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STRUCTURAL HEALTH MONITORING OF AN ALASKA BRIDGE

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ABSTRACT

The Chulitna River Bridge is at mile post 132.7 on the Parks Highway in the State of Alaska. This bridge is one of the major Alaska bridges that provide access to the oil fields on the North Slope. If this structure requires repairs or closed; it will have a major financial impact to the state. The bridge is remote in a cold climate and it is not easily accessible. The bridge was widened and strengthened in 1993 but it is unclear as to how the renovation was done and the extent of built in stresses. The superstructure is somewhat unusual in that there are two exterior girders and three interior truss stringers that support a precast concrete deck. Further, some of the support bearings are not in contract with the substructure.
The research team installed a unique structural health monitoring system on the Chulitna River Bridge in August, 2012 and provided Alaska Department of Transportation& Public Facilities (AKDOT P&F) a way to monitor the structural response due to traffic, weather and/or earthquake excitations. The research team installed accelerometers, tilt meters, strain gauges, temperature sensors, and rosettes. All are fiber optic and this was chosen to provide stability over time. Ambient accelerations were measured at the beginning of the test program using 15 accelerometers (this provides a baseline for the health of the structure). An aggressive load testing program was performed over an 8 hours using three loaded pre-weighed and pre-measured (belly dump/side dump) trucks. At the end of the test day, these loaded trucks were once again weighed. A significant amount of computer modeling was being done to calibrate the bridge response and to insure that it is performing as expected. The health monitoring system is unique in that the monitoring equipment is 2.5 miles from the bridge in a heated, secure controlled room off sight. The multiplexer is on the bridge and it provides the information to the data acquisition system using dark fiber. The research team accesses the data acquisition system using "DSL" and communicates with a virtual server at the University of Alaska Fairbanks (Fairbanks, Alaska) that provides access to AKDOT (Juneau, Alaska), Washington State University (Spokane, Washington) and AUTC researchers (Fairbanks, Alaska). Summary reports are generated once per week if the bridge is functioning properly. There are warning flags to insure the bridge is performing satisfactorily.

KEYWORDS

Structural health monitoring, fiber optics, data collection, load test, ambient test.

BRDGE DESCRIPTION

The Chulitna River Bridge, built in 1970, is located at Historic Mile Post 132.7 on the Parks Highway between Fairbanks and Anchorage, Alaska. The Parks Highway is the most direct route connecting Anchorage with Fairbanks and Prudhoe Bay.The Chulitna River Bridge is one of the major Alaskan bridges that provide access to the North Slope and if the bridge is under repair or there is a safety issue, there would be cause major financial impact to the state. It is remote in a cold climate and it is not easily accessible. Heavy, overload vehicles, up to 410,000 pounds, regularly travel the route. The original 1970 bridge was a 790-foot long, 5 span, continuous bridge with two exterior steel plate girders and three sub-stringers. It had a cast-in-place concrete deck 34 feet wide. In 1993, the bridge deck width was increased to 42 feet 2 inches by replacing the original cast-in-place deck with precast concrete deck panels. To accommodate the increased loads, the two original exterior plate girders were strengthened, three new longitudinal steel trusses were installed utilizing the original stringers as top chords, and steel bracing was added to the piers (Figure 1).The bridge was widened and strengthened but it is not clear how the work was done and what built in states of stress exist within the structure. According to Alaska DOT Inspection reports, the supporting structure is unusual and five of the bearings are in contact with the substructure. As part of the study, the authors conducted an ambient test using 15 accelerometers was conducted on the bridge to provide a health base line of the structure. This test was followed a few days later by the more traditional static and dynamic load tests in which two loaded pre-weighed and pre-measured loaded belly dumps and one pre-weighed and pre-measured side dump were placed on the bridge at pre-selected locations for the static tests. The trucks in various configurations were driven over the bridge at speeds of 24 kmh (15mph) to 72 kmh (45 mph). The ambient test data was used to calculate the bridge general condition; this was done by calculating vertical modes, longitudinal modes, transverse modes and torsional modes of the structural system. The fiber optics structural health monitoring system was installed on various bridge members to monitor accelerations, strains, bearing movements, and temperatures at specific locations. This system utilized fiber optic accelerometers, strain sensors, rosettes, tilt meters and temperature sensors; the system was prepared to provide AKDOT&PF an accurate way to monitor in real time the overall general location condition of the structure.

