USAGE OF FIBER GRATING SENSORS TO PERFORM CRITICAL MEASUREMENTS OF CIVIL INFRASTRUCTURE

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ABSTRACT

Fiber optic grating sensors have been used to support long term health monitoring of the Horsetail Falls historic bridge in Oregon, traffic monitoring on the I-84 freeway, testing of large bridge structures and most recently preparations for instrumentation of a major bridge in Portland, Oregon. This paper overviews these efforts.

1998 HORSETAIL FALLS BRIDGE INSTALLATION

The first major civil structure installation of Blue Road Research was the Horsetails Falls Bridge in the Colombia River Gorge National Scenic Area located approximately 33 miles east of downtown Portland, Oregon [1-3]. This bridge, shown in Figure 1, is a historic bridge constructed in 1914 that was originally intended to support lightweight automobiles and horse carriages. Because it is located in the most heavily visited natural tourist area in Oregon the Oregon Department of Transportation sought means to strengthen the bridge to support tour buses while maintaining the appearance of the bridge in conformance with requirements of the Colombia River Gorge Commission. A composite over wrap method was selected and Blue Road Research produced approximately 60 long gage length fiber grating sensors that were placed in full scale test beams subject to break testing and 28 sensors in the Horsetail Falls bridge to measure both shear strain and tensile strain in key beam locations. The fiber grating sensors were placed both in the composite over wrap and in the concrete beams by cutting 3 mm grooves.

The bridge was subject to extensive static testing over the past 5 years. Data obtained was used to support analytical studies conducted at Oregon State University showing the bridge had been strengthened beyond expectations. When Blue Road Research developed high speed, high sensitivity read out units demonstrations were performed to show that the speed and weight of vehicles on the bridge could be monitored with sufficient sensitivity that a man walking and running on the bridge could be detected, as shown in Figure 2 [3].

These demonstrations on the Horsetail Falls Bridge served as the basis for more extensive testing both to monitor traffic and for larger scale bridge structures.

FIGURE 1. HORSETAIL FALLS BRIDGE

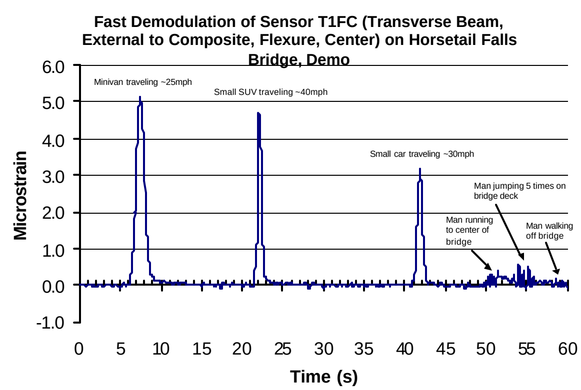

FIGURE 2. DYNAMIC TESTING OF A FIBER GRATING SENSOR ON THE HORSETAIL FALLS BRIDGE

TRAFFIC MONITORING ON THE I 84 FREEWAY USING LONG GAGE LENGTH FIBER GRATING SENSORS

To monitor traffic on freeways to count traffic and to perform weigh in motion studies a series of electrical sensors have been developed. These include Hall effect sensors for traffic counting and piezoelectric based devices to support monitoring vehicle speed and weigh in motion. There are difficulties installing these electrical sensors and they are prone to early failure. The piezoelectric based devices often give the highest accuracy but they are surface mounted and tire induced wear often severely limits their lifetime. What was needed was a system that could be place approximately 7.5 cm under the freeway surface with sufficient sensitivity to identify traffic by axel counting, measure speed and eventually support weigh in motion. Blue Road Research with support from the Oregon Department of Transportation has installed two sets of four sensors each on the I 84 freeway [4-7]. The first set of fiber grating sensors was installed in August of 2001. Figure 3 shows cuts being made in the I 84 freeway to support the first set of fiber grating sensors.

