Fiber Grating Systems for Traffic Monitoring

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Abstract

Blue Road Research has designed, built, and installed fiber grating sensor systems onto bridges, and most recently into an asphalt and concrete highway test pad. The sensitivity levels of the fiber grating sensors are sufficiently high to enable detection of people standing on the bridge or highway. This paper briefly overviews the usage of these sensors for traffic monitoring.

Introduction

This paper will describe the results obtained at two installations. The first is the Horsetail Falls bridge in the Colombia River Gorge National scenic area, shown below, which was instrumented by Blue Road Research in September, 1998 with 28 fiber grating sensors[1,2] (see Figure 1). Two of the fiber grating sensors were damaged during sensor installation, but the other 26 have been operational and used to support testing for over a year and a half, showing no measurable change in performance of the structure.

Figure 1. Horsetail Falls Bridge in the Colombia River Gorge National Scenic Area.

Figure 2. 1.0 m fiber grating sensors used to support multipoint, high-speed dynamic strain measurements.

The tests initially performed on the Horsetail Falls Bridge were made with a portable optical spectrum analyzer that had a resolution of about 5 microstrain. This system was adequate for static strain measurements to establish that the fiber reinforced polymer (FRP) composite strengthening approach to upgrade the bridge was successful. Additional static testing was performed periodically over the course of the next year. In order to perform more comprehensive testing, the Oregon Department of Transportation (Oregon DOT) wanted sub-microstrain resolution and, ideally, a response of at least 100 Hz.

Blue Road Research has been developing fiber grating based spectral demodulation systems for the past five years. With improved light sources, fiber grating filters, and receivers, Blue Road Research has been able to achieve less than 0.1 microstrain resolution at 2000 Hz[3,4]. To support multi-point, high-resolution testing on the Horsetail Falls bridge, five of these systems were deployed by Blue Road Research in November, 1999.

The second set of tests were performed on asphalt and concrete test pads that were built at the Blue Road Research facility. The objective was to improve traffic sensor performance using fiber optic grating technology. Potential applications include vehicle classification, axle counting, weigh in motion, and possibly traffic signal activation. Blue Road Research and Smartec sensors were used with Blue Road Research fiber optic grating strain sensor demodulation systems. The first demodulation system had an absolute accuracy of approximately 2 microstrain with a resolution of about 0.2 microstrain. Its bandwidth was on the order of 0.5 Hz. The second system has been able to achieve less than 0.1 microstrain resolution at 10 kHz. The first system was used for benchmarking the installation while the second was used for dynamic testing. The first part of this paper will provide an overview of traffic monitoring on the Horsetail Falls Bridge. The second part of the paper will present results from the test pad.

Static and Dynamic Tests on the Horsetail Falls Bridge

On November 3, 1999 the Horsetail Falls Bridge was closed by the Oregon Department of Transportation for evaluation. Test positions for a test vehicle were marked onto the bridge. Figure 3 shows the three-axle dump truck that was used as a test vehicle. The truck was positioned at seven discrete locations along the bridge for the static measurements of flexural strain. Ten 1.0 m flexural sensors were monitored.

Figure 3. Test vehicle used for static and dynamic testing of the Horsetail Falls Bridge.

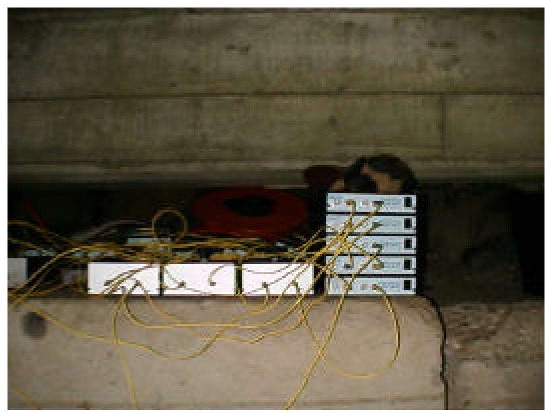

Figure 4. Five high-speed, high-sensitivity fiber grating demodulation systems used by Blue Road Research for measurements.

The five high-speed fiber grating demodulators with a bandwidth of 10 kHz that were used for the dynamic tests is shown in Figure 4. The test truck ran at two different speeds while strain measurements were taken. A single 1.5 mW, l300 nm light source was used to support all five channels. The fiber grating filters used were tunable and had a dynamic range of approximately 400 microstrain. The data acquisition speed during the tests was 10 kHz.