Figure 1. Current Picture of the Chulitna River Bridge

AMBIENT TESTING

A set of short term dynamic field tests were conducted on the Chulitna River Bridge. An ambient free-decay response approach was used to estimate the dynamic properties of the bridge. Stationary and dynamic tests were used to measure the acceleration response of the bridge at different locations and in different orientations during excitation caused by pedestrian traffic and AKDOT&PF boom trucks. The natural frequencies were identified and characterized by the fast Fourier transform (FFT) methods. The results of this testing show that the bridge exhibits the following vibration modes: 1.50, 2.20, 2.85, 3.23, 4.58 Hz. The 2.85, 3.23, 4.58 Hz frequencies are the bridge's vertical modes; the 1.50, 2.20 Hz frequencies are the bridge's longitudinal modes. This experimental data compared quite well with the finite element model (FEM) results. Modal parameters identified from the bridge response recorded at different locations, were compared with other sensors in close proximity. This was done to check data consistency, and to help with the calibration of the FEM model and its analytical results. Modal parameters were found to be consistent with the FEM results. At the Chulitna River Bridge, we plan to use these modal properties as a benchmark. We have a scheduled another ambient test for May, 2013 to see if there have been any changes to the structure. In other words, ambient tests may be performed on the same day that the bridge is inspected. They are quick, inexpensive, and the results may be used to help in the evaluation of an on-going health monitoring program of a given bridge.

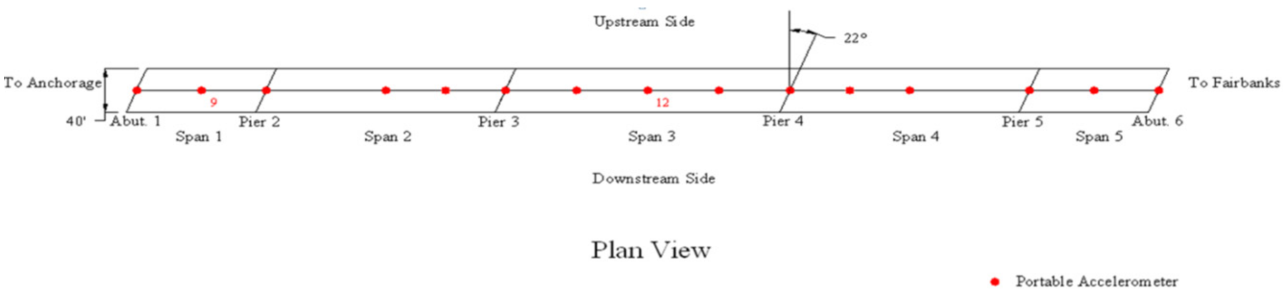

Figure 2. Portable Accelerometer Location and Number

A total of 15 portable accelerometers were used in the ambient tests as shown in Figures 2. The accelerometers were located at piers and mid-spans. Spans 2, 3 and 4 had more data collection points, because of their longer spans. Accelerometers were all put in one line in the center width of the deck. They were placed on the flat clean driving surface. Each test was repeated three times to ensure accuracy. Vertical, transverse and longitudinal accelerations were measured. The accelerometers used measured acceleration in only one axis. Because of this, each test of the three tests had to be repeated three times to capture acceleration in all three axes.

As part of the controlled ambient test, an A-30 AKDOT&PF boom truck was used to excite the bridge. Traffic control was used to stop pedestrian traffic in an effort to isolate the excitation caused by the test vehicle. The bridge was closed and non-windy during the dynamic test which reduced the influence of other erroneous input loads. The A-30 boom truck crossed the bridge from Fairbanks to Anchorage (traveling south) in the upstream lane with a speed of 45 mph. The bridge was kept closed until the vibration was totally damped out.

