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BUILDING SUSTAINABLE CONTINUOUSLY REINFORCED CONCRETE PAVEMENT USING GFRP BARS: CASE STUDY-HIGHWAY 40 WEST-MONTREAL, CANADA

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ABSTRACT

Continuously reinforced concrete pavement designs (CRCP) are premium pavement designs that are often used on heavily-trafficked roadways and urban corridors. Although CRCP typically is an effective, long-lasting pavement design, it can develop performance problems when the aggregate-interlock load transfer at the transverse cracks is degraded. The prevalence of wide cracks in CRCP has frequently been associated with ruptured steel and significant levels of corrosion. Because of that, there has been recent interest in identifying new reinforcing materials that can prevent or minimize corrosion-related issues in CRCP. Glass fibre-reinforced polymer (GFRP) bars are one product being investigated for use in CRCP in place of traditional steel bars. This paper summarizes the construction details, material properties, early-age behaviour, and preliminary monitoring results of GFRP CRCP after 12 months in service. The project is located westbound HW-40 in Montreal, Qc, Canada, and presents a collaboration between the Ministry of Transportation of Quebec (MTQ) and the University of Sherbrooke. Varieties of sensors were installed in this project in order to monitor the early-age behaviour and the effects of repeated traffic loads and environmental conditions on the performance of CRCP slabs.

1. INTRODUCTION

Recently, glass fiber-reinforced polymer (GFRP) reinforcing bars have been used in several concrete structures such as bridges, marine structures, parking garages where steel corrosion causes major problems. One of the potential applications of the GFRP bars is as reinforcement for concrete pavements. The continuously reinforced concrete pavement (CRCP) is a kind of pavement where the longitudinal reinforcement is continuous for its length and has no transverse joints, other than construction joints. Traditional CRCP, reinforced with steel bars, has been applied for a few decades (since 1921) and its performance has been reported by many researchers (Van Breemen 1950; Selezenva and Rao 2004). Up to this point, there has been no precedence of the use of GFRP as reinforcement in CRCP, and little related research has been conducted in this area (Benmokrane et al. 2008).

The corrosion of steel reinforcement in the CRCP, which has been attributed to the development of transverse cracks above and along the length of the reinforcement, is a major concern, especially in the presence of de-icing salt applications. Several techniques, including epoxy coating of the reinforcing bar, increased concrete cover thickness and polymer concrete overlays have been used to inhibit or eliminate corrosion. None of this technique; however, has proven to be cost-effective or a long-term solution.

Glass FRP has several advantages, which include, eliminating steel corrosion, resistance for magnetic field, and stiffness compatibility between GFRP and concrete. However, there are many differences between steel and GFRP in bond characteristics, strength, elastic modulus and mode of failure. Moreover, the design equations for steel-reinforced CRCP are semi-empirical and thus cannot be used to evaluate the CRCP reinforced by GFRP bars. Hence, the behaviour of GFRP reinforced element cannot be extrapolated from that of the steel reinforced ones. Therefore, it is necessary to study the structural performance and to develop the design mechanism for the CRCP reinforced with GFRP bars through real experimental study.

Historically, cement concrete pavements built in Quebec have not always performed satisfactorily (Thébeau 2002). This was mainly linked to the following factors: use of slabs not always suited to our climate, poor design and construction practices, an increase in traffic volume and load, as well as, a decrease in funds allocated to maintenance.

