figure 2 provides details of slab geometry. Two types of GFRP were tested in addition to control specimens consisting of epoxy-coated steel dowels. Two levels of base support were implemented: a weak support provided by a matrix of steel springs, and a stiff support provided by limestone aggregates. A summary of the testing program is provided in Table 1. The shear strength of the GFRP and steel dowels was also determined by testing individual bars in double shear and is given in Table 2. Table 2

Table 1—Experimental testing program

Phase	No. of specimens	Base support	Test method
Phase I	1 epoxy-coated steel	Steel springs	Monotonic to failure
	1 GFRP-Type 1		
	1 GFRP-Type 2		
Phase II	2 epoxy-coated steel	Limestone aggregate base	Monotonic to 300 kN, unloading, monotonic reloading to failure
	2 GFRP-Type 1		
	2 GFRP-Type 2		
Phase III	1 epoxy-coated steel	Limestone aggregate base	Cyclic to 1 million cycles
	1 GFRP-Type 1		
	1 GFRP-Type 2		

Table 2—Summary of dowel double shear tests

Dowel type	Dowel diameter, mm	No. of samples	Ultimate double shear load, kN	Shear strength, MPa	
				Mean	Standard deviation
Epoxy-coated steel	31.75	3	901	570.00	8.8
GFRP-Type 1	38.10	3	244	107.00	3.8
GFRP-Type 2	38.10	3	343	150.00	3.2
GFRP-Type 3	38.10	3	231	101.30	3.1

also includes the properties of a third GFRP material, GFRP Type 3, which was not part of the experimental program but was part of the field trial presented in this paper. The GFRP dowels were produced by three different U.S. manufacturers that used the pultrusion process. The three types of GFRP dowels contained unidirectional (longitudinal) E-glass fibers and a polyester resin with a fiber content of 65 to 70%.

To simulate weak subgrade, the slab/joint system is supported by steel springs with a stiffness (base modulus) of 3.6 MN/m^3 , as shown in Fig. 2. In the case of stiff subgrade, a base layer of limestone aggregates was prepared and compacted in three 100 mm layers. The stiffness modulus of the base was determined from plate loading tests.^{9,10} Based on the measured values, an average of 133.3 MN/m^3 is used for all the tests employing aggregate base. Because significant crushing of the limestone base took place, especially near high load levels, the base layer was replaced at the end of each test. The crushing and compaction was more evident in the zone closer to the loading plate, while no further compaction occurred away from the load as the slab ends were lifting away from the base.

The load was applied through a servohydraulic closed-loop testing system with a capacity of 5000 kN. The loading frame applied monotonic or repeated loading on one side of the joint through a footprint of 600 x 250 mm. The footprint of the load is selected so that loads higher than the actual axle loads can be applied uniformly to the entire width of the test specimen, simulating a dual tire configuration and that ultimate failure can be limited to the dowels and load transfer mechanism. The test specimens were instrumented with linear variable differential transducers (LVDTs) and dial gages to measure vertical and horizontal displacements.

TEST RESULTS

Phase I: static tests using weak base

This condition represents weakening of the base support at the location of the joint due to base erosion and pumping. The base support modulus was determined to be 3.6 MN/m^3 . Performance of the three types of dowels was governed by failure of the concrete slabs due to excessive deformations rather than

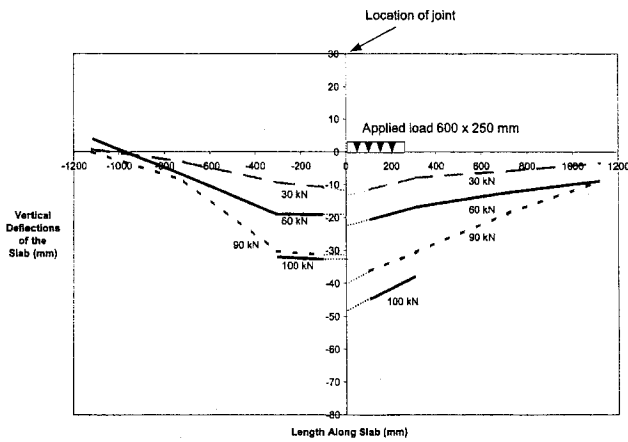


Fig. 3—Recorded vertical displacement along slabs: Phase I.