We investigated the dynamic behavior of the Chulitna River Bridge by using an ambient free-decay response. By using a frequency spectrum analyses, several components at 1.50, 2.20, 2.85, 3.23, 4.58 Hz were characterized. The measured frequencies of 2.85, 3.23, 4.58 Hz are bridge vertical modes and 1.50, 2.20 Hz are bridge longitudinal modes. The measured acceleration data for the ambient tests compared well with the analytical values that were calculated using a SAP200 three-dimensional finite element model (FEM).

STRUCTURAL HEALTH MONITORING SYSTEM

The sensor layout was prepared to address specific issues that were of concern to AKDOT&PF. These issues included evaluating the state of stress in the plate girders, how load is transferred through the cross frames, how load is distributed between the girders and trusses, and how the system responds to load when the bearings are not in contact with substructure.

This is aimed at providing ADOT&PF with information to track how much load is carried by the girders due to the truss's low stiffness relative to girders and trusses and due to some of the bearings not in not being contact with pier cap. Initially, we studied the sensor placement that was used by Bridge Diagnostics, Inc. (BDI) in a previous study a SAP2000 three-dimensional finite element computer model (Figure 3) was used to simulate truck loading Based on those results, we prepared a sensor placement plan to address most of the concerns and still be within a reasonable time line and budget.

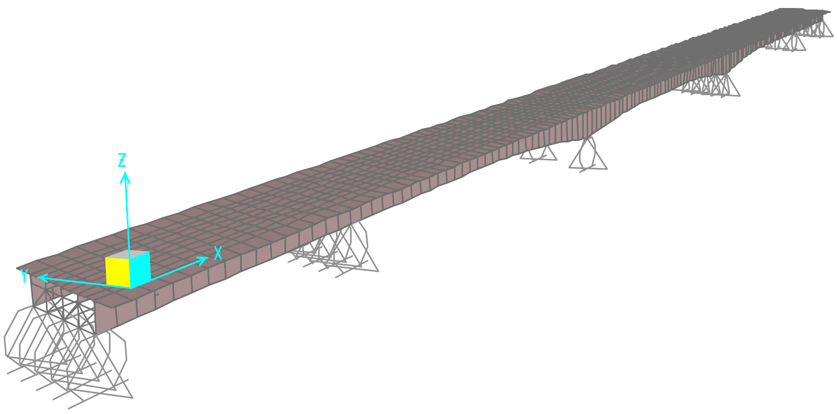

Figure 3. Chulitna River Bridge: 3-D FEM Model Looking NW

A total of 73 sensors were selected to be installed to monitor the behavior of this bridge. The sensor layout shows as Figure 4. The sensor arrangement was selected to best provide information about changes in the load distribution in girders and trusses. Most of the sensors are located in places that have the lower load rating factors and others are used to observe load distribution throughout bridge.

We attempted to measure the shear force effects by placing eight optic fiber Bragg grating (FBG) rosette strain sensors near the piers on the outside girders in that the disconnection of inside bearings will increase shear force on outside girder. We are attempting to measure flexural strain caused by moments near the mid-spans. These mid-span flexural strains are monitored by twelve optic FBG strain sensors placed near mid-spans of the girders. To monitor bending and axial forces in the trusses, fifteen optic FBG strain sensors are located within the composite trusses. The live load distribution in the girders and the trusses can be calculated by comparing the force distribution between the girders and the trusses. For monitoring the load transfer through the cross frames and the concrete deck, twelve optic FBG sensors are placed on the cross frames' diagonal trusses and the concrete deck. Other optic FBG sensors are located on members that are considered to have the lower load ratings. Five optic accelerometers are used to monitor changing of stiffness's in the trusses and girders. The supports are monitored for rotation with optic tilt meters. If all supports are not free to rotate as they should the bridge may exhibit a twisting condition. This accounts for an additional four sensors. Five displacement optic sensors are used to monitor the displacement of the truss bearings.