Since the early 1990s, the Ministry of Transportation of Quebec (MTQ) has placed renewed emphasis on constructing long-lasting concrete pavements suiting local traffic and climatic conditions. In 2000, these efforts led to the installation of Canada's first roadway with continuously reinforced concrete pavement (CRCP). Five years later, however, concerns were raised about the long-term performance of CRCP, as portions of this initial installation were found to have insufficient cover over the bars and core samples showed that the longitudinal reinforcement was corroding at transverse cracks (Thébeau 2006). These observations, coupled with the knowledge that up to 60 tonnes (65 tons) of salt per year can be spread on a 1 km (0.6 mile) long stretch of two-lane pavement in Montreal (nearly three times the amount of salt used on roads in the state of Illinois), led the MTQ to select galvanized steel as the standard reinforcement for subsequent CRCP projects and to continue investigating other systems with enhanced corrosion resistance. As part of these investigations, the MTQ and University of Sherbrooke began studying the use of glass fiber-reinforced polymer (GFRP) bars for CRCP since 2006. A 150-m long section of Highway 40 East (Montreal) was selected to demonstrate in September 2006 (Benmokrane et al. 2008). In September 2013, it was decided to implement the GFRP bars in one of the CRCP highways in Quebec (300 m long). A stretch of test pavement has since been constructed on westbound HW-40 in Montreal. This paper summarizes the construction details, material properties, early-age behaviour, and preliminary monitoring results for the 300 m GFRP CRCP after 12 months in service.

2. OBJECTIVES AND PHASES

The objectives of the current study are as follows:

- Investigate the mechanical and cracking behaviors of CRCP-GFRP and compare them with those of conventional - CRCP;
- Long-term monitoring GFRP CRCP;
- Develop an analytical model, based on nonlinear finite elements, for CRCP-GFRP; and
- Provide design and construction recommendations of the CRCP reinforced with GFRP bars.

3. EXPERIMENTAL PROGRAM

3.1 Test Zone

Highway 40 (Montreal consists of three lanes each 3.7 m (12.1 ft) wide. The investigated test slab represents a 300 m (984 ft) long section of the highway with the full width. The construction work in the demonstration area started at the end of August 2013. The total thickness of the CRCP foundation was 600 mm according to MTQ recommendations The CRCP foundation is composed of three layers: the base, the subbase, and the subgrade soil. 750 mm thick subbase material identified as MG-112 (according to MTQ specifications) was used. MG-112 often referred to as class A material. Its maximum grain size is 112 mm, with MTQ specifications permitting between 35 and 100% particles smaller than 5 mm and between 0 and 10 % passing a No. 200 mesh sieve. Afterwards, a 150 mm thick base course was placed over the subbase surface composed of well-graded crushed aggregates with a maximum grain size of 20 mm and an average grain size of 4-9 mm referred to as MG-20.

GFRP bars placement started in the middle lane by placing the horizontal reinforcement bars as shown in Figures 1.a. Afterwards, longitudinal bars were placed according to the designed plan Figure 1.b. Different sizes of galvanized steel strips were used to supporting the longitudinal reinforcement up to meet the designed reinforcement level. Due to the light weight of GFRP bars, and to ensure that the bars will stay in the designed place during casting, the strips were tied to the base layer with nails. Details about the location of the bars and the strain gauges are presented in Fig. 2.

(a) Transverse GFRP bars placed at a 30-degree angle

(b) Transverse and longitudinal bars

Figure 1. GFRP bar placement in center lane

3.2 Design Details

The test slab was 315 mm (12.4 in.) thick. The reinforcement ratio of GFRP was determined according the Vetter's equation (Vetter 1933), AASHTO code, USDT, and ACI 440 (Table 1 and 2). The GFRP reinforcement ratios are 1.2% and 0.365% for longitudinal and transverse reinforcement, respectively, in the CRCP-GFRP slab. However, the reinforcement ratios of the steel bars in the CRCP-steel slab are calculated according to AASHTO code (0.1% for transverse rebar and 0.739% for longitudinal bar).

