FRP Dowels for Concrete Pavements

By

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Introduction

Joints are used in concrete pavements in order to control cracking due to thermal and environmental conditions. Dowels span joints to transfer load from one slab to an adjacent slab and to provide vertical and horizontal alignment. Currently, smooth epoxy coated steel dowels are placed across transverse joints to transfer load and to allow for longitudinal thermal expansion and contraction.

Corrosion of steel dowels due to the application of de-icing salts causes severe deterioration of concrete highway pavements due to the expansion of steel during the corrosion process. This expansion can create large stresses, sufficient to cause cracking and spalling of the concrete. This also causes a reduction of the load that the joint can transfer. In an attempt to reduce the effect of de-icing salts on dowels, epoxy coated steel dowels are used. Small defects during handling inevitably occur in the epoxy coat. Thus, corrosion remains a problem with the epoxy coated steel dowels and therefore, a better solution must be found.

Fiber reinforced polymer (FRP) dowels could provide an alternative solution to steel dowels due to their corrosion-free characteristics. FRP material is known for its high ultimate tensile strength in the direction of the fibers, however, it has a relatively low strength perpendicular to the fibers. An experimental study was conducted at the University of Manitoba to provide data on the behaviour and performance of FRP dowels for concrete highway pavement joints.

Objective

The objective of this research was to investigate the behaviour of FRP dowels for transverse construction joints of a concrete highway pavement under the effect of typical traffic loading conditions. The behaviour of glass fiber reinforced polymer (GFRP) dowels is compared to that of epoxy coated steel dowels.

Scope

This research encompasses testing of GFRP and steel dowels using a model of a concrete pavement slab joint subjected to static and cyclic loads. A field application of the GFRP Dowels was also initiated along Bishop Gradin Boulevard.

Highway pavements

Highway pavements should provide the best combination of ride quality, strength, durability, and economy. Within the pavement, joints are provided to control thermal cracking at designated locations. At these locations, dowels are used to provide the necessary load transfer and rigidity of the joints.

Typically, plain concrete has been used for highway pavements in Manitoba. During the curing process of concrete pavements, stresses created by thermal gradients experienced from the environment as well as the concrete hydration can create random cracking of the concrete. In order to control and reduce the randomness of the cracking, joints are introduced into the pavement.

Joints can be created in a number of ways: providing a groove, saw cutting, or butting. The most commonly used method is the saw cut. Cutting through one third of the slab thickness creates the concrete pavement joint. During the curing process, the joint behaves as a controlled crack location and the crack initiated by the cut propagates through the remainder of the slab under shrinkage and thermally induced stresses as shown in Figure 1.

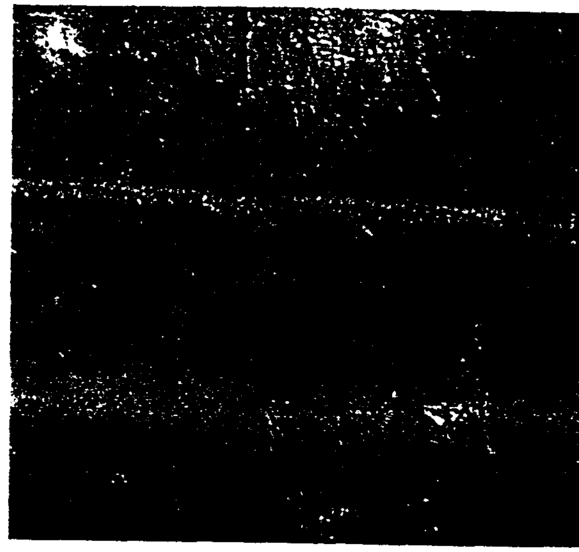

Figure 1: Crack propagation leading from saw cut

Joint spacing is based upon crack patterns that have been experienced and observed over the past 50 years of highway pavement construction. Currently, transverse joints are placed at 3 m to 6 m (10 ft to 20 ft) apart. Some highway agencies use different joint configurations.