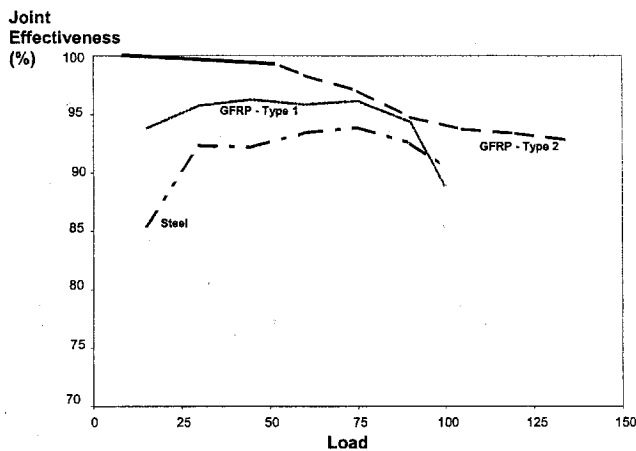


Fig. 4—Joint effectiveness of slabs under static loading and using weak subgrade: Phase I.

failure of the dowel bars. The load-versus-displacement between the loaded and unloaded slabs is shown in Fig. 3.

To determine the effectiveness of the dowels, the deflection of each of the loaded and unloaded slabs is required according to Eq. (1). Figure 4 illustrates the load transfer effectiveness over the loading range. The tests were terminated as the loads approached 100 kN, due to slab failure, and the joint effectiveness of all types of dowels tested was in the range of 86 to 100%, as shown in Fig. 4. Observed failure mode was due to crushing of the concrete at the joint following closure of the joint opening and the cracking of the concrete under the loading plate.

Phase II: static tests using stiff base

The second phase of this program included testing two replicate slab/joint specimens of each of the three types of dowel materials used in Phase I. The slabs were supported by a 300 mm compacted, well-graded limestone base placed on the strong floor of the laboratory. The modulus of base support was determined from plate loading tests and corresponded to an average of 133.3 MN/m^3 . The test setup is shown in Fig. 5. The effectiveness of the joints ranged from 90 to 97% up to a load of 300 kN, as shown in Fig. 6.

All six slabs experienced concrete crushing following closing of the joint opening at loads in excess of 200 kN. With the joint opening closed and the two faces of the joint

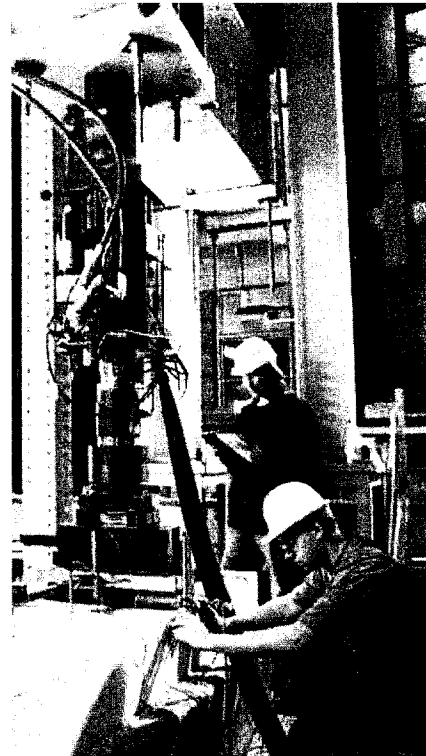


Fig. 5—Taking measurements during test.

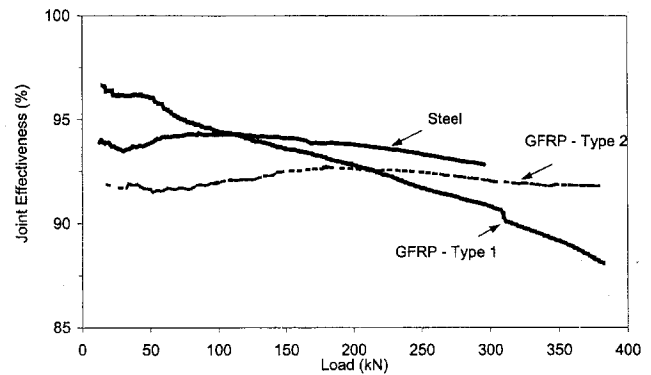


Fig. 6—Joint effectiveness of slabs under static loading and using stiff subgrade: Phase II.

