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STRUCTURAL HEALTH MONITORING OF GFRP REINFORCED BEAM AT VETERAN AFFAIRS BROOKSIDE CEMETERY

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Abstract

One major issue concerning all cemeteries across Canada is the rapid deterioration of the markers and the reinforced concrete beams supporting these markers. While the extreme temperature fluctuation causing freeze-thaw cycles is one concern, the corrosion of the steel rebar is the other. The problem of corrosion may be eliminated through the use of glass fibre reinforced polymer (GFRP) as reinforcement bars and anchor rods. In addition, the implementation of a structural health monitoring system in the reinforced concrete beam will provide information on the performance, behaviour and state of condition of the beam, which allows for the optimum design of such units. This work involves the design, instrumentation, and periodic monitoring of a field trial beam at the Veteran Affairs Brookside Cemetery. Prior to casting of the reinforced concrete beam, a total of 12 sensors were installed at critical locations in the reinforced concrete beam. The beam was monitored during and after the installation of the GFRP reinforced concrete beam at Brookside Cemetery. The measurements taken include temperature of the concrete beam, frequency response of the beam to a 68 kg mass excitation at the mid-span, deflection of the beam, and crack width. The beam has been monitored periodically and the measurements have provided insight into the performance and state of the reinforced concrete beam.

INTRODUCTION

Premature deterioration of marker anchor assemblies at the graves of veterans is a growing concern for cemeteries across Canada, including Brookside Cemetery, located in Winnipeg, Canada. Existing marker anchor assemblies have experienced deterioration in the form of longitudinal cracking of the concrete beams and concrete degradation due to frost action. The main causes of deterioration of the markers and support beams were: poor quality of reinforced concrete beams, moisture infiltration and frost attack, inadequate bearing at the supporting ends of the reinforced concrete beams, and deterioration of the reinforcement.

In the past few years, the Veterans Affairs Brookside Cemetery became part of on an ongoing research program to suggest improvements to the current design. The use of glass fibre reinforced polymer (GFRP) as reinforcement bars and anchor rods was investigated as a method to increase the service life of the marker anchor assemblies under harsh environmental conditions. Fibre reinforced polymer (FRP) composite materials possess many advantages over traditional steel reinforcement such as high tensile strength and corrosion resistance. In 2004, a full scale trial marker anchor assembly and concrete beam was designed and constructed using solely GFRP for reinforcement and anchor rods. A structural health monitoring system was also installed in the reinforced concrete beam to provide information on the performance, behaviour, and state of condition of the beam. Reports published so far described the development and characterization of GFRP reinforced concrete beams [1,2] and the installation of the structural health monitoring system [3].

This paper describes the design, instrumentation and the periodic measurements obtained from the monitoring of the field trial beam at Brookside Cemetery (Fig. 1). The GFRP reinforced concrete beam has been periodically monitored over a 30 month period and measurements taken from August 2004 to February 2007 are reported in this paper. This report also describes the remedial work performed to reduce the deflection of the beam.

Figure 1. GFRP reinforced concrete beam at Brookside Cemetery

DESIGN AND INSTRUMENTATION

The GFRP reinforced concrete beam was designed in accordance with Canadian Code standards (Concrete Design Handbook A23.3-94, CSA S806 and ISIS Canada Design Manual III [4-6]). Analyses for shear and bending moment were performed for the standard length of 7.32 m for a ground support beam used in the field.

The marker locations and beam position are shown in Figure 2. The markers are equally spaced at 1219.2 mm on centre. The centre to centre distance between the supports is 6781.8 mm and the clear span distance between the supports is 6375.4 mm. A detailed view of the GFRP reinforcement in the north end of the beam is shown in Figure 3.