The American Concrete Paving Association (ACPA) provides information on concrete pavements used

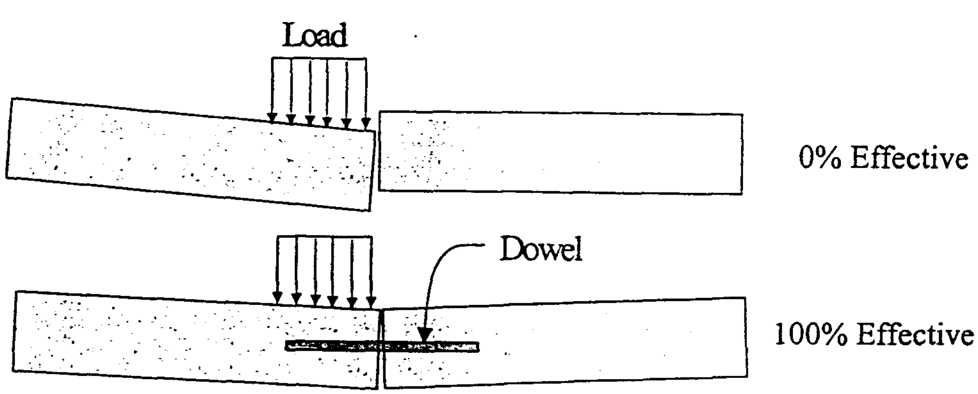

Figure 2: Positive effect of dowel load transfer

for street and highway construction. In order to determine the usefulness of a concrete highway joint, ACPA uses Joint Effectiveness to measure the performance of the joints. If a joint is 100 percent effective, the deflections on both sides of the joint are equal due to the sharing of the applied load. Zero percent effectiveness means the unloaded side is experiencing no deflection at any specific load level. This is illustrated in Figure 2. The measure of Joint Effectiveness is based upon the measured deflections of the loaded and unloaded side of the joint as given in Equation 1.

$$E = \frac{2d_u}{d_l + d_u} \times 100 \qquad \text{Equation 1}$$

where E is the joint effectiveness, d_u is the deflection on the side of the joint without the direct application of load or the unloaded deflection, and d_l is the deflection on the loaded side. A joint is considered adequate if the effectiveness is 75 percent or greater.

Experimental Program

The experimental program included testing of GFRP and steel dowels using a full-scale concrete slab thickness, Figure 3. Each slab contained two dowels to transfer the applied load across the joint.

