Traffic Monitoring Using Fiber Optic Grating Sensors On the I-84 Freeway & Future Uses in WIM

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Abstract

Blue Road Research has demonstrated the use of fiber optic Bragg grating sensors in roads and highways to develop traffic sensors that could count and classify traffic usage on roadways, providing statistical information for maintenance, safety, and growth. This paper reviews the progress by Blue Road Research that led to installation of traffic sensors on the I-84 freeway and outlines the benefits of developing a fiber optic weigh-in-motion sensor.

Keywords: Bragg grating, vehicle classification, traffic monitoring, WIM

Introduction

Efforts are under way to harness optical fiber for use as an accessory to vehicle and roadway monitoring. The use of fiber Bragg grating sensors for traffic studies began by Blue Road Research (BRR) as an effort with the Oregon Department of Transportation (Oregon DOT) to monitor composite bridge strengthening efforts with fiber optic sensors. Using 26 embedded fiber Bragg long gage sensors to verify laminated composite-overwrap strengthening in the 1914-built historic Horsetail Falls bridge, the fiber grating sensors were able to confirm an increase in the weight capacity of the bridge after the laminated overwrap was installed[1]. Yet they also yielded some unexpected information about traffic characteristics[2]: Between formal captures of data using a truck as a loading mechanism, traffic was allowed to pass over the bridge. Figure 1 shows the Horsetail Falls bridge and traffic information collected.

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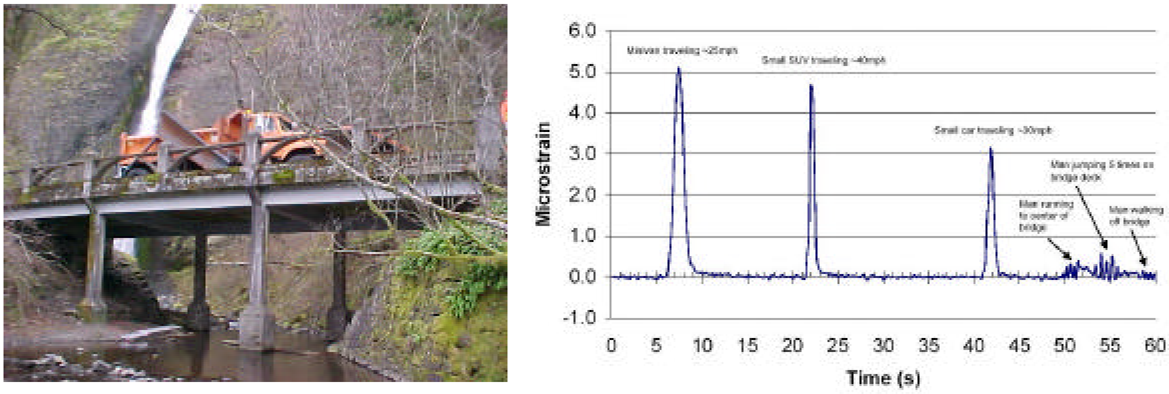

Figure 1. (left) A truck is used as a loading mechanism to determine deflection on the Horsetail Falls bridge; (right) Data collected from fiber optic sensors identifies various types of traffic crossing the bridge.

Observing the graph shown in Figure 1, from left to right, a minivan, an SUV, a small car, and then pedestrian traffic is observed. Note that the amplitude and width of the peaks correspond to expectations of weight and speed measurements as the traffic approached the sensor embedded under the center beam of the bridge. Because the bridge serves as a loading mechanism (e.g. weigh scale), individual vehicles crossing the bridge can be classified by weight. However, the complexity of identification and classification of vehicle types and weights intensifies as multiple vehicles enter the loading scale, or when a suspended loading scale is not available, as is the case in a common roadway.