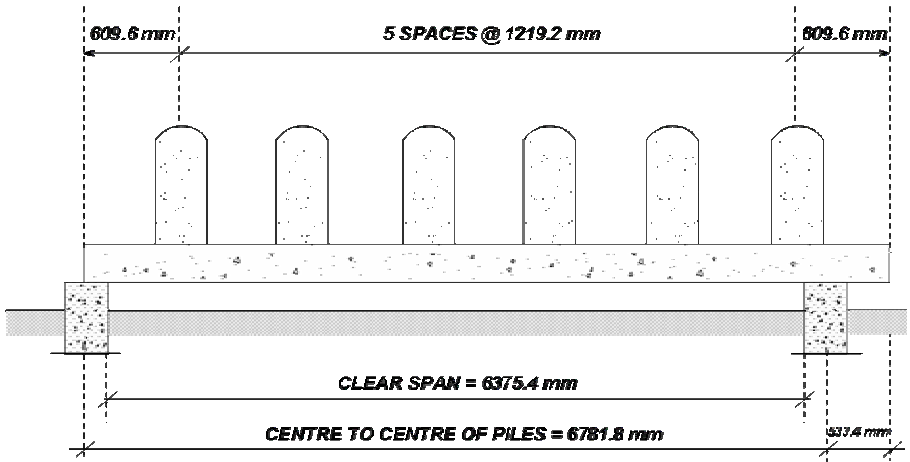


Figure 2. Locations of markers and beam position on support piles

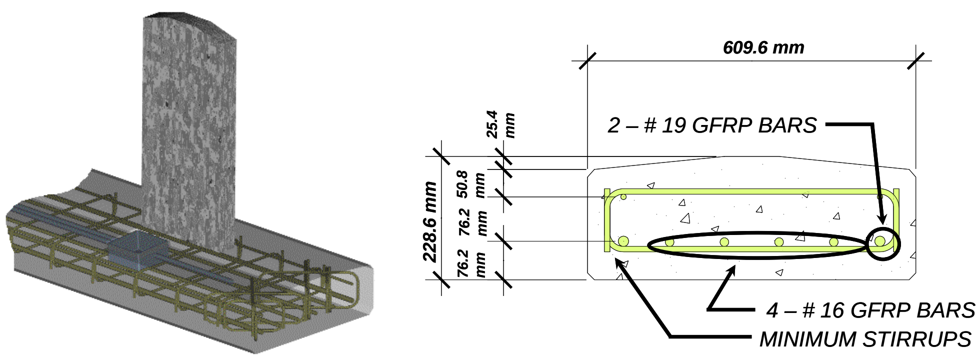


Figure 3. Reinforcement details for concrete beam

The structural health monitoring system consisted of a total of 12 sensors, which were installed at critical locations in the reinforced concrete beam prior to casting. In order to gain a comprehensive representation of the condition of the beam and validate the theoretical calculations of mid-span deflection and natural frequency, three types of electrical sensors were selected. Each type of sensor would provide information on a different aspect of the concrete beam. Electrical strain gauges were used to provide strain measurements on the GFRP reinforcing bars. Thermocouples were also installed to measure the temperature inside the beam. Finally, an accelerometer was installed at mid-span to measure the frequency response of the beam to an applied load.

At each end of the beam, two strain gauges on the stirrups and a thermocouple on the reinforcement bar were installed as shown in Figure 4. At the mid-span, four strain gauges, a thermocouple and the accelerometer were installed on the bottom reinforcement bars. The majority of the sensors were placed at the mid-span since it was expected to experience the largest amount of deflection and strain.