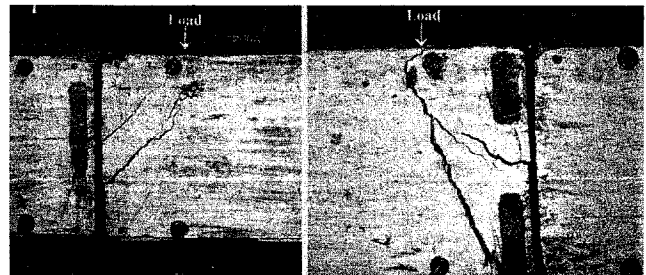


Fig. 7—Cracking and crushing of concrete on both sides of loaded slab.

bearing against each other, the dowel experienced excessive bending. The biaxial compression under the loading plate from the load footprint and the bearing stresses caused spalling of the joint faces, as shown in Fig. 7.

The results suggest that 38 mm GFRP dowels provide comparable effectiveness to 32 mm steel dowels under static loading conditions. Reductions of the effectiveness of the joints using GFRP-Type 1 dowels at loads well above ser-

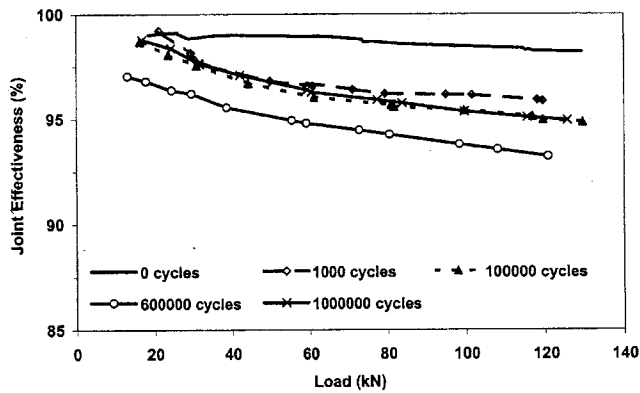


Fig. 8—Joint effectiveness of steel dowel slab under cyclic loading: Phase III.

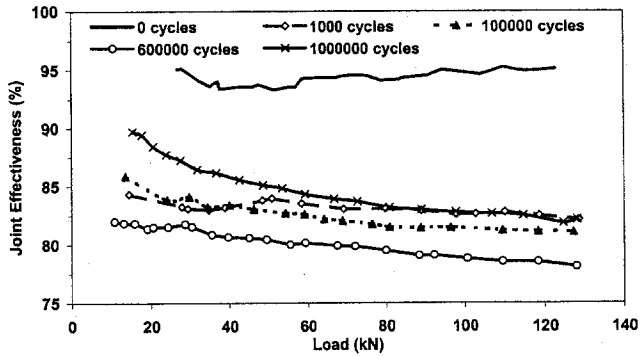


Fig. 9—Joint effectiveness of GFRP-Type 1 dowel slab under cyclic loading: Phase III.

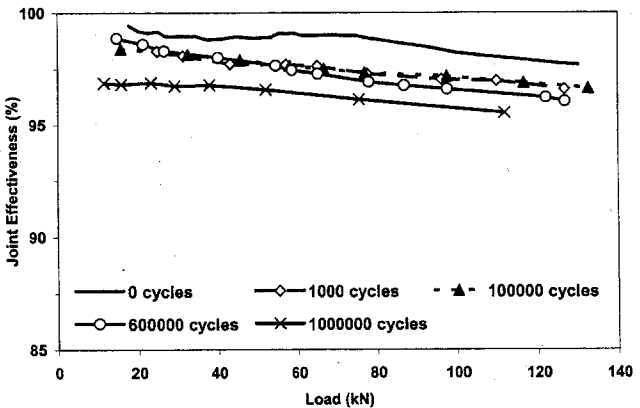


Fig. 10—Joint effectiveness of GFRP-Type 2 dowel slab under cyclic loading: Phase III.

vice levels were noticeable in comparison to GFRP-Type 2 and steel dowels that maintained consistent load transfer throughout the test. All of the dowels, however, showed an acceptable load transfer up to the failure of the concrete slabs at load levels far exceeding service conditions.

