

Newly Developed GFRP Dowel Bars for Jointed Plain Concrete Pavement

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Abstract

Corrosion of steel dowels in jointed plain concrete pavements (JPCP) reduces their effective service-life and creates considerable maintenance and repair expenditures. Glass fiber-reinforced polymer (GFRP) dowel bars are a non-corrodible and maintenance-free alternative that will potentially reduce the life-cycle cost of JPCP, especially in harsh environmental conditions. This paper describes the performance of the newly developed GFRP dowels under static loading and compares their behavior with that of the epoxy-coated steel dowels. GFRP and epoxy-coated steel dowels were used for jointed pavement prototypes (slab/joint) and were tested under laboratory conditions. The test prototypes measured 2440 mm-long $\times$ 610 mm-width $\times$ 254 mm-depth. The slabs were cast with a butted joint and each test prototype contained two dowel bars spaced at 306 mm. The test parameters included: (i) dowel bar type (GFRP and epoxy-coated steel), and (ii) dowel bar diameter (34.9 mm and 38.1 mm for GFRP and 28.6 mm for epoxy-coated steel). The test results revealed that both 34.9 and 38.1 mm GFRP dowels showed similar crack pattern and failure mode as epoxy-coated steel ones. Besides, both 34.9 and 38.1 mm GFRP dowels showed higher joint effectiveness than that of the 28.6 mm steel dowels.

Introduction

Jointed plain concrete pavements (JPCP) are commonly constructed with contraction joints to accommodate slab movements due to temperature and moisture variation (Ioannides and Korovesis 1992). Joints may either be longitudinal joints, parallel to traffic, or transverse joints, perpendicular to traffic. Transverse joints are placed at regular intervals creating discontinuities in the pavement and forming a series of slabs. Load transfer within a series of concrete slabs takes place across these joints (Porter 2005). Dowel bars are installed at the transverse joints of the concrete slabs to reduce the deflections and stresses at the joints while transferring the traffic load from one slab to the adjacent one (Westergaard 1928). Plain round steel dowels are the most frequently used load-transfer devices in the JPCP between two adjacent slabs at the joint location. In addition, the dowel bar system works well with both narrow and wide joints (Maitra et al. 2009). The load-transfer efficiency of a joint is assessed by the joint effectiveness as specified by the American Concrete Pavement Association (ACPA) (AASHTO 1993). Joint effectiveness based on the measured deflections of loaded and unloaded sides of the joint which is given by Eqn. (1).

$$E = \frac{2 \cdot \delta_u}{\delta_l + \delta_u} \times 100 \quad (1)$$

Where E is the joint effectiveness, δ_u is the deflection of the unloaded slab, and δ_l is the deflection of the loaded slab. When the deflections of slabs on both sides of the joint are equal, the joint is considered 100% effective. On the other hand, if the unloaded side of the joint is experiencing no deflection, the joint is considered 0%

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effective. The ACPA recommends an adequate effectiveness of 75% in the pavement joints.

Another quantitative measure to evaluate the joint efficiency is the load-transfer efficiency (*LTE*) (AASHTO 1993). The deflection-based and stress-based *LTE* are given by Eqns. (2) and (3), respectively:

$$LTE = \frac{\delta_u}{\delta_l} \times 100 \quad (2)$$

$$LTE = \frac{\sigma_u}{\sigma_l} \times 100 \quad (3)$$

Where σ_u is the stress of the unloaded slab, and σ_l is the stress of the loaded slab.

Corrosion of steel dowels in the contraction joints of the JPCP is characterized as one of the main reasons of premature concrete failure. The penetration of chloride containing deicing salts through the joint initiate the corrosion. Since the smooth dowel bars are assumed to be frictionless and permit free relative movement of slabs due to temperature changes, the corrosion of steel dowel bar creates exfoliation of steel surface causing steel dowels to lock in the joint. Locking in turn, causes excessive tensile loads on the surrounding concrete with attendant stress concentration on the concrete and greater movement around the joint which hasten the rate of joint failure (DBT 1998). Furthermore, corrosion of steel dowels may restrain the free movement under temperature variations. The restriction of free movement of the concrete slabs over the dowel bars produces high tensile stresses, which in turn result in mid-slab cracking (William and Shoukry 2001; Shoukry et al. 2002).