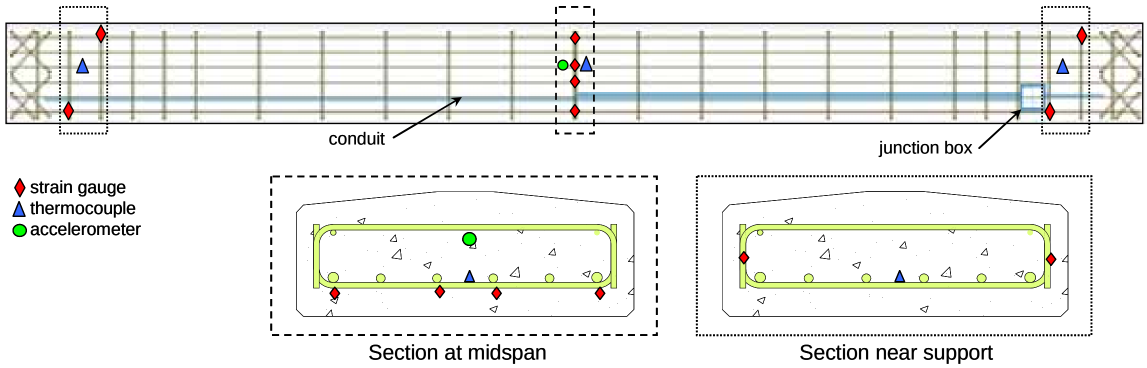


Figure 4. Locations of sensors installed in reinforced concrete beam

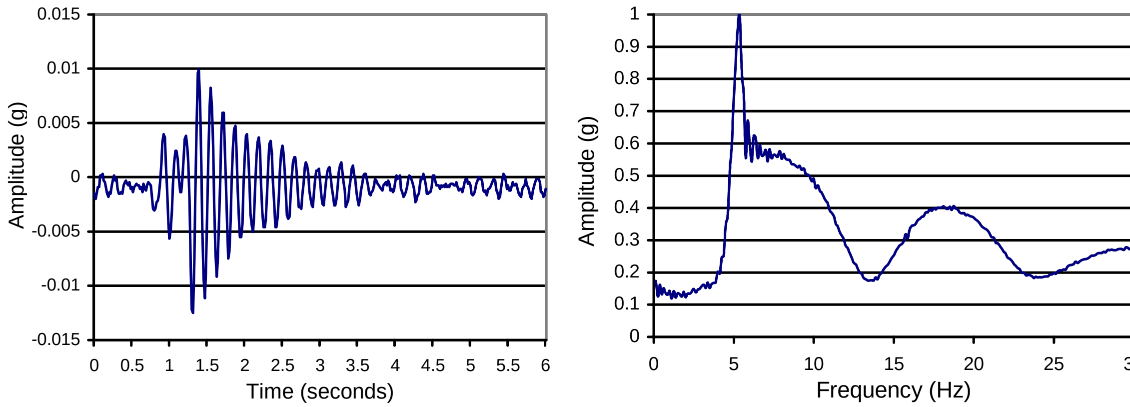
STRUCTURAL HEALTH MONITORING

The instrumented GFRP reinforced concrete beam was installed at Brookside Cemetery on August 26, 2004. Two backhoes with chains and straps were used to lift the beam on each end and place it on the existing concrete piles (Figure 5). During this process, the sensors installed in the beam were monitored and strains of up to 200 $\mu\varepsilon$ were recorded while nominal strains were observed at the support sections.