In 1999, the Oregon DOT sponsored 2 traffic testing pads at the Blue Road Research facilities in Fairview, Oregon with the intent of determining the feasibility of a fiber optic vehicle classifying sensor for embedded use in a roadway. The test pads consisted of an asphalt concrete (AC) and portland cement concrete (PCC) test pad, each 3 meters x 3 meters by 10 centimeters thick. In total, eight traffic sensors were embedded, representing varying depths, sensor widths, and adhesive combinations. One fiber optic temperature sensor was also installed.

Once Blue Road Research and Oregon DOT had gained some experience[3,4] with the test pad installation and sensor functionality relating to low-speed traffic, two sensor types were installed into a busy traffic area on the Interstate 84 freeway outside Portland, OR (August, 2001). A fiber optic backbone line was placed to facilitate readout and testing from the Blue Road facilities about a third of a mile away.

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Although the four initial sensors were damaged before the remainder of the system came online, two sensors were still highly responsive, providing reflective spectral data that could be converted to time and amplitude information used for traffic classification. Because an unknown event--likely overstrain--had already detached the fibers inside their packaged housings, it was determined that the fibers could possibly last in their current condition for a period of up to decades. Also in their detached states, the sensitivity of the fiber traffic sensors compared well with conventional traffic sensors, but the heavy vehicle strains on the roadway caused a baseline-shift, due to the physical relocation of the grating, as shown in the graph of Figure 2.

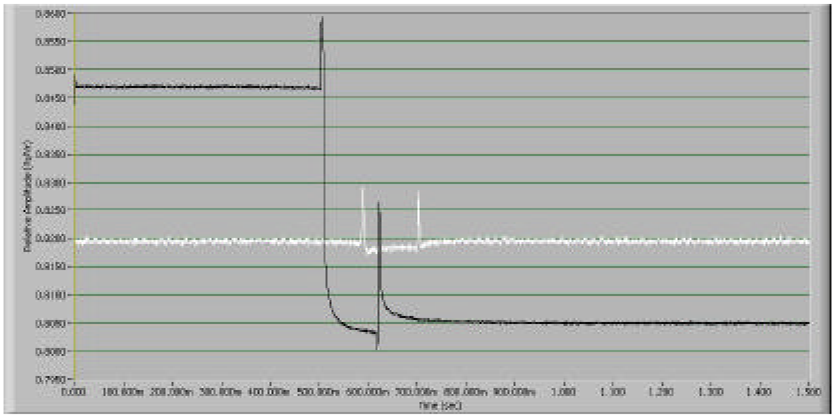

Figure 2. Data recorded by detached fiber optic sensors.

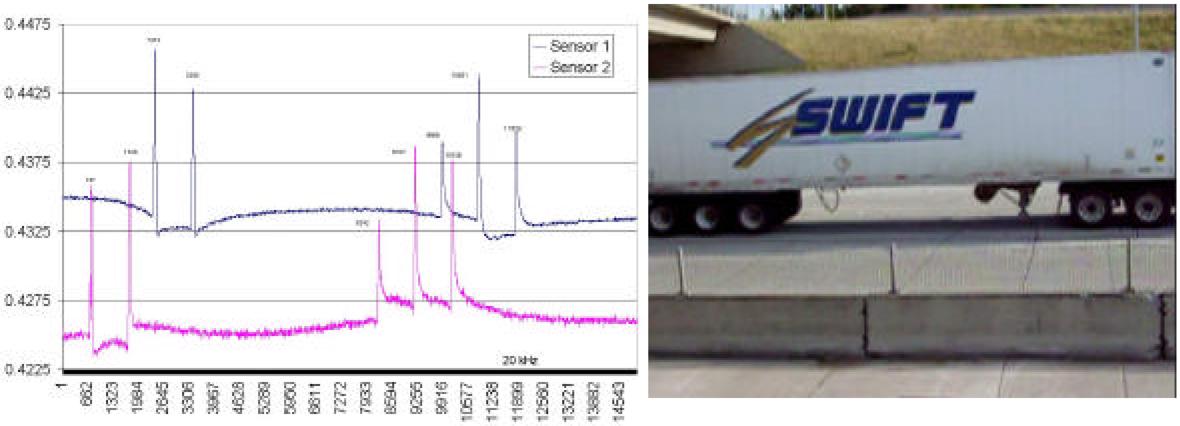

Figure 3. (Left) Axle profile and counting of (Right) a semi-trailer crossing the sensors embedded in the roadway.