FIGURE 3. INSTALLATION OF FIBER GRATING SENSORS INTO THE I 84 FREEWAY

Once the fiber grating sensors were installed they were used to support the demonstration of the ability to measure the speed of traffic, to count axels and determine axel spacing. The last two functions were used to support the identification of truck types.

As an example Figure 4 shows a truck trailer whose signature from two of the sensors in the I 84 freeway is shown in Figure 5. The truck trailer has two leading and three trailing axels. The separation in time between the leading edge events may be used to determine truck speed. The separation between peaks can be used to determine the axel separation that in turn may be used to identify the type of truck trailer being used.

FIGURE 4. PHOTO OF TRUCK TRAILER PASSING OVER THE I 84 FREEWAY IN THE VICINITY OF THE FIBER GRATING STRAIN SENSORS, SEE FIGURE 4

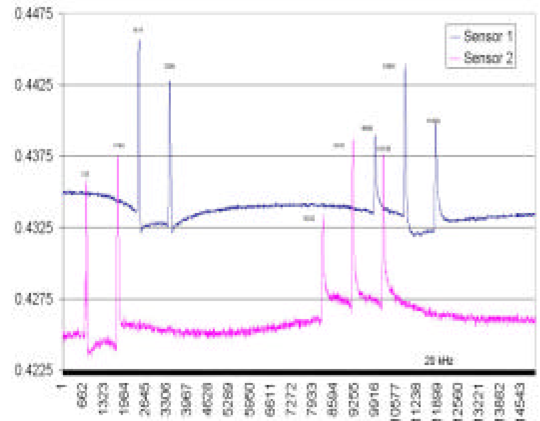

FIGURE 5. DATA FROM TWO DISPLACED SENSORS USED TO MEASURE THE SPEED AND AXEL SPACING OF THE TRUCK TRAILER OF FIGURE 4

To support weigh in motion efforts and improve overall performance a second set of fiber grating sensors was installed on the I 84 freeway in August 2002 using a variety of improved packages. These sensors were superior in terms of ruggedness and their baseline return to zero improved which will allow their continued development with the final objective of achieving weigh in motion capabilities for a system that can be buried deeply into concrete highways.

REAL TIME DAMAGE ASSESSMENT OF LARGE CIVIL STRUCTURES

A third area of investigation that has been pursued by Blue Road Research in collaboration with the University of California in San Diego involves performing real time damage assessment of large civil structures using high speed, high sensitivity fiber grating strain sensors.

In 2002, the Federal Highway Administration and Caltrans performed a full-scale test on some of the components that will be used for the planned I-5/Gilman Advanced technology Bridge in California, USA. As a part of this test Blue Road Research used its developmental system to validate the use of this damage detection technique and to compare the results with conventional modal analysis tools. Figure 6 shows a drawing of the proposed Gilman bridge.

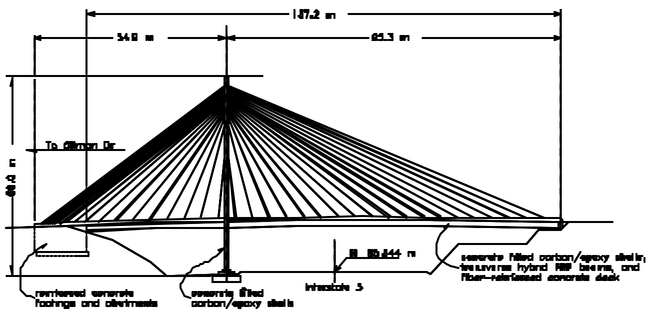

FIGURE 6. DRAWING OF THE ADVANCED TECHNOLOGY GILMAN BRIDGE

One of the components tested consisted of prefabricated carbon/epoxy shells filled with concrete form the longitudinal girders for the I-5/Gilman Advanced Technology Bridge. These cylindrical girder shells are 0.91m (3 ft) in diameter, 9.75m (32 ft) long, and to achieve ductile connection and system behavior; they are spliced together with mild steel reinforcement. The interfacial shear resistance between the girder and the deck is provided by shear stirrups embedded in the concrete core and protruding the composite shell through two rows of 51mm (2 in) diameter holes drilled along the top edge of the girder.