A common method that has been employed for more durable dowels was the fusion-bonded epoxy coating of steel dowels. Unfortunately, the epoxy-coated steel dowels demonstrated the same performance problems that are normally associated with surface coating including voids and damage during transportation and handling. The concentrated corrosive mechanisms at the defected area, in some cases, lead to more rapid failure than same steel-reinforcement without any epoxy coating (DBT 1998). Thus, finding a solution to the corrosion of steel dowels is essential to maintain a cost-effective pavement system with adequate service life.

Glass fiber-reinforced polymer (GFRP) dowels are non-corrosive and maintenance-free. Consequently, employing GFRP dowels in the JPCP as an alternative to the commonly used epoxy-coated ones will eliminate the potential of corrosion and extend the service life of concrete pavements. Few studies have been conducted to investigate the feasibility of GFRP dowel bars as an alternative to the steel ones in concrete pavements (Porter et al. 1996; Davis and Porter 1998; Porter et al. 2001; Eddie et al. 2001; Smith 2001). These investigations supported the use of GFRP dowels as a potential solution for the corrosion problems of steel dowels in pavements. Through an extended collaboration project between the Ministry of Transportation of Quebec (MTQ), University of Sherbrooke (UdeS), and a Canadian FRP manufacturer, new GFRP dowels were developed and their long-term durability characteristics were investigated (Robert et al. 2010; Montaigu et al. 2011). These investigations demonstrated the high stability of vinylester-based GFRP dowels in concrete pavement environments. This paper, however, investigates the feasibility of using the newly developed GFRP dowels (34.9 and 38.1 mm) in JPCP. In addition, it investigates the structural performance of the newly-developed GFRP dowels in JPCP under static loading in laboratory conditions.

Research Significance

GFRP dowels appeared as a possible cost-effective solution for the JPCP. Few studies have been conducted on the feasibility of using GFRP dowels in pavements. This paper investigates the structural performance and effectiveness of the newly-developed GFRP dowel bars (34.9 and 38.1 mm) under static loading. In addition, it compares the behavior of JPCP when both GFRP and epoxy-coated steel dowels are employed in transverse joints.

Experimental Program

Characteristics of the GFRP dowel bars GFRP dowels of 34.9 and 38.1 mm-diameter (commonly used diameters) were used in this investigation in addition to the reference epoxy-coated steel ones of 28.6 mm-diameter. The GFRP dowels were made of continuous E glass fibers impregnated in vinylester resin (Pultrall 2010) using pultrusion process with a fiber content of 80.6% by weight. Figure 1 shows the GFRP dowels of both diameters (34.9 and 38.1 mm). The physical properties of the GFRP dowels were determined using the appropriate test methods provided by the CSA S-807 (2010). Details about the physical characteristics of the GFRP dowels can be found elsewhere (Montaigu et al. 2011).



Figure 1: GFRP dowels of 34.9 and 38.1 mm-diameter

The mechanical characterization included testing of representative specimens of the GFRP dowel bars to determine the shear strength (ACI 440 2004), interlaminar shear (short beam test) (ASTM D 4475-02 2002), flexural strength, and flexural modulus of elasticity (ASTM D 4476-03 2003). Figure 2 shows the mechanical characterization tests of the GFRP dowels of 34.9 and 38.1 mm-diameter used in this study. Table 1 presents the mechanical properties for the GFRP dowels obtained from testing.

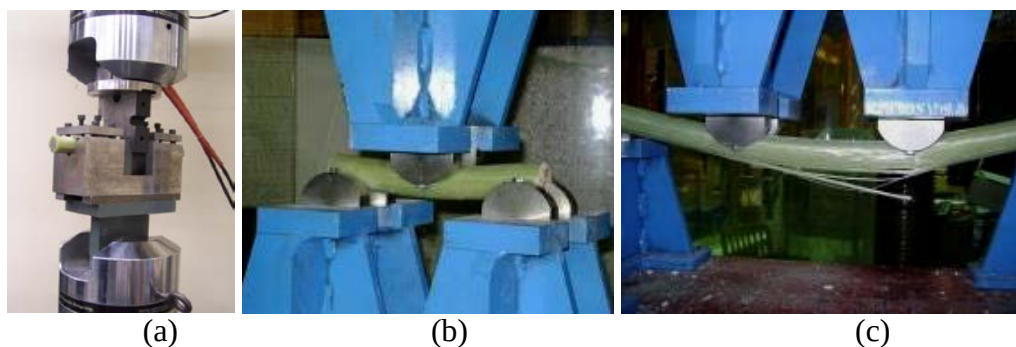


Figure 2: Mechanical characterization of the GFRP dowels: (a) direct shear test; (b) short beam test; (c) flexural test