Figure 5 shows the results of running the truck over the bridge at a speed of 18 km per hour (10 mph). The sensitivity levels are approximately 0.2 microstrain for the sensor responses shown.

The tests were performed in support of health monitoring of the fiber reinforced polymer (FRP) upgrade to the Horsetails Falls Bridge. Another application that is apparent is the ability to monitor vehicular traffic. Measurements of value to departments of transportation include weighing vehicles, classifying vehicles, and being able to detect their presence on the bridge. The ability to detect very light vehicles such as motorcycles is also important for traffic monitoring applications.

To verify the ability of a system to perform these tasks, one transverse beam with two centrally-located sensors (T0FC and T1FC) and one offset sensor (T1FR) was selected. Three high-speed fiber grating demodulation systems were used to monitor strain. The demodulation systems were supported by approximately 250 µW of optical power at 1300 nm. The results are shown in Figure 5.

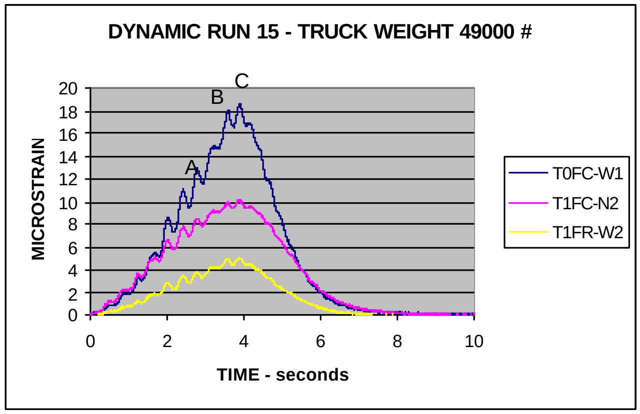

Figure 5. Output from three high-speed fiber grating flexural strain sensors under the Horsetail Falls Bridge as a fully loaded truck passes over.

Calculations show that Peak A corresponds to the front axle of the truck passing directly over the instrumented beam. The flattened area of the curve between points A and B is likely due to a balanced condition when the front and back axles are straddling the beam. Peaks B and C are the two rear axles crossing the beam. This was verified by noting the time the peaks occurred, the geometry of the trucks wheelbase (Figure 6), and calculating the truck velocity, which was calculated to be 9.4 mph. The truck driver had been instructed to approach the bridge from a distance and cross at a constant speed 10 mph.

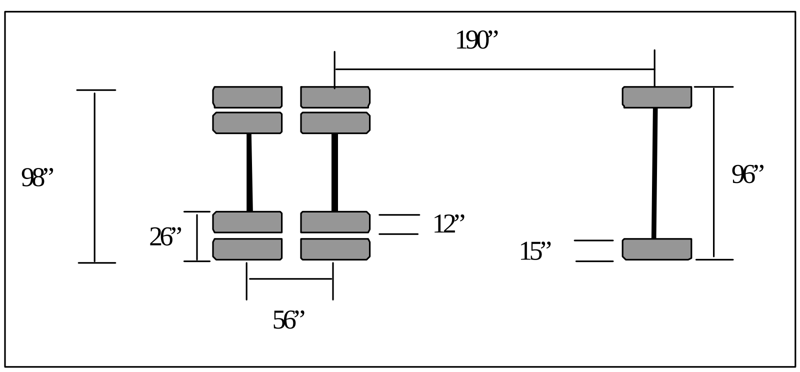

Figure 6. Dimensions of the test truck wheelbase.

In Figure 7, three vehicles are shown: a minivan, an SUV, and a small car. The strains measured in this manner can be used to estimate vehicle weight. The ability to measure small weights is shown by the signals generated by a 180 lbs. man running and jumping on the bridge. Each of these signals is clearly distinguishable in the plot. While the intent of the tests was not to monitor pedestrian traffic, it is evident that light loads can be monitored.