Figure 5. Installation of reinforced concrete beam on piles

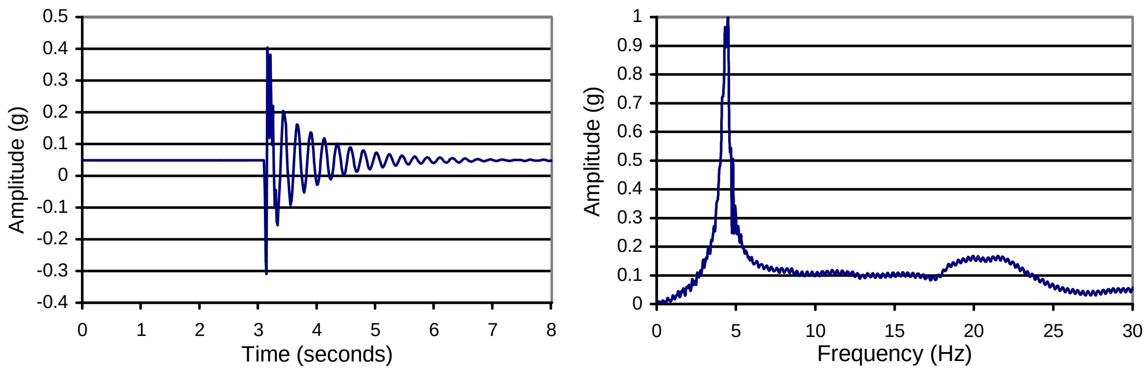
Following the installation at Brookside Cemetery, periodic measurements were taken from the GFRP reinforced concrete beam to monitor its performance over the course of 30 months. The static and dynamic response of the beam was recorded using a data acquisition system. The deflection of the beam was also measured each time as well. By monitoring the beam over a long term period, researchers were able to observe the condition of the beam.

The dynamic response of the beam was measured using the embedded accelerometer. The beam was excited at mid-span with a 68 kg mass and the readings were recorded with a data acquisition system. The frequency of the beam was then determined by taking the fast Fourier transform (FFT) of the accelerometer response. The accelerometer response and frequency of the beam after installation of the markers is presented in Figure 6. In July 2006, accelerometer readings using the same excitation were recorded (Figure 7). As seen in Figures 6 and 7, the frequency of the beam in August 2004 was approximately 5.4 Hz; while in July 2006, the frequency was 4.5 Hz. This reduced frequency is caused by the decreased stiffness of the beam as the concrete has cracked over time.



a) b)

Figure 6. Frequency response of concrete beam in August 2004
a) Accelerometer response; b) Natural frequency



a) b)

Figure 7. Frequency response of concrete beam in July 2006
a) Accelerometer response; b) Natural frequency

REMEDIAL WORK

Over the monitoring period of 30 months, the deflection of the beam at mid-span has been of interest. During each inspection, the deflection of the beam was measured using a theodolite. It is important to note that the trial beam has a very shallow depth due to design constraints and because no gravel bed was placed below it during its installation. Hence, the beam continued to deflect due to creep of the concrete. As the deflection of the beam increased to 84 mm over a two year period (Figures 8), remedial work was discussed to raise the beam to improve the aesthetics.

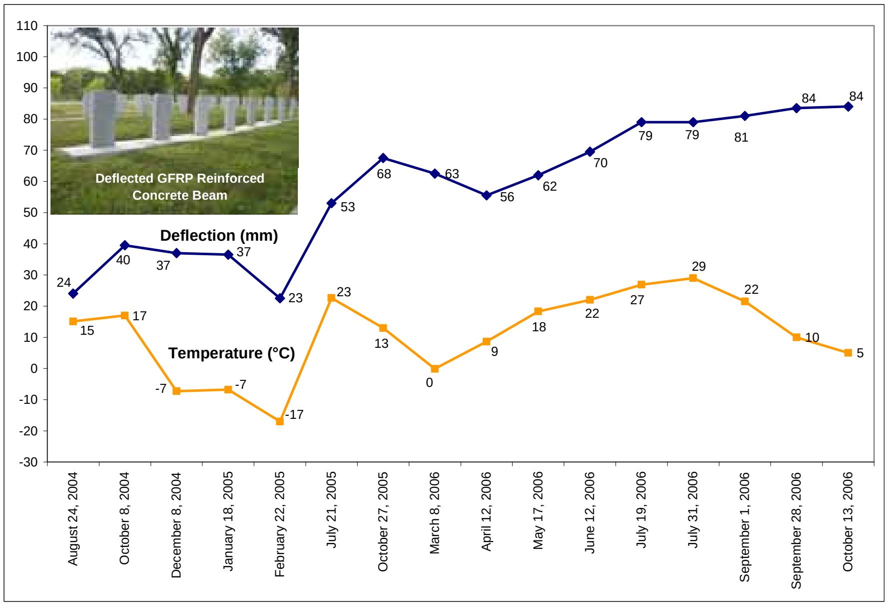


Figure 8. Periodic measurements of deflection at mid-span and temperature

After discussions with Veteran Affairs Canada, City of Winnipeg Cemeteries, and Concrete Restoration Services, a plan of action was agreed upon to raise the beam. This plan of action involved using four hydraulic jacks at middle third points to lift the beam.