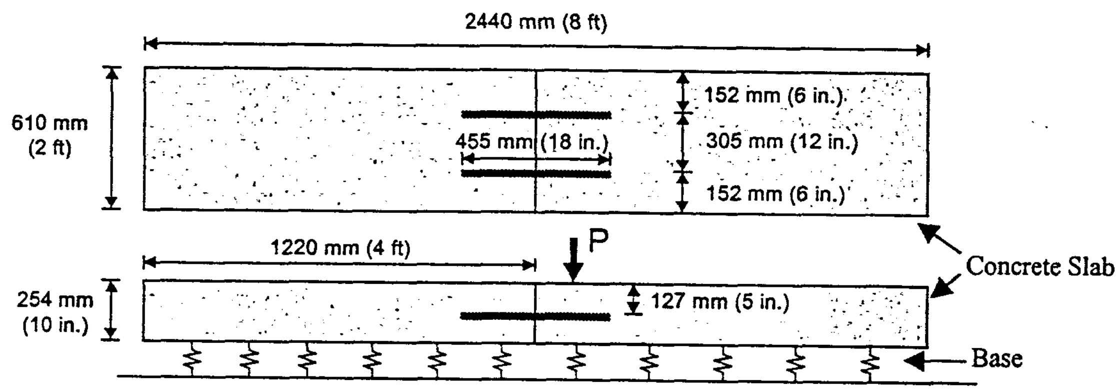

Figure 3: Slab and dowel dimensions

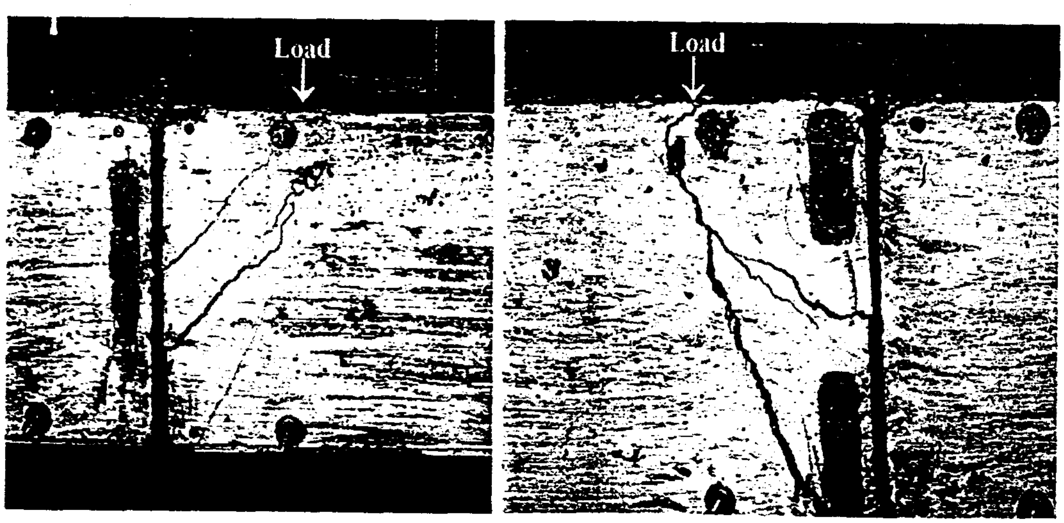

Figure 4: Typical failure mechanism of the test specimens

Figure 5: Failure of FiberDowel at load of 540 kN (121.5 kips)

Figure 6: Exposed Steel dowel after slab failure

Figure 7: Crushing of concrete on Glasform specimen

Epoxy coated steel dowels were also tested to provide control specimens to the GFRP specimens. The shear strength of the GFRP and steel dowels was also determined based on testing individual bars in double shear.

The experimental program included testing of twelve specimens using three types of dowel material; Glasform GFRP, FiberDowel GFRP, and epoxy-coated steel.

Test Results

Testing the model slabs under a static load to failure illustrated the typical failure mechanism that occurs in

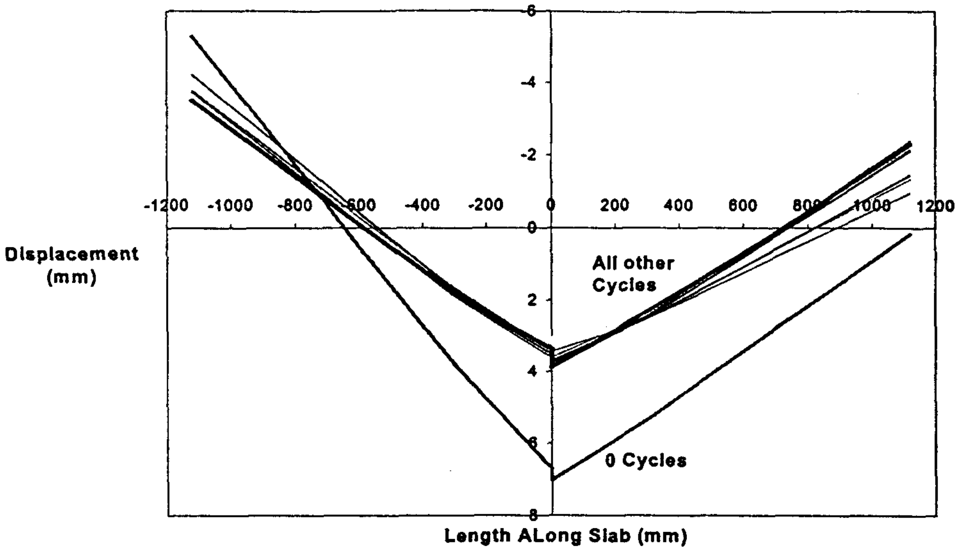

Figure 8: Displacement along Glasform specimen at 130 kN (29.25 kips)

highway pavements as shown in Figure 4. A crack develops under the application of load where the concrete would be experiencing high compressive loads but also tensile loads due to the leverage from the dowels themselves during transfer of load to the adjacent slab. Additional failures are shown in Figures 5 through 7 but all occurred at load levels significantly higher than would be experienced in the field during its service life.