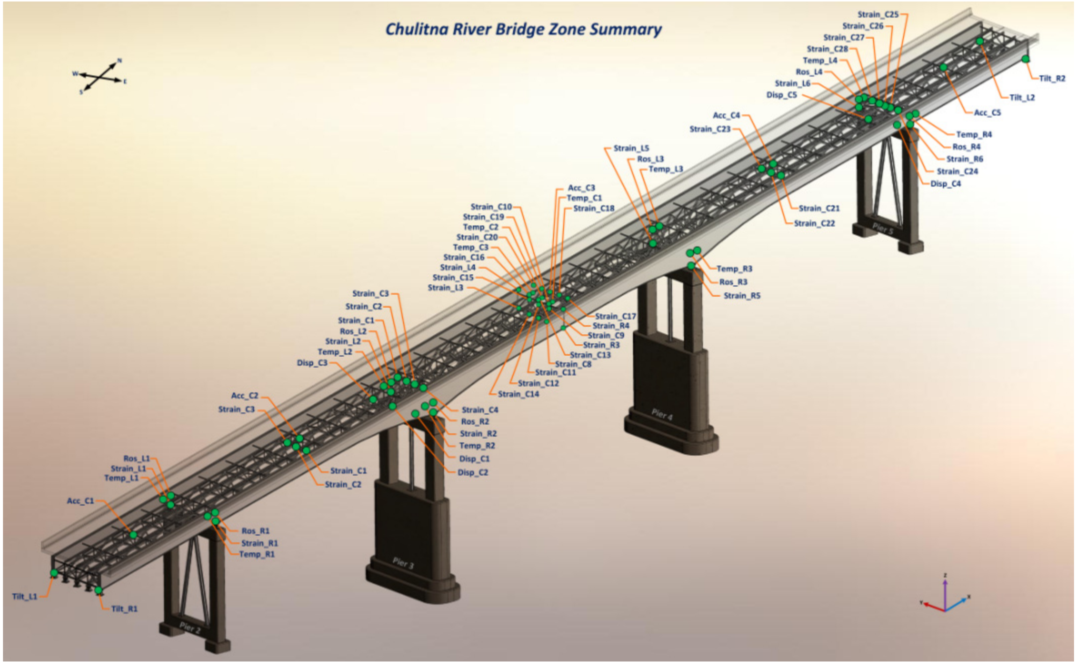

Figure 4. Sensor layout

The structural health monitoring system is composed of five parts: sensors, sensor multiplexer, sensor interrogator, local computer and remote computer. The sensor Multiplexer is located in a control panel at the bridge. The panel has instruments that regulate both temperature and humidity within the enclosure. The sensor interrogator and local computer are located in control panel at the Mt. McKinley Princess Wilderness Lodge approximately 4 km (2.5 miles) away.

The sensor interrogator sends four optic signals (lasers) from the Utility room to the sensor multiplexer at the bridge via four fiber optic channels. The multiplexer is composed of four switches; these four switches distribute the incoming four channels to sixteen channels. Each of the sixteen channels is capable of supporting a sensor array of up to eight sensors. That laser signal, via the multiplexer, is sent to each sensor array. The laser signal is then reflected back to the interrogator by mirror-like imperfections in the fiber strand at each of the sensor locations. These imperfections, called fiber Bragg gratings (FBG), change in dimension when strained. This strain in the grating produces variations in the laser wavelengths that are reflected. Each sensor in an array contains a unique FBG that only reflects specific wavelengths exclusive to that sensor back to the interrogator. The interrogator then interprets these optic signal reflections and transforms the optic signal to a digital signal and sends it to the local computer. The local computer then calculates stores and exports the data to a remote computer via DSL internet (Figure 5). The fiber optic sensors are connected in series within arrays. Fusion splices are preferred over mechanical connectors to minimize signal loss (attenuation).