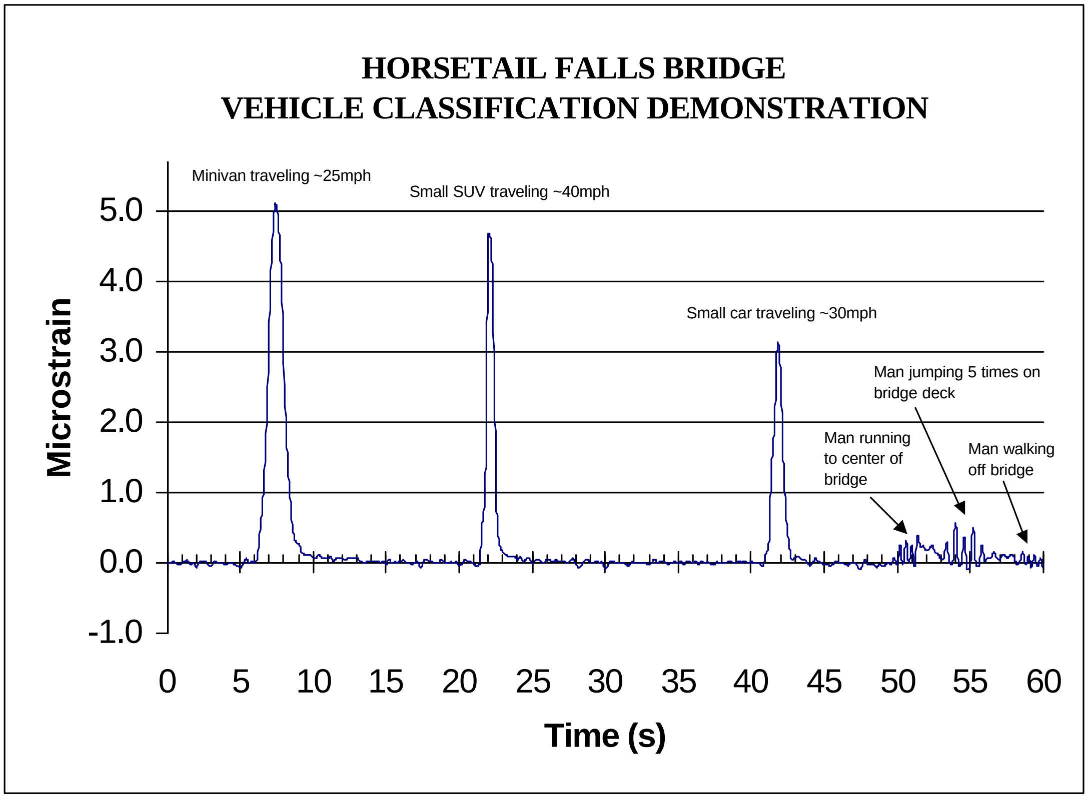

Figure 7. Output from the high-speed, high-sensitivity fiber grating sensor system to demonstrate the viability for vehicle classification and weighing on the Horsetail Falls Bridge.

If the corresponding sensor on the adjacent beam was monitored at the same time as the sensor that produced the data for Figure 7, the distance between the sensors could be used to determine the speed of the vehicle. It is apparent that the peak amplitude and width (area) could be used to estimate the weight of the vehicle. A single fiber grating used together with radar could yield the same information. If the time base were changed and a footprint similar the that in Figure 5 was obtained, the individual axles and vehicle classification could be resolvable, along with weight and velocity.

Embedding Fiber Grating Strain Sensors into an Asphalt and Concrete Test Pad

Two adjacent test pads, one of asphalt and one of concrete, have been constructed at Blue Road Research to support the development of fiber sensor-based traffic monitoring systems. Each pad is 3m x 3m x 10cm and was placed on a 10 cm gravel base. The asphalt pad was placed in two 5 cm lifts.

Two different types of sensors were used. The first set was developed by Blue Road Research to be used mainly on structures. The overall diameter of the sensor is 3 mm (.125 inches) in diameter with end anchors of 6 mm (0.250 inches) in diameter. Half the slots in the test pads were cut to accommodate these sensors. Smartec, SA in Grancia, Switzerland which is collaborating with Blue Road Research on it dynamic fiber grating sensor system manufactured the second set of sensors, with the body of these sensors approximately twice that of the Blue Road Research sensors. Figure 8 shows the slots being cut into the pads to facilitate the sensor installation.

Figure 8. Cutting slots into the asphalt and concrete sections of the Blue Road Research test pads.