Phase III: cyclic tests

Three slabs were tested in Phase III to 1 million cycles. The load followed a sinusoidal waveform that varied between 20 and 130 kN at a frequency of 6 Hz. The minimum load was required to maintain contact between the slab and loading plate and minimize impact loading and degradation of base support. This is a closer representation of field conditions where the load is applied and removed gradually as

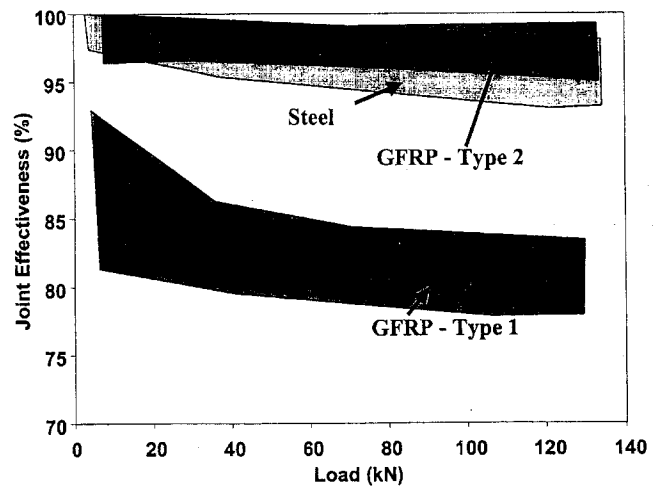


Fig. 11—Range of joint effectiveness versus load: Phase III.

the vehicle approaches the joint or moves away. Due to the degradation of the base following the load cycling, a newly compacted granular base was used at the beginning of each test. Before cycling, as well as after predetermined sets of cycles, the load cycling was interrupted and a monotonic loading test was conducted to assess the joint performance at different stages of service life.

The joint effectiveness of the steel-doweled slab over 1 million cycles is shown in Fig. 8. The initial joint effectiveness at 0 cycles exceeded 98%. Subsequent tests indicated slightly lower effectiveness between 94 to 97%, which can be attributed to further base compaction or dowel looseness.

The joint effectiveness of the GFRP-Type 1 slab is illustrated in Fig. 9. Test results indicate a substantial reduction of effectiveness in the range of 10% was experienced at the onset of load cycling. The range of joint effectiveness experienced for the GFRP-Type 1 slab was 80 to 90%. Although the effectiveness remained above the 75% acceptability level, it is significantly lower than the effectiveness of the steel dowels.

The joint effectiveness of the GFRP-Type 2 doweled slab over 1 million cycles of loading is shown in Fig. 10. The joint effectiveness was found to be above the 95% level. The overall range of joint effectiveness for steel GFRP-Type 2 and GFRP-Type 1 are shown in Fig. 11.

The slabs in Phase III were tested under service loads. Only hairline cracks were observed and all slabs remained intact after 1 million loading cycles. In all three cyclic tests, an apparent small increase in joint effectiveness was observed as the load cycling approached 1 million cycles. Because of the accelerated nature of the laboratory test, base erosion and pumping are not considered. Continued cycling resulted in further compaction of the base layer that contributed to the slight increase in joint effectiveness. This condition, however, is not observed in field performance, as the environmental effects cause much higher damage to the pavement base course.

Discussion

The static and cyclic laboratory testing demonstrated that GFRP dowels with a 38.1 mm diameter are acceptable for use as load transfer devices, replacing the 31.75 mm epoxy-coated steel. It is recognized that the larger GFRP dowel diameter and lower elastic modulus of GFRP will reduce bearing stresses between the dowel and concrete support, and therefore reduce

Table 3—Sequence for testing load transfer

Type of dowels	Drop height	No. of tests per pavement joint	No. of completed tests	Mean of peak contact pressure, kPa	Standard deviation of peak contact pressure, kPa	Coefficient of variation, %
Epoxy-coated steel	DH1 (low)	4	10	414.02	6.25	1.51
	DH2	4	10	577.42	10.20	1.77
	DH3 (high)	2	10	834.80	10.14	1.21
GFRP-Type 1	DH1	4	10	410.25	5.85	1.43
	DH2	4	10	571.17	6.79	1.19
	DH3	2	10	828.45	10.27	1.24
GFRP-Type 2	DH1	4	10	412.35	5.23	1.27
	DH2	4	10	570.67	4.35	0.76
	DH3	2	10	830.40	7.80	0.94
GFRP-Type 3	DH1	4	8	410.78	3.41	0.83
	DH2	4	8	567.25	6.19	1.09
	DH3	2	8	824.25	4.04	0.49

Note: Mean of peak applied load at Drop Height DH1 = 29.1 kN (6.4 kips); Drop Height DH2 = 40.4 kN (8.9 kips); and Drop Height DH3 = 58.6 kN (12.9 kips). Total number of tests = 380 tests.

the dowel looseness or faulting. In particular, GFRP-Type 2 performed satisfactorily in both static and cyclic tests.