Cyclic Tests

The results gathered from the testing of the doweled slabs under cyclic loading showed no signs of concrete failure under the load range of 20 kN

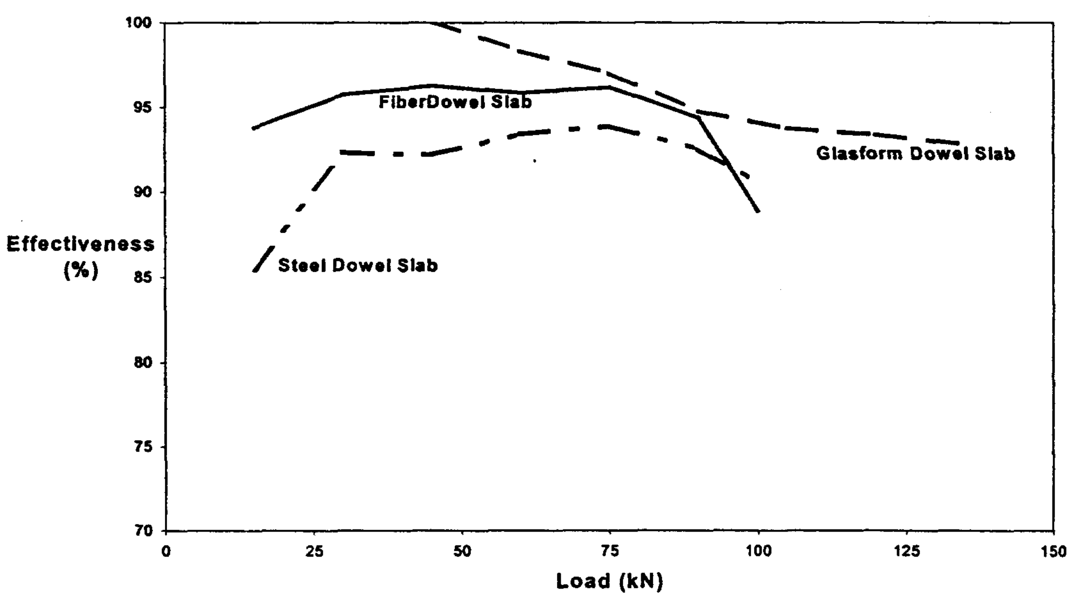

Figure 9: Joint effectiveness of slabs tested on a weak subbase

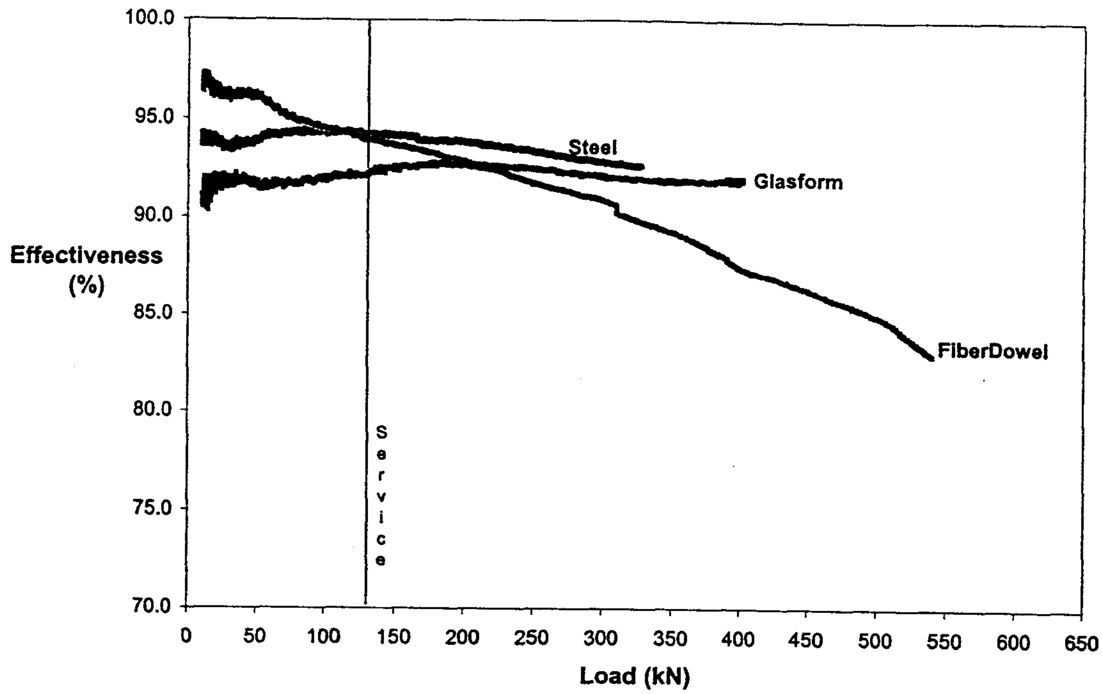

Figure 10: Joint effectiveness for slabs tested on a stiff subbase

(4.5 kips) to 130 kN (29.25 kips). The largest change in displacement can be seen to follow the first static test when the base material is initially compressed under the applied load. An example of the displacement experienced, the Glasform doweled slab displacement is shown in Figure 8.

Analysis of Test Results

Static Tests

The joint effectiveness ranged from 86 to 100 percent when the specimens were tested on a weak subbase. Figure 9 illustrates the dowel bars effectiveness over the load range. It can be seen that the dowels continue