Table 1: Longitudinal Reinforcement Ratio

Equation	Vetter's, 1933	AASHTO 1993	USDT 1996	ACI 440.1R-06	Proposed Design
Reinforcement Ratio (%)	1.36	1.212	1.67	1.17	**1.2**

Table 2: Transverse Reinforcement Ratio

Equation	AASHTO 1993	USDT 1996	ACI 440.1R-06	Proposed Design
Reinforcement Ratio (%)	0.36	0.06	0.442	**0.365**

3.3 Material Properties

Sand-coated GFRP bars Grade II were used to reinforce the GFRP CRCP- 300 m slab in the longitudinal and transverse directions. The longitudinal reinforcement was 25 mm (#8) GFRP bars, while 19 mm (#6) GFRP bars were used as transverse reinforcement. The tensile properties of GFRP bars were determined according to ASTM D7205, as reported in Table 3. The GFRP bars were pultruded (Pultrall 2012). Sand coating was used on the surface of the longitudinal and transverse FRP bars to improve the bond to concrete, which is the standard industry practice.

Table 3: Mechanical properties of the GFRP reinforcement (Pultrall 2012).

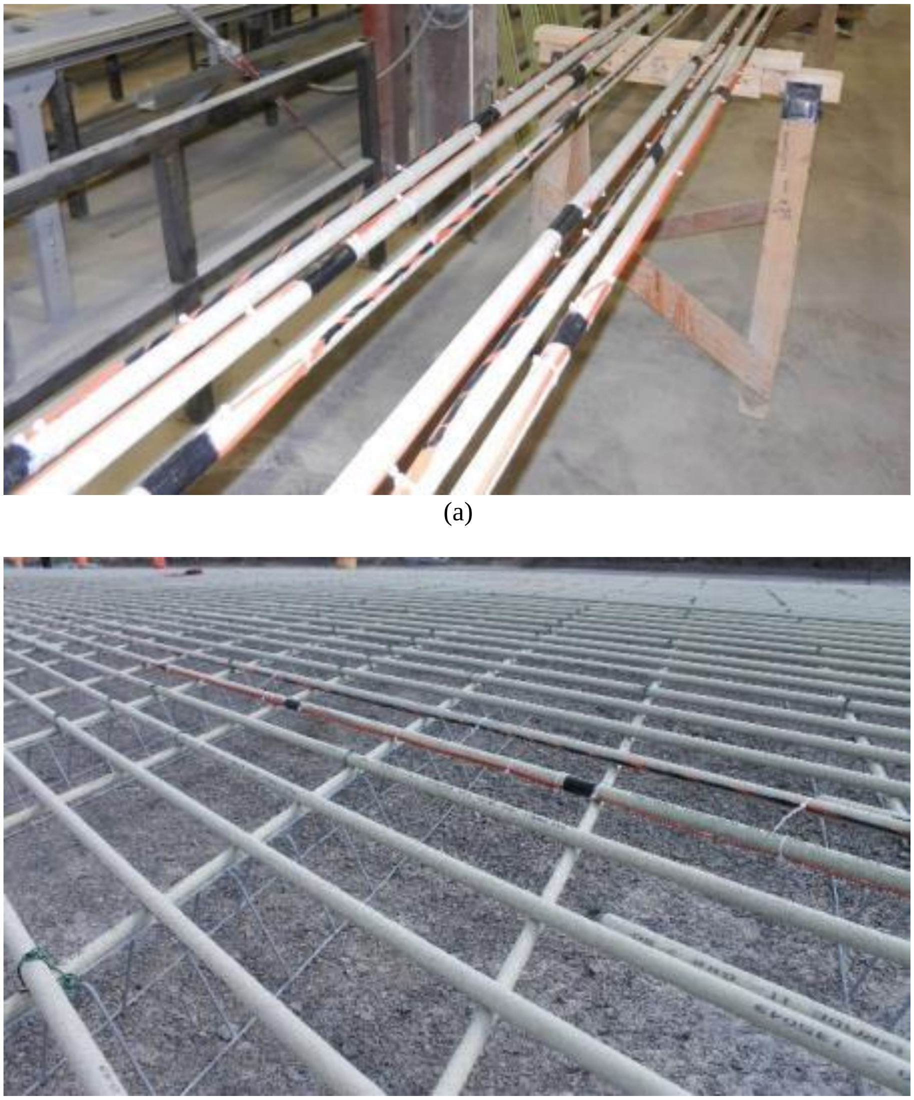
Bar Size	Diameter (mm)	Area (mm^2)	Elastic Tensile Modulus (GPa)	Tensile Strength (MPa)	Tensile Strain (%)
# 6	19	285	56.5	807	1.43
# 8	25	506	52.9	703	1.33