The first phase of the work involved pinning the ends of the beam to the concrete piles supporting it. The purpose was to ensure the ends of the beam remained in constant contact with the piles during the raising of the beam. A hole was drilled at each end of the beam up to a depth of 152 mm into the concrete pile. A 9.5 mm GFRP bar was then inserted into each hole and epoxy was used to bind the bars to the concrete beam and piles.

The next phase involved the placement of the four 20 ton hydraulic jacks. Two jacks were placed at each of the middle third points of the beam: one on the east side and the other on the west side of the beam. At each middle third point section, the beam was supported by a steel channel section spanning the two jacks (Figure 9). The beam was then raised simultaneously by the four hydraulic jacks. After the beam was raised, steel shims were hammered in between the GFRP reinforced concrete beam and the existing beam below it. The hydraulic jacks were then released and removed. Finally, the previously removed earth was replaced around the beam (Figure 10).

a) b)

Figure 9. a) Hydraulic jack underneath channel section supporting the beam; b) Installation of steel shims

Figure 10. GFRP reinforced concrete beam after remedial work

During the lifting of the beam, both internal and external sensors were used to monitor its behaviour. The strains on the top surface of the concrete and on the internal GFRP reinforcement bars were recorded. A graph of the strain recovered in the reinforcement at mid-span during the lifting of the beam is shown in Figure 11. A Pi gauge and a Demec gauge were installed externally to measure the strain on the top surface of the concrete. The deflection of the beam was measured using a theodolite and a linear variable differential transducer (LVDT).

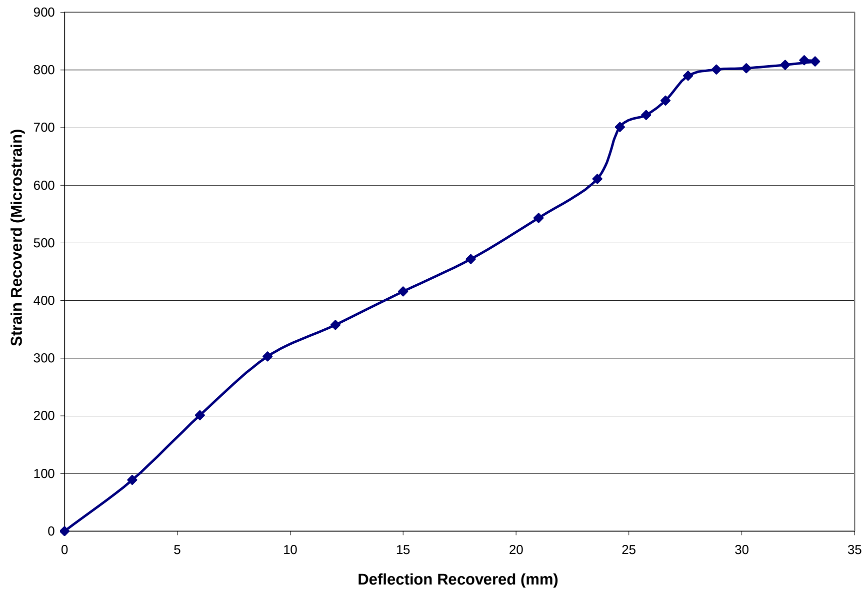


Figure 11. Strain in the midspan internal reinforcement during lifting of the beam

After completion of the remedial work, the deflection of the beam was decreased to 43 mm as seen in Figure 12. Thus, the beam was raised by 41 mm from the maximum deflection of 84 mm.