Table 1: Mechanical properties of the GFRP dowel bars

GFRP dowel diameter (mm)	Direct shear strength (MPa)	Short beam shear strength (MPa)	Four-point flexural strength (MPa)	Flexural modulus of elasticity (GPa)
34.9	184	61.1	1210	50.3
38.1	173	53.9	1077	51.6

Test prototypes

A total of three JPCP prototypes were constructed and tested. The prototypes included one reinforced with GFRP dowels of 34.9 mm diameter, one reinforced with GFRP dowels of 38.1 mm diameter, and one reinforced with epoxy-coated steel dowels of 28.6 mm diameter. The prototypes were tested under monotonic load until 200 kN to induce cracks at the joints. Thereafter, the load was released and the prototypes were re-loaded up to failure. The test prototypes measured 2440 mm long $\times$ 610 mm width $\times$ 254 mm depth. The slabs were cast with a butted joint of 19 mm width and each test prototype contained two dowel bars spaced at 306 mm. Figure 3 shows the dimensions and details of jointed slab prototypes.

The length of the specimens was selected based on the finite element modeling conducted by Maitra et al. (2009) which simulated the experimental study conducted by the U.S. Naval Civil Engineering Research and Evaluation Laboratory (Keeton and Bishop 1957). Through this study it was noticed that, the vertical shear force in a dowel beyond a distance of about 1200 mm (4 ft) from the center of the load was quiet insignificant. Thus, 2440 mm (8 ft) was selected as the total length of the jointed slab prototypes. It should be mentioned that the geometry and dimensions are in agreement with jointed slab prototypes tested by Eddie et al. (2001).

The prototypes were fabricated using MTQ Type III-A concrete with a target compressive strength of 35 MPa after 28 days. The concrete mix had 380 kg/m³ of GUB-SF cement and water/cement ratio (w/c) of 0.42 in addition to super-plasticizers to maintain a slump of 80 mm for the mix. Based on testing of 5 concrete cylinders (150 $\times$ 300 mm) on day of the test, the average concrete strength of the slab prototypes was 45 MPa.

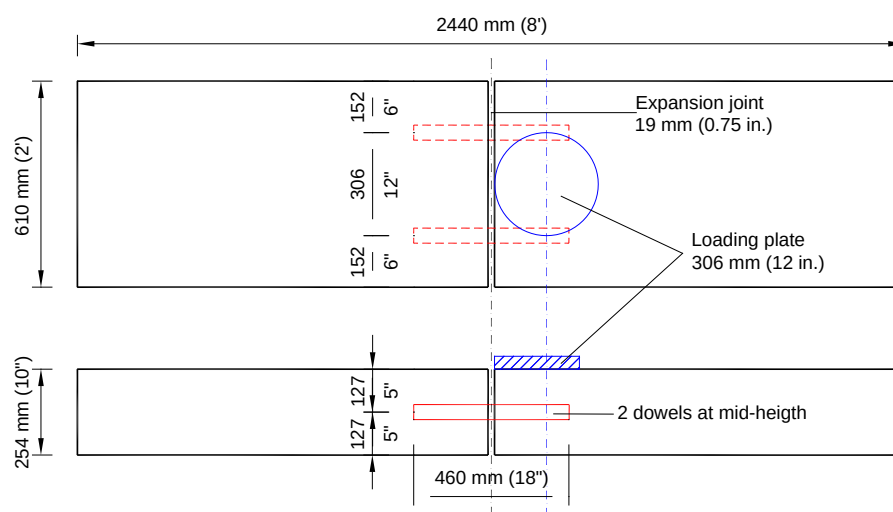


Figure 3: Dimensions and details of the test prototypes

Subgrade base layer

The granular base was made of three layers of 100 mm-thick limestone aggregates, compacted using a vibrating plate of 90 kg weight. The granular mixture was carried out according to the AASHTO specifications (Class A). The granular subgrade mixture consisted of 50% sand (0-5 mm), 20% of crushed rock of 10 mm (5-14 mm) and 30% of crushed rock of 20 mm (14-28 mm). Aggregates were moistured before placing for maximum efficient compaction. The base was extended by 300 mm (=thickness of the base layer) from all sides to allow for load distribution and prevent the failure of the base layer container. The overall dimensions of the base layer were 1.524 m-width $\times$ 3.353 m-long (5 $\times$ 11 ft). Upon completing the base, a compaction test was conducted using a Briarude Compacting Device and the base modulus (stiffness) was 110 MPa/m.