3.4 Construction

Test zone construction started in August 2013 with compaction and grading of the subgrade soil followed by the installation of a 750 mm (30 in.) thick sub-base, a 150 mm (6 in.) thick base course. GFRP bars #6 (diameter 19 mm) was used for the transverse and GFRP bars #8 (diameter 25.4 mm) was used for the longitudinal reinforcement in GFRP CRCP-strip. Transverse reinforcing bars were placed 500 mm (20 in.) center to center at a 30 degree angle relative to the transverse line to avoid producing transverse cracks directly over the transverse bars. Longitudinal bars were then placed 173 mm (7 in) center to center according to the design plans. The MTQ Type IIIA concrete was used for the concrete pavement. The reconstructed stretch of HW-40, including the demonstration area, was opened to traffic at the end of December 2013.

3.5 Instrumentation

The GFRP-CRCP investigated strip was instrumented at different locations to measure the internal strain data using Fabry-Perot fiber-optic sensors (FOSs) (Roctest 2012). The objective of using FOSs was to allow for the long-term monitoring and future field tests of the GFRP-CRCP. The slab was instrumented with 30 FOSs, at different locations. FOS sensors were mounted on the bars and embedded in the concrete. Six (6) GFRP bars were instrumented with the 30 FOS sensors (5 for each bar). The 30 FOSs were glued to the GFRP reinforcing bars. The GFRP bars were instrumented at the FRP manufacture as shown in Figure 2. Thereafter, the bars were shipped to the construction site, where they were installed at the designated location during the construction stage. Typical instrumentation layout in the CRCP slabs is shown in Figure 3. The FOS was controlled and their readings were captured using a 50 Channel DMI unit. Measurement devices were connected to two data loggers that could be accessed remotely for monitoring data in real time and retrieving stored data.



(a)

(b)

Figure 2: (a) GFRP bars prepared with FOS (b) Instrumented GFRP bars placed in place at the site