transferring the load up to a maximum value in the range of 60 kN (13.5 kips) before a loss of effectiveness. The joint effectiveness of all types of dowels tested on the weak subbase was relatively high and in the range of 90 percent when compared to an acceptable effectiveness value of 75 percent.

The joint effectiveness ranged from 96 to 99 percent when the specimens were tested on a stiffer subbase at a load of 280 kN.

Cyclic Tests

The combination of the ranges of joint effectiveness of all the materials is shown in Figure 11. Glasform comes out on top, followed by steel and finishing with the FiberDowel. A slightly different comparison with the same result is made when plotting the joint effectiveness versus the log scale of the number of cycles as shown in Figure 12.

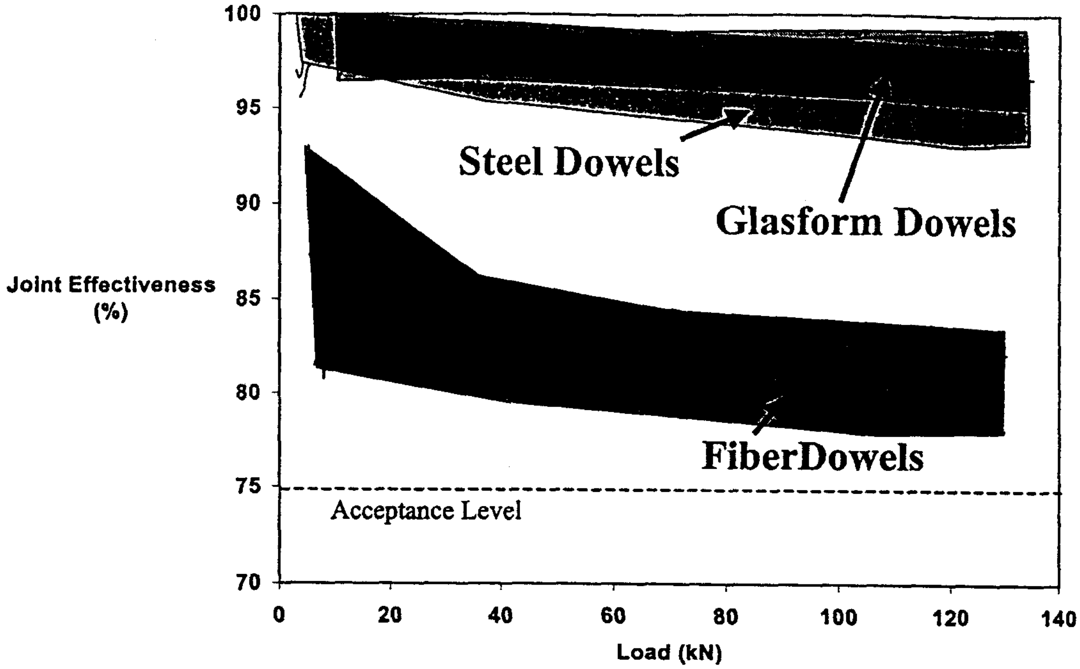

Figure 11: Joint effectiveness range vs. load for all materials under cyclic loading