It should be mentioned that, the jointed pavement prototypes were not cast directly over the subgrade base. The prototypes were cast and cured. Thereafter, they were transported to the testing area and placed over the base. The behavior, however, is assumed to simulate that of the real conditions where the jointed concrete pavements are directly cast over the subgrade base.

Testing loads and procedures

As the spacing of the dowel bars was about 300 mm, each single dowel is expected to resist a service load of 40 kN, which is equal to $\frac{1}{2}$ of the equivalent axle load.

The monotonic load was applied with a displacement controlled rate of 0.01 mm/sec to allow for the progressive contact and loading. The load was applied using a 1000-kN hydraulic actuator on one side of the joint over a loading plate (footprint) of 306 mm-diameter (12 in.). The prototypes were loaded up to 200 kN (5 times the service load) and then the load was released. Thereafter, the prototypes were re-loaded until failure. The 200 kN was enough to induce cracks in the pavement prototypes so that cracking effect on the efficiency of the joints could be assessed. The joint effectiveness (E) and load-transfer efficiency (LTE) were evaluated at 40 kN from the deflection measurements using two linear variable differential transducers (LVDTs) at both joint sides. Figure 4 shows the test setup.

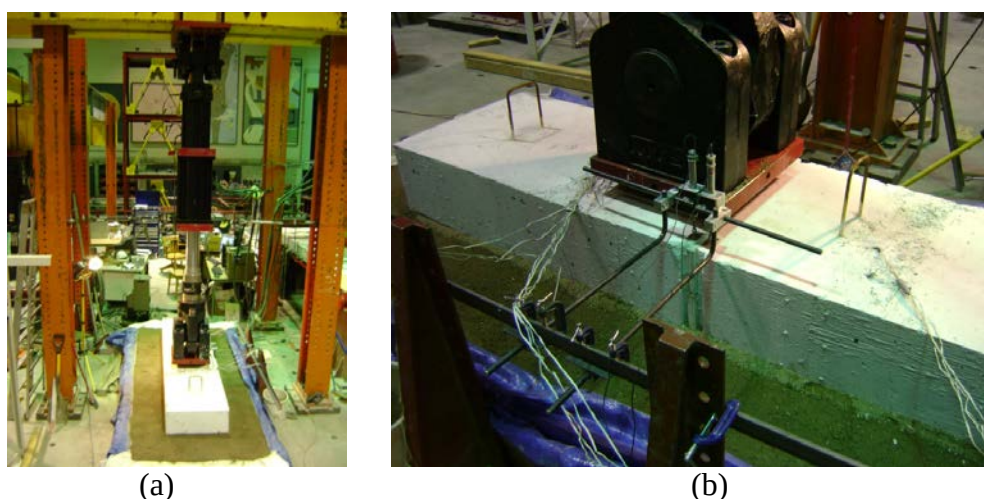


Figure 4: Test setup: (a) Overall view; (b) Loading plate and LVDTs

Test Results

Cracking and failure

When the JPCP prototypes were submitted to 200 kN, cracks appeared in the loaded slabs in all tested prototypes. The unloaded slabs, however, did not experience any cracks during the test. Table 2 gives the cracking and failure loads of the test prototypes. Figures 5 to 7 show the cracking patterns and failure modes of the three prototypes tested herein: 28.6 mm steel dowels, 34.9 mm GFRP dowels, and 38.1 mm GFRP dowels.