The performance of the beam has been periodically monitored after the remedial work was completed. The deflection of the beam has not changed in the four months after it was raised as seen in Figure 12. The trial beam is safely carrying the marker and its own weight and there is ample reserve ultimate strength. The restoration effort will keep the deflections small. The GFRP pin connections are working very well between the markers and the trial beam. The durability of the beam is excellent. As part of the restoration effort, it is anticipated that the deflection of the beam will be further reduced to 20 mm.

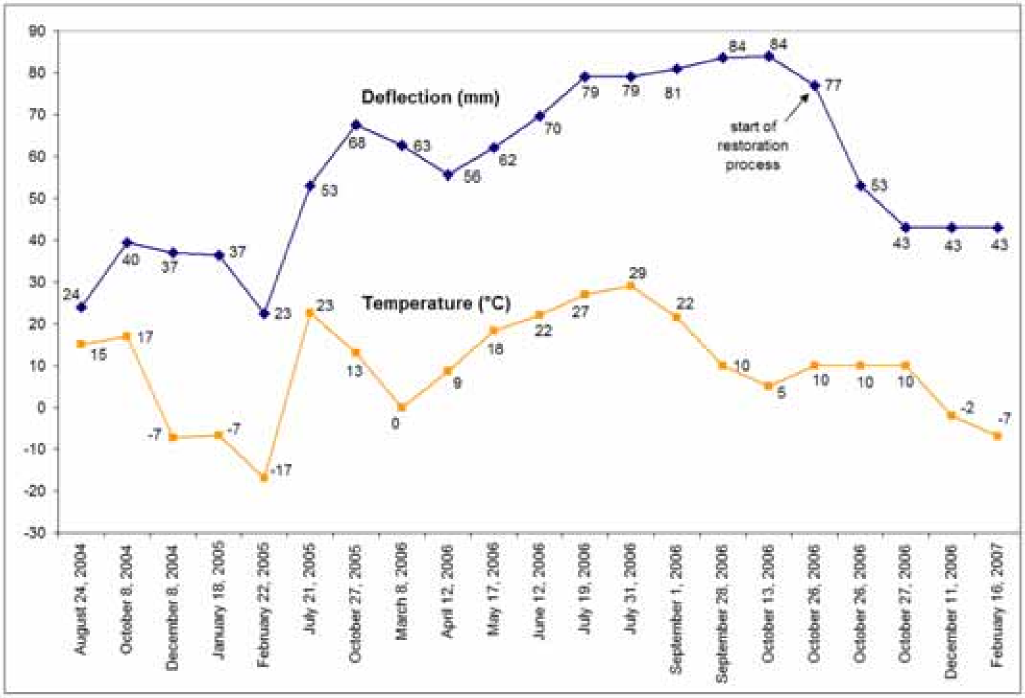


Figure 12. Periodic deflection and temperature measurements up to the completion of remedial work

CONCLUSION

To address the concern over the rapid deterioration of marker anchor assemblies at Veteran Affairs Cemeteries across Canada, a field trial beam was constructed using GFRP reinforcement. The reinforced concrete beam was instrumented with conventional sensors and monitored periodically over a 30 month period. The initial frequency of the beam was 5.4 Hz and over a two year period, it has decreased to 4.5 Hz. Through periodic monitoring, researchers were able to observe the long term performance of the beam. Upon visual inspection, the condition and durability of the concrete beam is excellent. The increase in the deflection of the beam alerted researchers to take remedial action and raise the beam. After the restoration process, the deflection of the beam was reduced by approximately 50%. The beam has maintained its deflection for four months after the restoration process. Future work involves reducing the deflection to 20 mm. This project has provided substantial information that will be useful for future designs of marker anchor assemblies for cemeteries across Canada.

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