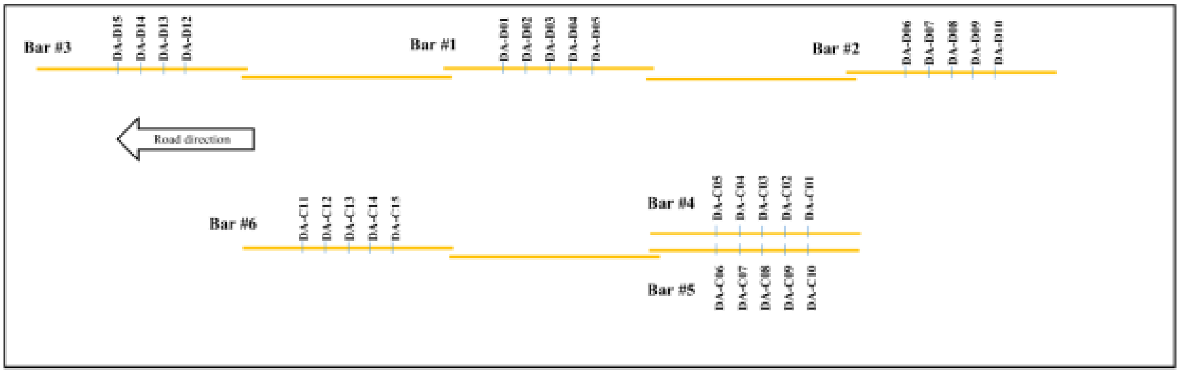
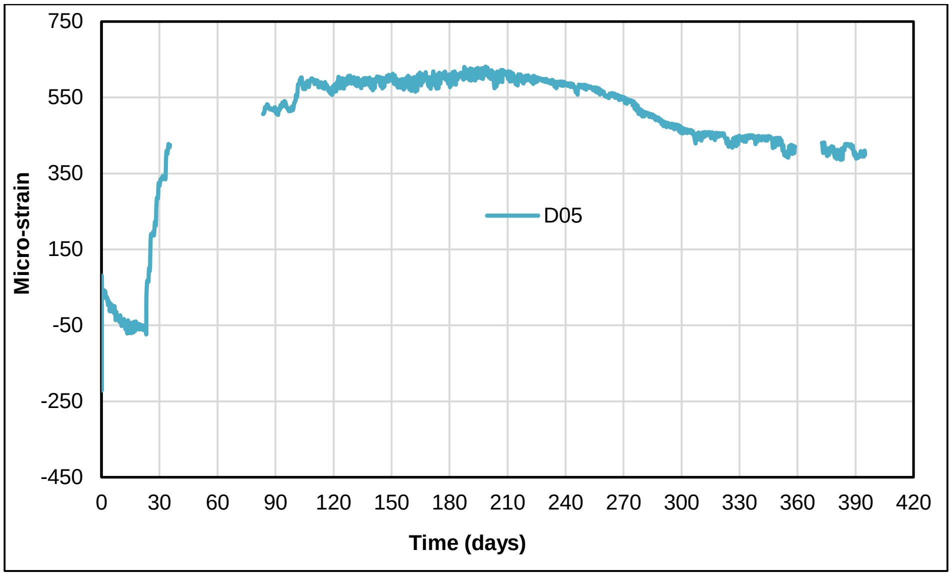


Figure 3: FOS Layout in the GFRP-CRCP test-zone

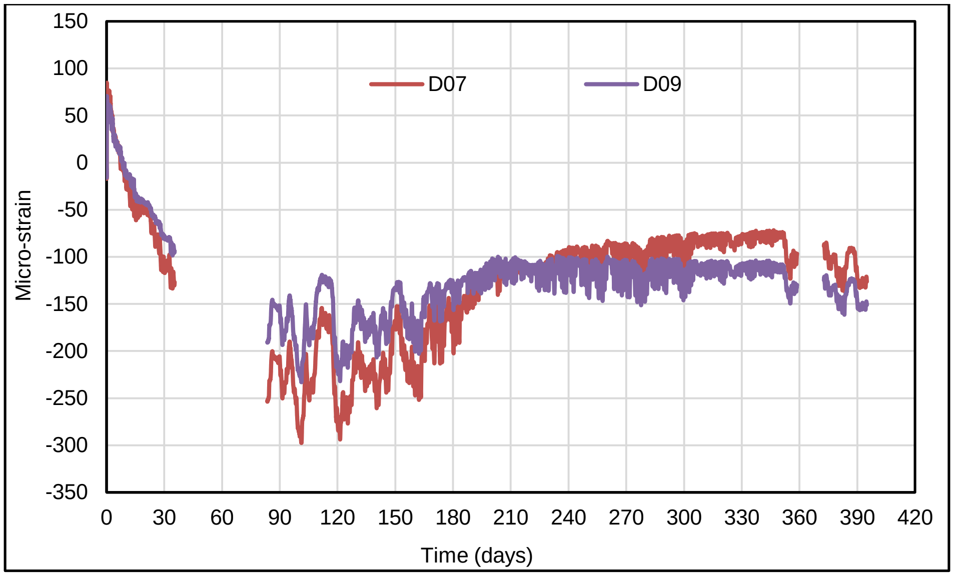
4. PRELIMINARY MONITORED FIELD RESULTS

4.1 GFRP Strain Behavior

The purpose of the reinforcement is to limit the contraction/expansion movements of concrete in the CRCP slabs, which in turn will affect the crack width and crack spacing in the surface of the CRCP. In general, the strains in the reinforcement of CRCP depend on different parameters such as the age of the CRCP slabs, temperature, and the location of the cracks in the slab related to the FOS instrumented points. Figure 5 shows the strain behavior in the GFRP reinforcement in the first 12 months. The reported strain values in the first 10 days represented concrete shrinkage. The high temperature due to cement hydration at early age could be observed.