The sensors underwent a mechanical redesign to optimize strength and prevent over-strain. In August, 2002 three additional sensor types were placed in the freeway under the same high-shock and high-wear conditions, but at a slightly greater depth of approximately 3 inches.

These next-generation sensors diversified into using composites and other mechanical means to strengthen the physical housings. Embedded in

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bituminous sealant below the surface, all sensors were functioning after installation and continued to function without deterioration through the latest tests. Because composite beams are used with the sensors, the recovery response shift from traffic appears to be slower, creating a larger integrated area under the axle peaks. Further studies may show that this integration could function for calculating rapid weight measurements in weigh in motion (WIM) applications.

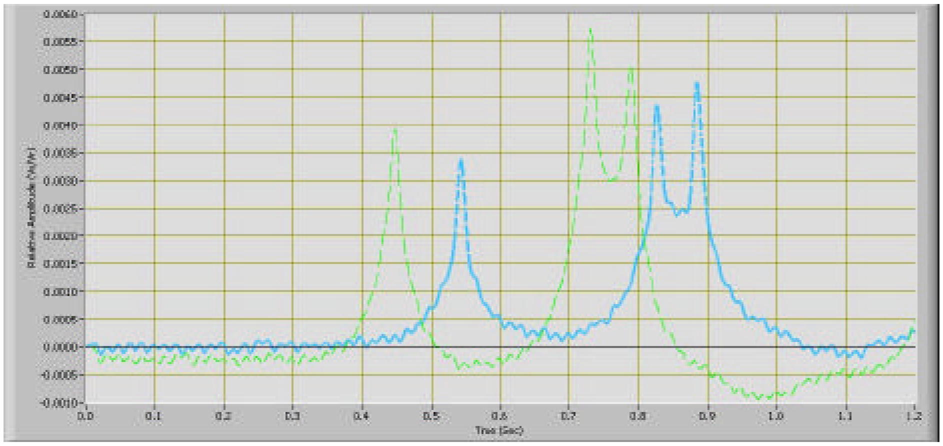

Figure 4. Data Collected from Long-gage Composite Sensors

Future Plans and the Argument for Fiber Optic WIM

There is little disagreement that federal and state transportation agencies face challenges in providing efficient and safe methods of travel. According to an Oct. 2002 report, as many as 27% of the country's 593,000 federal and local bridges are structurally deficient or functionally obsolete[5]. As roadways, structures, and bridges age beyond planned life spans, safety, reliability, and efficient commerce become critical factors demanding increased attention. Transportation agencies are scrambling to understand the conditions that cause structures to fail and find viable solutions to make roadways and structures last until repairs can be made. Among other efforts, additional load restrictions, more roadway monitoring, and alternate routing are options in use. It has also become a priority to find methods to increase commerce, reduce costs, and increase the service life of the infrastructure to efficiently stretch limited resources and funding.

Weigh-in-motion (WIM) devices are implemented to provide data critical to calculate wear and damage on roads and structures. The overall results provide information that is needed to improve enforcement, predict structural damage, estimate pavement wear, determine safety factors, and create regulatory and legislative policy.

Oregon Dept. of Transportation estimates that at its Woodburn, OR weigh station, through the use of WIM technologies to identify overweight trucks, 52% of trucks are allowed bypass static weigh station scales. This results in a focus

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on overweight trucks, resulting in less station congestion, more fines, and an estimated $200 million dollar savings over the next 10 years.