Table 2: Cracking and failure loads of the jointed pavement prototypes

	Steel-28.6 mm	GFRP-34.9 mm	GFRP-38.1 mm
Cracking load (kN)	140.7	100.0	124.8
Failure load (kN)	506.6	460.0	478.0

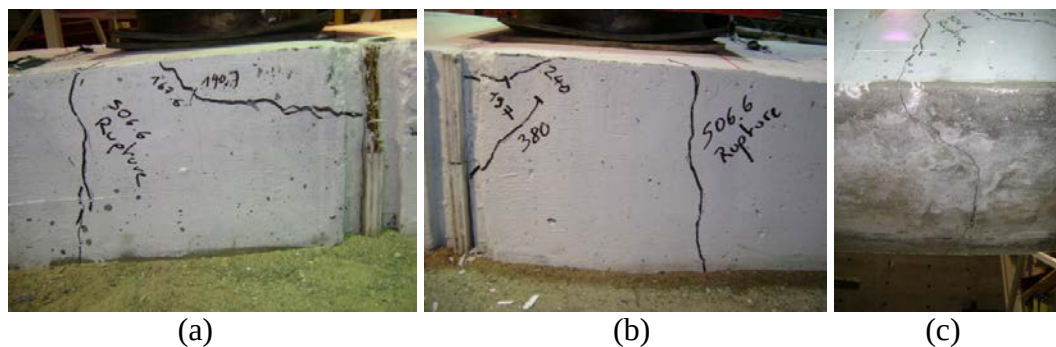


Figure 5: Cracking and failure of JPCP with 28.6 mm steel dowels: (a) Loaded slab-side 1; (b) Loaded slabs-side 2; (c) Shear failure of the loaded slab

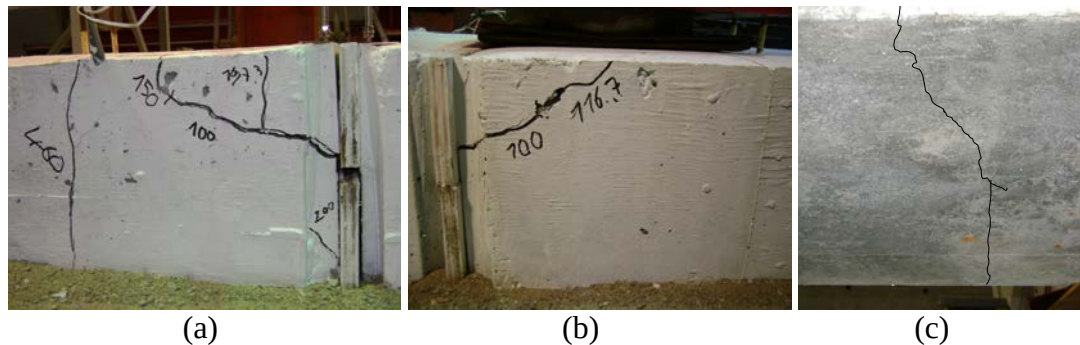


Figure 6: Cracking and failure of JPCP with 34.9 mm GFRP dowels: (a) Loaded slab-side 1; (b) Loaded slabs-side 2; (c) Shear failure of the loaded slab

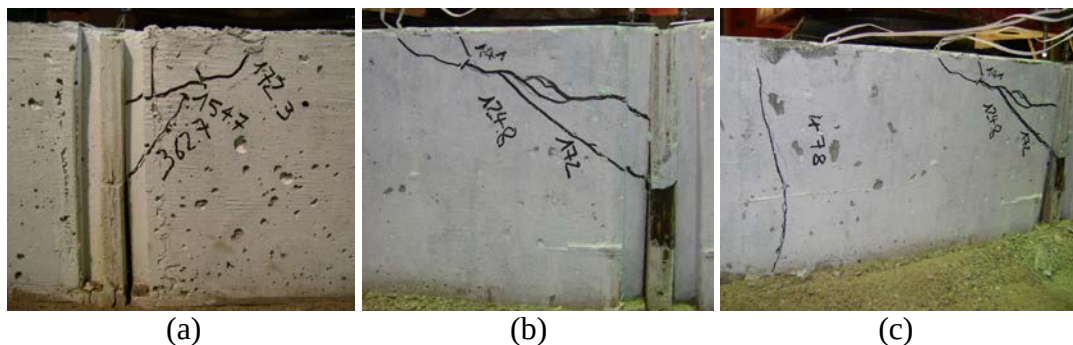


Figure 7: Cracking and failure of JPCP with 38.1 mm GFRP dowels: (a) Loaded slab-side 1; (b) Loaded slabs-side 2; (c) Shear failure of the loaded slab

In case of 28.6 mm-diameter steel dowels, the first crack appeared in the loaded slab at 140.7 kN in one side and at 197.0 kN in the other side. The crack appeared at the level of dowel bars and continued to the surface. The second crack appeared under the load at about 380 kN. The slab prototype failed at 506.6 kN by shear failure of the loaded slab beyond the dowel bars. The GFRP-doweled prototypes showed crack patterns and failure modes similar to the steel-doweled one. The cracking loads were 100 and 124.8 kN for both 34.9 mm- and 38.1 mm-diameter GFRP dowels, respectively. These loads represent 71% and 89% of the cracking load of the steel-doweled prototype. On the other hand, the failure loads of the 34.9 mm- and 38.1 mm-diameter GFRP dowels were 460 and 478 kN, respectively, which represent 91% and 94% of the failure load of the steel-doweled prototype.