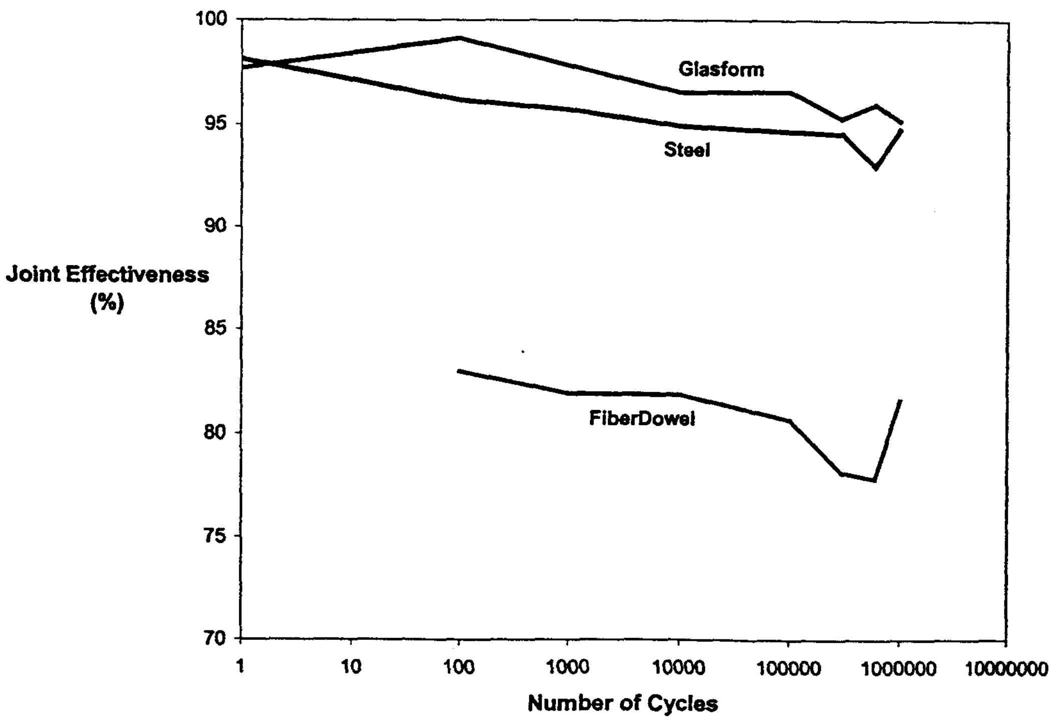

Figure 12: Joint effectiveness at service load vs. log number of cycles for all three dowel types

Field Application

The pilot application of Glass FRP dowels in Canada is located in a test section along the newly constructed extension of Bishop Grandin Boulevard west of Waverley Street, Winnipeg, Manitoba. Three types of GFRP dowels were used. The first is manufactured by Glasforms Inc. in San Jose, California; the second is FiberDowel produced by RJD Industries in Laguna Hills, California; and the third is produced by Creative Pultrusions, Inc., in Alum Bank, Pennsylvania.

Standard epoxy-coated steel dowel assemblies were to be used in the joints along Bishop Grandin Boulevard. But a straight test section on the eastbound lane contains the GFRP dowels which replace the epoxy-coated steel dowels. A total of 780 - 38 mm (1.5 in) by 460 mm (18 in) GFRP dowels were used spaced at 300 mm (12 in) on center. The location of the dowels is shown in Figure 13.

Site Handling

Before the steel baskets containing the GFRP dowels were placed, the dowel ends were coated with asphalt to protect the glass fibers from direct contact with the concrete. For assembling the dowels in the baskets, the dowels were slid in the open side of the basket and rested against finger pins as shown in Figure 14.

The baskets supported the dowels at mid-height of the 225 mm (9 in) slab and were held in place by standard pins driven into the base material as shown in Figure 14. Because the dowels were not welded to the baskets, as the case for the steel dowels, the dowels tended to move during casting of the concrete. The finger pins were placed against the direction of casting to maintain the proper positioning of the dowels during casting, as shown Figure 15.