(a) Strain at induced crack



(b) Restraint strains

Figure 4: Selected GFRP rebar strain response

Figure 4 shows that the maximum recorded tensile strain reached to approximately 150 microstrains, directly one day after casting the pavement. These strains induced the shrinkage cracks in the slabs as it was observed in the first week after casting. In this period, the number and width of the cracks in the GFRP-CRCP were a little higher than that in the steel-CRCP. Beyond that, the concrete pavement started to shrink as the weather temperature at the time went down, that contraction is resisted by the reinforcement and the subgrade induced friction. The concrete developed tensile stresses until it reached its tensile capacity and a crack forms at the weakest points in different sections of the pavement. Tension in the concrete near the crack was thereby relieved, and a tensile force is developed in the reinforcement at the crack, as shown in Figure 4.a. This continues until several cracks have developed and the tensile force in the concrete is no longer enough to result in additional cracks. The maximum tensile strain ranged from 500 to 600 microstrains during the winter. The measured values indicate that the GFRP reinforcement strains were insignificant, as they represented less than 1.0% of the ultimate strain of the GFRP bars. On the other hand, Figure 4.b shows the restraint strain in the GFRP reinforcement as resulted from the contraction of the pavement. The maximum compressive strain ranged from 150 to 300 microstrains during the winter.

4.2 Crack Spacing and Width

Crack spacing and width are generally acknowledged as the most critical indicators of CRCP slab performance. Tracking of crack propagation on the surface of the CRCP slabs was carried out in order to monitor the development of the cracking pattern, and to calculate the cracking rate and average crack spacing. All the concrete cracks observed were transverse cracks; there was no longitudinal crack. Figures 5 and 6 show the crack width and crack distribution along the length of the GFRP-CRCP and steel-CRCP sections, respectively; the crack width of each crack was traced at seven different ages after the construction. As can be seen in the figure, a drastic crack number change appears after the days of casting. This is because a large number of cracks were generated due to a combination of large concrete volume change due to drying shrinkage and low concrete strength, which is inherent at this early age. Field investigation indicated that the cracking rate for the steel-CRCP V2 is higher the cracking rate for GFRP-CRCP. The field performance of the GFRP-CRCP appeared satisfactory, particularly because the crack widths satisfied the AASHTO limiting criterion for crack width as ≤1 mm (0.04 in.) which is an essential requirement to maintain the integrity of the pavement by securing adequate aggregate interlock at the crack.