Joint effectiveness and load-transfer efficiency

The joint effectiveness (E) and load transfer efficiency (LTE) were calculated using the deflection measurements resulted from the two LVDTs placed on both joint sides. Table 3 list the calculated joint effectiveness and load transfer efficiency at service load (40 kN) for the tested JPCP prototypes with steel and GFRP dowels. All tested prototypes showed joint effectiveness and load transfer efficiency higher than 75% and 60%, respectively, which meet the requirements of the ACPA.

Both GFRP dowel diameters (34.9 and 38.1 mm) showed joint effectiveness (E) and load-transfer efficiency (LTE) higher than those of the 28.6 mm-diameter steel dowels. The 34.9 mm-diameter GFRP dowels showed joint efficiency (E) of 89% and load transfer efficiency (LTE) of 81% while the 38.1 mm-diameter GFRP dowels showed joint efficiency (E) of 95% and load transfer efficiency (LTE) of 92%. Comparing the values in Table 3 reveals that using 34.9 mm-diameter GFRP dowels instead of 28.6 mm-diameter steel dowels increased the joint effectiveness (E) and load-transfer efficiency (LTE) by 9% and 8%, respectively. On the other hand, replacing the 28.6 mm-diameter steel dowels by 38.1 mm-diameter GFRP dowels increased the joint efficiency (E) and load-transfer efficiency (LTE) by 10% and 23%, respectively.

The joint effectiveness (E) and the load-transfer efficiency (LTE) revealed that the behavior of the jointed pavement with 34.9 mm-diameter GFRP dowels was almost the same as that with 28.6 mm-diameter steel dowels. Furthermore, as seen from Table 3, reloading the specimens after getting them cracked from the initial loading phase (200 kN) yielded very low joint effectiveness (E) and load-transfer efficiency (LTE). The 38.1 mm-diameter GFRP dowels showed joint effectiveness (E) of 74% which is very close to 75% provided by the ACPA. Thus, to assure the stability and good performance of the JPCP the slabs have to remain uncracked to enable achieving efficient joints.

Table 3: Joint effectiveness and load-transfer efficiency at service load (40 kN)

	Steel 28.6 mm		GFRP 34.9 mm		GFRP 38.1 mm	
	$E(\%)$	$LTE(\%)$	$E(\%)$	$LTE(\%)$	$E(\%)$	$LTE(\%)$
First loading	86	75	89	81	95	92
Reloading	65	45	64	47	74	59

The joint effectiveness (E) and the load-transfer efficiency (LTE) were plotted against the applied load in Figures 8 and 9, respectively. It should be mentioned that the load-transfer efficiency (LTE) corresponding to joint effectiveness (E) of 75% is equal to 60%. Figures 8 and 9 demonstrate that after an initial loading interval till

about 50 kN the joint effectiveness (E) and the load-transfer efficiency (LTE) stabilized. Besides, there was no significant difference between the two prototypes with 34.9 mm GFRP dowels and 28.6 mm steel dowels after 50 kN. The difference between the two prototypes before 50 kN may be related to the better compaction of the subgrade base after testing the first prototype which was the prototype with 28.6 mm steel dowels.

Furthermore, increasing the GFRP dowels to 38.1 mm increased the joint effectiveness (E) and the load-transfer efficiency (LTE). The Figures 8 and 9 also show that the cracking of the specimens during the first loading did not affect the joint effectiveness (E) because the load was not released until it reached 200 kN. During the reloading, the effect of the cracks in the test prototypes was experienced as shown in Table 3. The effectiveness of the joints (E) in the JPCP necessitates maintaining the jointed slabs uncracked.