FIELD APPLICATION

The field application involved the use of three brands of GFRP dowels in the construction of a new concrete highway pavement along Bishop Grandin Boulevard in Winnipeg, Manitoba. The two types of GFRP tested in the laboratory were used in addition to a third type, GFRP-Type 3 dowels, that were not available during the laboratory testing program and were only tested in double shear. The test data in Table 2 indicate lower shear strength for GFRP-Type 3 in comparison to the other two GFRP dowels. A total of 780 38.1 mm dowels were used for the 30 test joints constructed with GFRP dowels. Figure 12 illustrates the pavement construction utilizing the GFRP dowels. The GFRP dowels were supported by a typical steel basket assembly, which allowed for the dowel to be slid in one end, but restrained by a finger pin on the other. During casting, the parallel alignment of the dowels was monitored and corrected if a dowel became misaligned. The joints at the dowel locations were saw-cut within a few hours after casting and allowed to crack due to thermal contraction and shrinkage.

The falling weight deflectometer (FWD)⁹ is a nondestructive field test that involves applying impact loads to the pavement surface and monitoring the pavement deflection response through a series of velocity transducers placed on the pavement at specified distances from the load, as illustrated in Fig. 13. To simulate moving axle loads, the FWD load is applied by releasing a mass from a selected height to impact the road surface. The mass of the dropped load and the height from which the drop is made determine the peak contact pressure applied to the road surface. FWD testing was conducted on the trial section in May 1999, approximately 8 months after the road was opened to traffic. The testing program included two repetitions from each of the two smaller drop heights (DH1 and DH2) and only one drop from the largest height (DH3). Tests were made in the outer wheel path of the driving lane as close as possible to the joint. One-half of all tests were performed on the approach slab and the remaining tests were performed on the leave slab. For the purpose of analysis, no distinction is made between the two loading cases. In total, 380 FWD drops were successfully completed and reported.

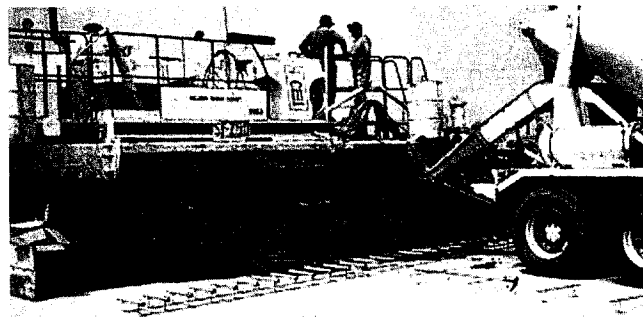


Fig. 12—Casting of GFRP dowels into Bishop Grandin Boulevard.

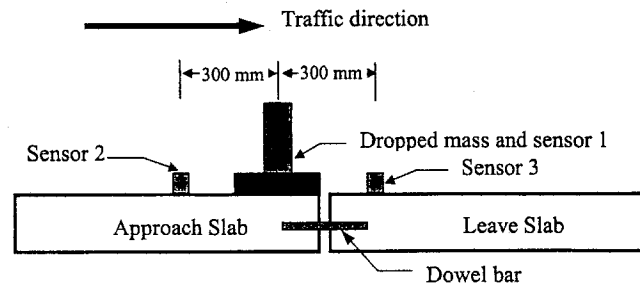


Fig. 13—In-place testing of load transfer using FWD device.

The distributions of applied contact pressures from the three drop heights, DH1, DH2, and DH3, are shown in Table 3. The radius of the loading plate is 150 mm, and as such, the peak applied dynamic load averaged 29.4, 40.4, and 58.6 kN (6.4, 8.9, and 12.9 kip) at DH1, DH2, and DH3, respectively. The peak applied dynamic loads were consistent and repeatable with a coefficient of variation of 0.49 to 1.77%. In this analysis, the coefficient of variation (COV) is the percent ratio of the standard deviation to the mean.