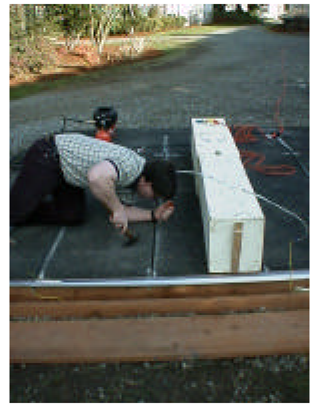

Figure 9. Slot preparation.

Figure 9 shows a slot being prepared to receive the sensor in asphalt. When the mechanical preparation was finished, the slot was cleaned and dried. A thin layer of epoxy was placed in the slot. Next, the sensor was installed (see Figure 10) and the slot was filled with epoxy. The rectangular box to the right (Figure 11) is a heater to help the epoxy cure during cold ambient temperatures.

Figure 10. Installing the sensor.

Figure 11. Heater boxes being used to cure epoxy.

After the epoxy had cured, the optical connections to the laboratory were made and the sensors were tested to make sure they survived the installation. This has been followed by a series of tests on the concrete and asphalt pad that are ongoing. Figure 12 shows the response of the pad to a 3500 pound car pulling onto and off of the asphalt test pad in the region of one of the fiber gratings.

Test Results for the Concrete and Asphalt Test Pad

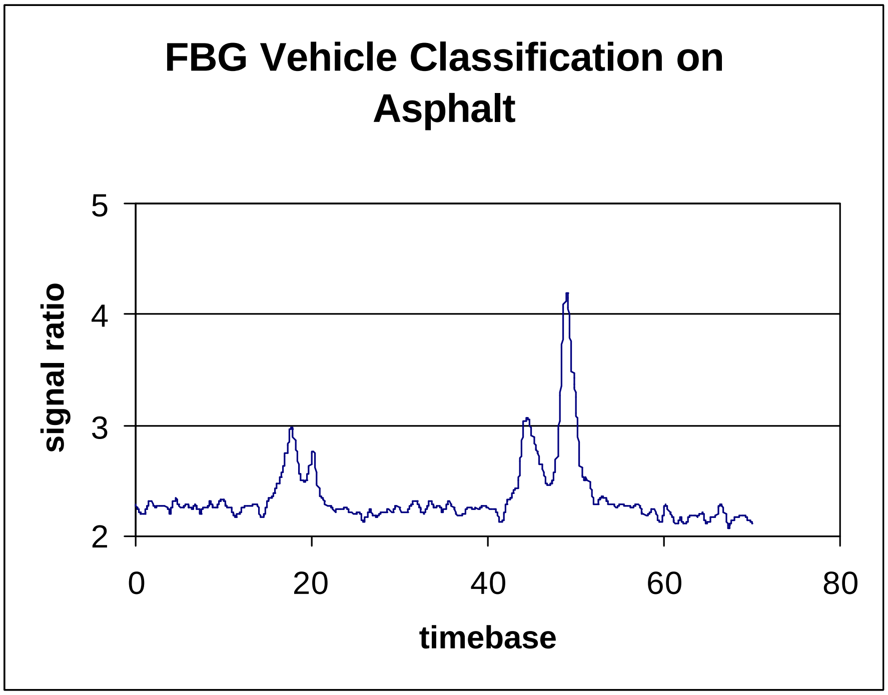

Figure 12. Response of an fiber grating strain sensor embedded in asphalt to a 3500 pound car pulling onto and off of the asphalt pad. The difference in response are due to changes in location of the tire rolling over the fiber grating strain sensor region.

Additional testing will be ongoing with the test pad in preparation for installation of this system into a freeway and overpass to test response of the system to both concrete and asphalt operating environments.

Summary

Dynamic high-speed testing was conducted on the Horsetail Falls bridge that allowed multi-point sub-microstrain measurements to be obtained to support health monitoring of this historic bridge. A single point fiber grating sensor was shown to be effective in monitoring vehicle traffic speed, weighing vehicles in motion and classifying traffic vehicles. The sensitivity of the single point fiber grating strain sensor system was shown to be sufficient to detect joggers on the Horsetail Falls bridge and adults walking.

Acknowledgements

The material for the first part this paper covering the Horsetail Falls bridge was drawn from a paper presented at OFS 14[5]. Blue Road Research would like to thank Smartec and Daniele Inaudi for assistance with the Smartec fiber grating sensor housings.

References

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