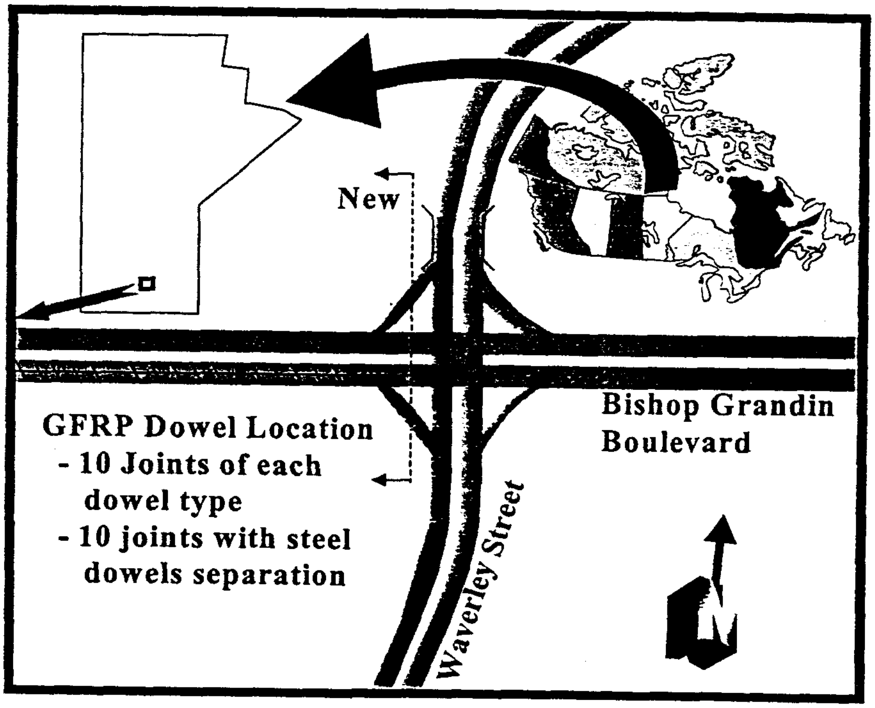

Figure 13: Field application location

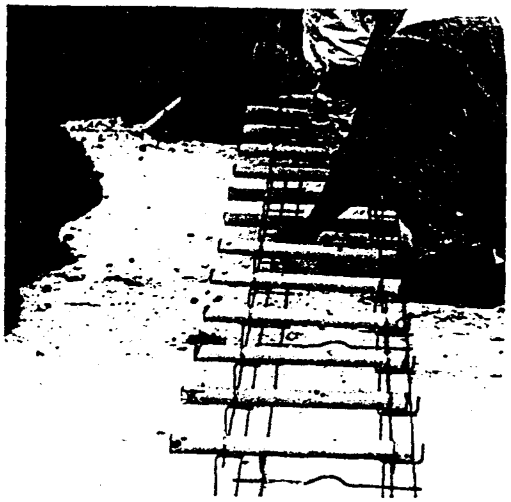

Figure 14: GFRP dowel assembly being nailed into place

Monitoring Performance

This field application provides excellent opportunity to monitor the long-term behaviour of GFRP dowels subjected to environmental and loading conditions. Monitoring of these GFRP dowels in comparison to steel dowels will provide unique information on the future use of these corrosion free dowels.

Conclusions

The objective of this research was to investigate the behaviour of FRP dowels for transverse construction joints under the effect of typical traffic loading. This was achieved through testing in three distinct phases.

This investigation of the behaviour of GFRP dowels has shown that GFRP dowels can be used in place of the standard steel dowels.

All doweled joints performed above the 75 percent joint effectiveness acceptance level while the Glasform consistently performed above 90 percent.

The use of deicing salts creates a harsh corrosive environment which

Figure 15: Casting a Concrete pavement with GFRP dowels in steel baskets

deteriorates steel dowels. Epoxy coated dowels are relatively protected, however, dents and cracks in the epoxy layer provide entry points for corrosion. GFRPs are a corrosion resistant material which will require no maintenance during the life span of the pavement. The lower elastic modulus of the GFRP and the larger dowel size both act to reduce the bearing stresses on the concrete, thus reducing faulting at the joint and extending the pavement service life.

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