Although WIM systems fill a critical void in gathering information, many traditional WIM sensors such as piezos and load cells currently in use have large disadvantages. For one, WIM costs are expensive. The US Dept. of Transportation estimated that the average cost per lane to monitor WIM near the end of the 1990s was $9,000 to $52,000 for installation, averaging $4,000 to $7,000 per annum over a 12-year life span[6]. Additionally, many WIM systems also lack the ability to achieve the high accuracy of static weighing systems.

Data collected by the BRR/Oregon DOT research and results from other studies of the fiber optic vehicle classification sensor indicate that further development and calibration of the fiber grating traffic sensor may yield an accurate and precise weight-in-motion (WIM) sensor. This sensor would be capable of performing numerous functions including monitoring speed, vehicle classification, and WIM. An interrogation system currently in development at Blue Road Research would give the fiber grating WIM sensor the additional ability to provide periodic information about the integrity and physical degradation of the structure where it is embedded. This may provide valuable aging and fatigue information, allowing better planning, improved monitoring, and timely reconstructive actions to be made. The systems may be used on approaches to bridges, providing a critical and constant information supply of bridge loading patterns in real-time.

An advantage of the fiber grating WIM sensor now proposed is that it has the unique advantage of being embedded up to three inches below the surface, providing a highly protective environment that serves to lengthen its life span, potentially through multiple pavement resurfacings. A fiber optic WIM sensor is anticipated to be competitive in cost but simpler to install and maintain, with a lifetime comparable to traditional WIM sensors. The fiber optic WIM sensor is anticipated to hold other advantages over conventional systems. Fiber optics have extremely high bandwidth, can be multiplexed to add many signals onto one line, are extremely small and lightweight, and are robust. Because they can transmit signals easily over several miles, WIM monitoring in remote areas does not have any electrical requirements and thus becomes easier to do. In addition, fiber grating sensors are immune to electrical interference that can be caused by rebar reinforcement in roadways and structures. The results collected to this point suggest that WIM data may be collected without large modifications to the current roadway installation, which consists of one three-inch depth saw cut perpendicular to the lane, sandwiching the sensor in bituminous sealant, and plugging the sensor in to be calibrated immediately. All of these characteristics make fiber optics ideal for use in traffic and bridge settings.

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These fiber grating WIM sensors offer a simple design and thus can be manufactured starting in small quantities at competitive rates to existing technology. (Large quantities in thousands may potentially drop costs by a factor of 10 below current WIM sensors.) Because of improvements in fiber optic sensor technology, it is expected that this approach would offer a cost-effective alternative to the difficult and important problem of vehicle speed, vehicle classification and weight monitoring, with an additional benefit of simplified installation that would reduce overall cost.

References

1. S. Soltesz, “Strain Monitoring For Horsetail Falls and Sylvan Bridges, Final Report SPR 304-081” Oregon Department of Transportation, Feb. 2002.

2. E. Udd, J. Seim, W. Schulz, R. McMahon, S. Soltesz and M. Laylor, "Monitoring Trucks, Cars, and Joggers on the Horsetail Falls Bridge Using Fiber Grating Strain Sensors", Proceedings of SPIE, Vol. 4185, p. 872, Dec. 2000.

3. E. Udd, M. Kunzler, M. Laylor, W. Schulz, S. Kreger, J. Corones, R. McMahon, S. Soltesz, R. Edgar, “Fiber Grating Systems for Traffic Monitoring”, Proceedings of SPIE, Vol. 4337, p. 510-516, Aug. 2001.

4. M. Kunzler, R. Edgar, E. Udd, T. Taylor, W. Schulz, W. Kunzler, S. Soltesz, “Fiber Grating Traffic Monitoring Systems”, Proceedings of SPIE, Vol. 4696, p. 238-243, Sept. 2002.

5. Better Roads Magazine, available at http://www.betterroads.com/articles/bridgeinv02.htm, November 2002.

6. “States’ Successful Practices Weigh-in-Motion”, US Dept. of Transportation, Federal Highway Administration, p. 3-4, Dec. 1997.

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