In regard to the longitudinal girder test program, a carbon shell specimen was cut into two equal halves, spliced together with mild steel reinforcement, and filled with concrete. The objectives of this test were to (1) determine the construct ability of the steel-spliced girder and (2) demonstrate adequate ductility of the splice connection.

Figure 7 shows the experimental set up for four point bend testing. Long gage length fiber grating strain sensors as shown in Figure 8 were mounted on the girder along with accelerometers. A shaker shown in Figure 9 was used to activate the girder and generate modes of vibration. A large instrumented hammer was also used.

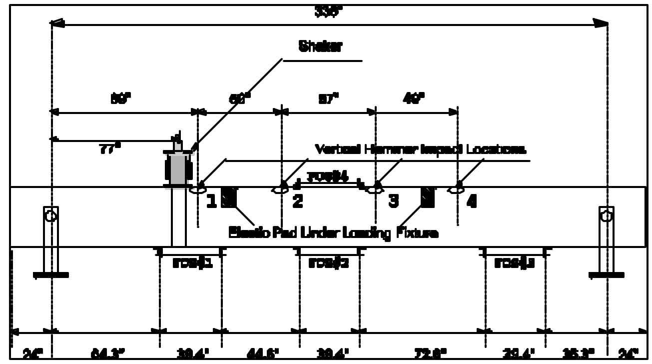

FIGURE 7. LAYOUT OF THE FOUR POINT BEND TEST OF THE BRIDGE BEAM

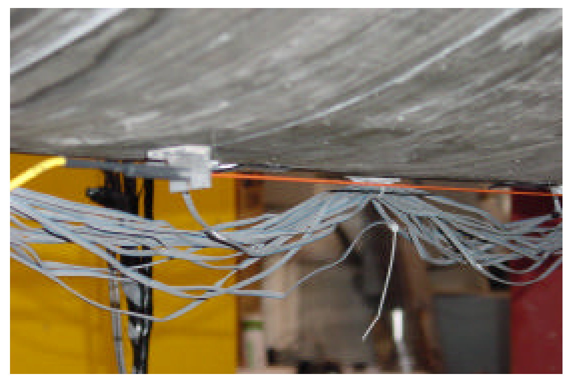

FIGURE 8. LONG GAGE LENGTH FIBER GRATING SENSOR MOUNTED ON THE BOTTOM OF THE BEAM

FIGURE 9. SHAKER USED TO GENERATE VIBRATIONAL MODES IN THE BRIDGE BEAM

The results from these tests showed strong agreement between the structural modal parameters inferred from data taken with the accelerometers and fiber grating sensors. This not only further validates the use of long gage length fiber grating sensors in system identification, but also indicates that the modal identification method of detecting structural damage has the potential to accurately diagnose degrading structural members. Quantifying changes in modal parameters with increasing damage is the first step toward complete damage identification. At this point, the algorithm is able to reveal a clear change in the vibration properties of a large structural component tested in its nonlinear range in laboratory conditions. Further developments in signal modeling and analysis will enable the location of the damage to be obtained as well as a quantified measure of the state of damage at that location.

NEXT STEPS

Blue Road Research is currently having discussions on the instrumentation of a major bridge in the downtown Portland area that would include using static and dynamic strain measurements to perform overall health monitoring. This system would incorporate many of the capabilities described in this paper in one installation.

SUMMARY

Fiber grating sensors may be used to support a wide variety of civil structures to monitoring systems. This includes both static and dynamic strain measurements. Dynamic systems may be used to enable real time damage assessment systems and to support such applications as traffic monitoring on highways and bridges.

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