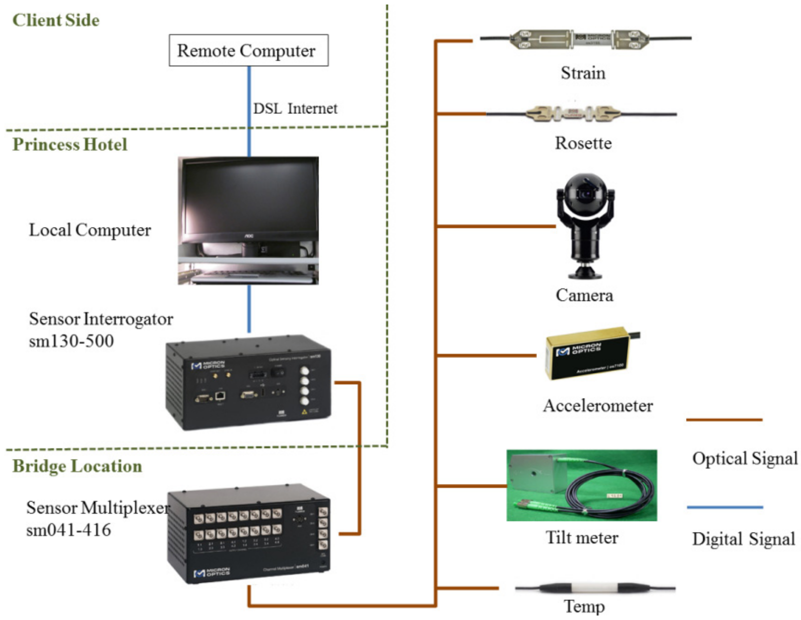

Figure 5. System configuration

LOAD TESTS

The objective of the following load test layout was to find the maximum positive bending moment of each span, the maximum negative moment of each pier and the load distribution among composite trusses and girders. Influence lines of the bridge were generated to determine what spans to load to produce worst-case bending moment conditions. Not only do influence lines show where to load the structure to generate worst case conditions, they also show where the applied loads will have the greatest bending moment effect.

The load test process was divided into three stages: load test truck measurement before bridge testing, bridge load testing, and load test truck measurement post bridge load testing. The trucks used for testing were two belly dumps and a side dump. The trucks were loaded with sand but the load was not covered. Therefore, in order to verify the loads used during testing, the trucks were weighed before and after testing. Both dynamic loading and static loading conditions were used in an effort to generate worst-case loading conditions. Dynamic testing was also conducted to capture the harmonic response of the bridge under various loading conditions.

A total of three AKDOT&PF dump trucks were used in the load test. On the evening of September 9th, the three empty AKDOT&PF dump trucks were measured for axle weight and axle distance at the weigh station. After being measured, the AKDOT&PF dump trucks were loaded with sand. The axle weight of the trucks was then measured again and the overall weight of the loaded trucks was recorded. The load test was conducted the following day. Immediately after the completion of the tests, the trucks were weighed again. Any change in axle weight from pre-test to post-test was recorded. Subsequent calculations for load distributions to the structure were based on the mean of the pre and post-test axle weights.

SUMMARY & CONCLUSIONS

This paper was written for the specific purpose of providing the reader with an understanding of how we conducted the structural health monitoring for this bridge. In general, we conducted two kinds of tests. These were:

1. One of the tests was conducted to determine the general base line condition of the bridge. In this test, we performed ambient acceleration tests using 15 very sensitive single axis accelerometers. This test is inexpensive, easy to conduct and has minimal impact to the traveling public. At another point in time, it can be very helpful in evaluating if the structural condition of the bridge has changed over the time period between tests.
2. Secondly, this series of tests is the more traditional approach in which we installed sensors and monitored their response to a given set of known loads. In this case, prior to the tests, we installed fiber optic sensors on the bridge structure. The sensors consisted of temperature sensors, strain sensors, rosettes, tilt meters, and accelerometers. The benefits of this system are: a). the fiber optic system is extremely stable (the

sensors do not drift like the more traditional electrical resistance gages) and it can be used for long term monitoring; b) When is loaded, we can monitor in real time the influence of the loads on the structure. These values can be compared to a computer model to evaluate the general health of the bridge; and c). The sensors provide the agency an opportunity to choose thresholds to provide safety alarms to help signal an unexpected condition event.

ACKNOWLEDGMENTS

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