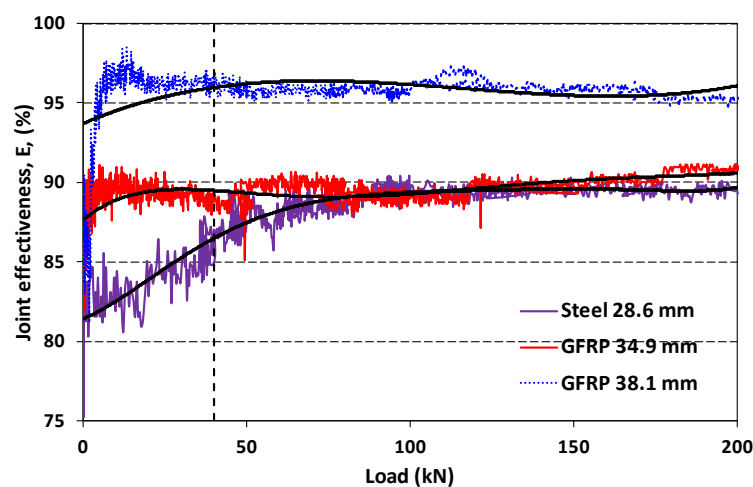


Figure 8: Joint effectiveness (E) under static testing up to 200 kN

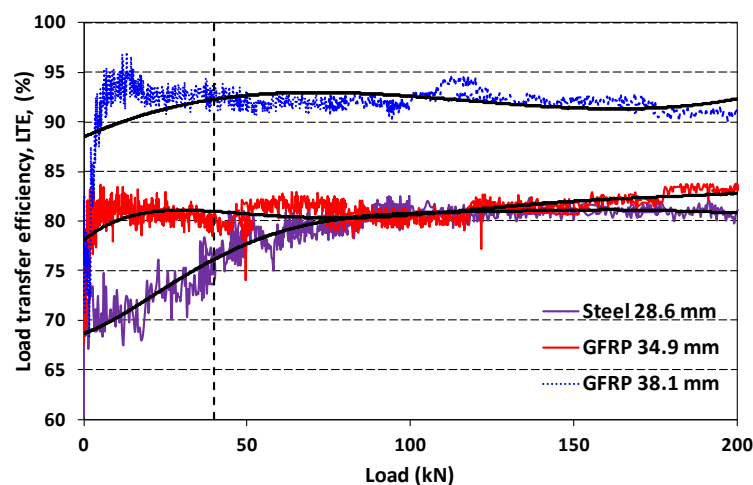


Figure 9: Load-transfer efficiency (LTE) under static testing up to 200 kN

Summary and Conclusions

Through an extended collaboration project between the Ministry of Transportation of Quebec (MTQ), University of Sherbrooke (UdeS), and a Canadian FRP manufacturer, new GFRP dowels were developed and their long-term durability characteristics were investigated (Robert et al. 2010; Montaigu et al. 2011). This paper, however,

investigates the feasibility of using the newly developed GFRP dowels in JPCP. In addition, it investigates the structural performance of the newly-developed GFRP dowels in JPCP under static loading. Based on the test results presented and discussed herein, the following concluding remarks can be drawn:

1. The developed GFRP dowel bars provide suitable and effective alternative to the common epoxy-coated steel dowels to overcome the corrosion problems and related deteriorations.
2. The pavement prototype with 28.6 mm steel dowels showed the first crack at 140.7 kN while the prototypes with 34.9 and 38.1 mm GFRP dowels showed first cracks at 100 and 124.8 kN, respectively. The cracking loads of the prototypes with 34.9 and 38.1 mm GFRP dowels were 2.5 and 3.1 times the service load (40 kN), respectively.
3. The pavement prototype with 28.6 mm steel dowels and those with 34.9 and 38.1 mm GFRP dowels showed similar crack pattern and mode of failure. The capacities of the three prototypes were 506.6, 460.0, and 478.0 kN, respectively.
4. The pavement prototypes with GFRP dowels (34.9 and 38.1 mm) showed joint effectiveness (E) and load-transfer efficiency (LTE) similar or higher than that of the prototypes with steel dowels (28.6 mm).
5. To assure the stability and good performance of the JPCP with GFRP dowels the slabs have to remain uncracked to enable achieving efficient joints and maintain efficient load-transfer.
6. Considering the tested material and setup configuration, the GFRP dowels of 34.9 mm-diameter showed very closed behavior to the steel ones of 28.6 mm-diameter. Thus, the 34.9 mm GFRP dowels may be a direct alternative to the 28.6 mm steel ones subjected to the same loading and boundary conditions.

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