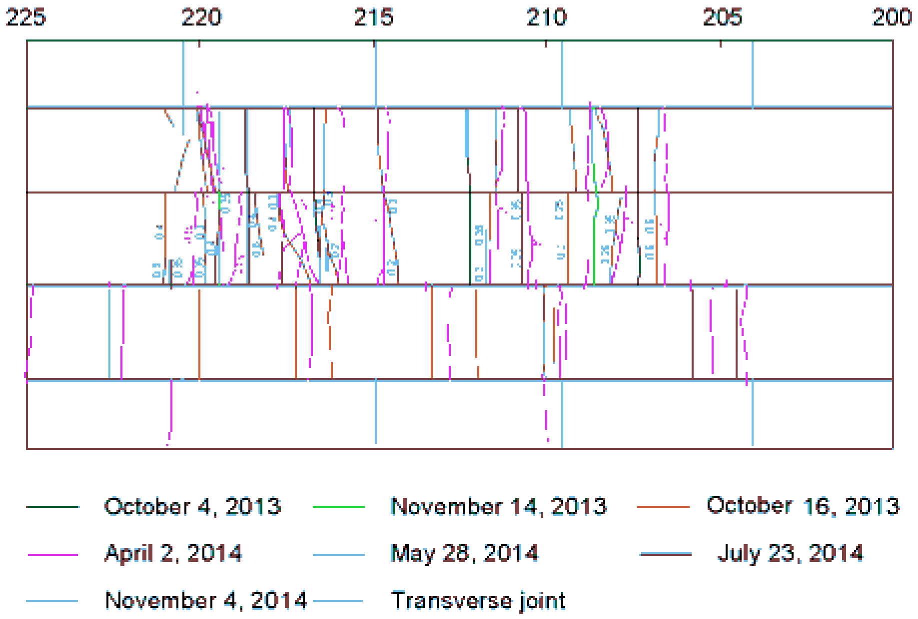


Figure 5: Cracks in concrete slab, section 200 to 225 (GFRP)

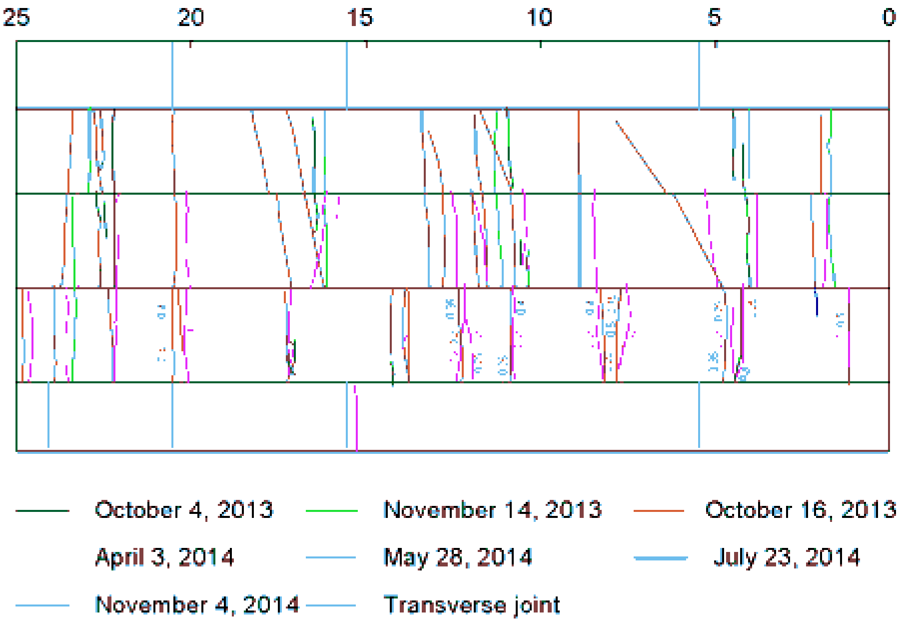


Figure 6: Cracks in concrete slab, section 0 to 25 (Steel)

5. CONCLUSION

According to the 16-month observation, the crack spacing and crack width of the GFRP-CRCP test section were similar to those of the steel-CRCP section. Nonetheless, the field performance of the GFRP-CRCP appeared satisfactory, particularly because the crack widths satisfied the AASHTO limiting criterion for crack width as ≤1 mm (0.04 in.) which is an essential requirement to maintain the integrity of the pavement by securing adequate aggregate interlock at the crack. Data from this experimental phase will allow the finite element modeling of the CRCP-GRFP slab.

Finally, this successful field application demonstrated the effective use of GFRP bars in a CRCP in the HW-40 in Montreal, Qc, Canada. The structural performance of this first application of its type and scale, based on the monitoring and continuous observations, was anticipated. This application opens the door to major application of FRP reinforcing bars in CRCP in North America and across the world. CRCP with GFRP bars would extend the life of such road applications to 100 years or more compared to steel-reinforced concrete, which needs major restoration after 25 years.

ACKNOWLEDGMENTS

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