A summary of joint effectiveness data for all joints is shown in Fig. 14. Although all joints performed adequately, it is evident that the effectiveness of the GFRP-Type 3 dowels is lower than the remaining types. The GFRP-Type 2 and GFRP-Type 1 matched or slightly exceeded the effectiveness of steel dowels. The deflections measured under the loading plate indicate that the steel dowels provide a higher

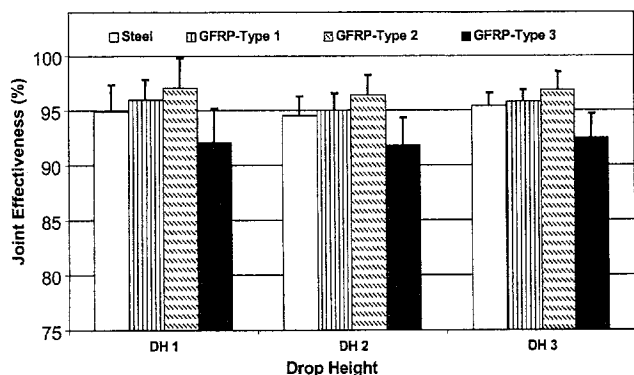


Fig. 14—Mean and standard deviation of joint effectiveness of all joints from three drop heights: DH1 = Drop Height 1; DH2 = Drop Height 2; and DH3 = Drop Height 3.

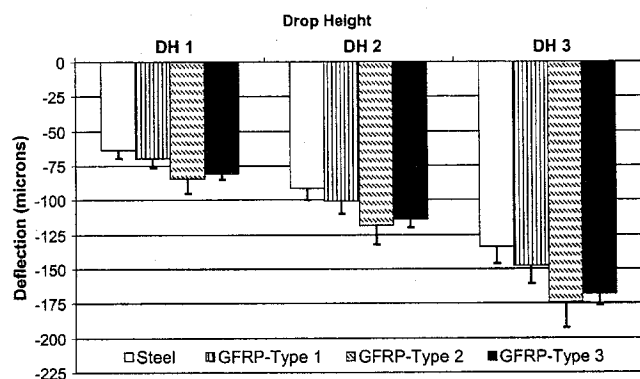


Fig. 15—Mean and standard deviation of deflections at center of loading plate: DH1 = Drop Height 1; DH2 = Drop Height 2; and DH3 = Drop Height 3.

joint stiffness and, therefore, significantly lower deflections are experienced in comparison to all the GFRP dowels, as shown in Fig. 15. The peak deflections under the center of the loading plate of the three types of GFRP joints are higher than those of steel-doweled joints by 10 to 30%, as given in Table 4. It should be mentioned, however, that there is no common standard for limiting the deflections other than ratios of load transfer efficiency or joint effectiveness.

The laboratory and field testing presented in this paper demonstrated that 38 mm GFRP dowels can match the performance of 32 mm epoxy-coated steel dowels. Although the GFRP dowels have lower shear strength, the increase in dowel diameter from 32 to 38 mm results in lower bearing stresses between the dowel and concrete, and hence, an equivalent performance to the steel dowels. Because the tests were performed after only 8 months of service traffic and the load transfer ratios do not show appreciable difference at this time, it will be necessary to collect longer-term data. A period of 2 to 5 years of service will be required to establish the environmental and traffic effects on the performance of GFRP dowels.

CONCLUSIONS

GFRP dowels are a viable, corrosion-free alternative to steel dowels. Test results at the laboratory level using two GFRP dowel types, as well as a field application using three types of GFRP, indicate similar performance of GFRP as dowels for concrete pavements in comparison to steel dowels. The study included static and cyclic loading tests using a full-scale model of concrete pavement slab/joint system. The lab-

Table 4—Ratio of average GFRP to steel peak slab deflections at center of loading plate

Drop height	Deflection ratio by type of dowel		
	GFRP-Type 1/steel	GFRP-Type 2/steel	GFRP-Type 3/steel
DH1	1.09	1.32	1.26
DH2	1.11	1.30	1.25
DH3	1.11	1.30	1.25

oratory testing showed that joint effectiveness or load transfer efficiencies are acceptable. The GFRP with relatively higher shear strength (GFRP-Type 2) resulted in a better performance than GFRP-Type 1. Under dynamic (impact) field testing, the three tested types of GFRP dowels exhibited higher joint deflections (lower joint stiffness) than steel dowels. Once again, the performance is consistent with the shear strength of these dowels. Presently, there is no design provision for limiting deflections at joints. Although higher deflections are typically associated with loss of support and shorter pavement service life, this may not be the case for GFRP. In fact, the lower flexural stiffness modulus of GFRP compared to the stiffness modulus of steel and the larger dowel diameter are both advantageous in this type of application because of the reduced bearing stresses on the concrete surrounding the dowel. Bearing stresses are one of the major causes of joint failure. The long-term effects of joint deflections on performance will require further investigation.

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CONVERSION TABLE

1 kN	= 0.224 kip
1 mm	= 0.039 in.
1 MPa	= 145.037 psi
1 MN/m ³	= 6342.974 lb/ft ³

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