Structural Health Monitoring and Condition Assessment of Chulitna River Bridge:

Sensor Selection and Field Installation Report

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13. ABSTRACT (Maximum 200 words)

The Chulitna River Bridge, built in 1970, is located at Historic Mile Post 132.7 on the Alaska Parks Highway between Fairbanks and Anchorage, Alaska. The Parks Highway is the most direct route connecting Anchorage, Fairbanks, and Prudhoe Bay. Heavy overload vehicles with loads up to 410,000 pounds regularly travel this route. The original bridge was 790 feet long, with five spans and is a 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 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.In August, 2012, the research team will design and install a real time fiber optic structural monitoring system on the bridge to determine if the girders are over-stressed for standard highway loads and permit vehicles. The final working thresholds will be established for automated notification if changes occur in structural response or established thresholds are exceeded. After September 2012, the research team will continue monitoring and analyzing the experimental data until December 31, 2013. The test results will be used to identify changes in load distribution for the girders and trusses. It will also be used to identify if structural changes occur. Further, the information will be used to provide alerts when sensing systems approach or exceed established limits. It will also be used to develop a protocol to apply an SHM program to bridge monitoring on other bridges in Alaska.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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We also want to thank the contributions by Kathy Peterson, Diane Wallace and Billy Connor at the Alaska University Transportation Center (AUTC). The efforts by Sandra Boatwright and Fran Peterson at the Institute of Northern Engineering (INE) were essential to the success of this research. We also want to acknowledge the contributions by the Civil and Environmental Engineering Department in the College of Engineering and Mines at the University of Alaska Fairbanks.

2. EXECUTIIVE SUMMARY

In August of 2012, Alaska University Transportation Center (AUTC) was requested by Alaska Department of Transportation & Public Facilities (AKDOT&PF) to install a structural health monitoring system on Chulitna River Bridge along the Parks Highway outside of Trapper Creek, AK. The objective of the study was to provide important information for a structural condition assessment of the Chulitna River Bridge and to provide the AKDOT&PF with a basis for selecting a future Strategic Health Monitoring System. This project is to serve as a base line for evaluating systems for use in extreme temperature environments and to evaluate the conditions that need to be addressed for selecting or evaluating future Strategic Health Monitoring Systems. The instrumentation of this project began on August 18th and finished on September 9th. In total, 73 sensors were installed, including strain sensors, rosettes, displacement sensors, temperature sensors, accelerometers and tilt meters. Load tests were performed on September 10th. The load test involved measuring the bridge's response to static and dynamic loading for three AKDOT&PF dump trucks.

This report provides details regarding the structural health monitoring system layout and instrumentation procedure. This report also outlines the unexpected obstacles and subsequent solutions to these problems that came about during the preparation and installation.

3. 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. 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).

Figure 1. Current Picture of the Chulitna River Bridge

From the inspection report produced by HDR [1], there are five truss rocker bearings that do not contact or only partially in contact with the masonry plate bearings. These bearings are: all three truss bearings at Pier No. 3 and the two lane truss bearings at Pier No. 5 (Figure 2). This is believed to result in load transfer from the composite trusses to girders through the cross-frames and the concrete deck.

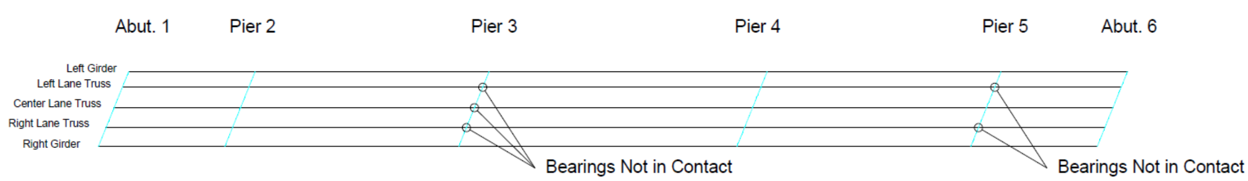

Figure 2. Bearings Not in Contact with substructure support

4. PLANNING, PERMITTING AND COORDINATION

Before any work could be implemented and before funding was available, we had to assist AKDOT&PF with the preparation of a permit. In this case the permit involved bringing buried power, and fiber for both phone and DSL (internet service) for real time reporting of data for the instrumentation that was to be installed on the bridge.

Prior to the funding, Dr. J. Leroy Hulsey prepared himself by reading the available literature and attending conferences such as the "SENSORS TECH FORUM" held in Boston on October 10-12, 2011 and "Transportation Research Board" Meetings in January, 2012.

We began the study by evaluating which type of technology would likely be the most stable for long term monitoring and likely to be the best performers for extreme temperature conditions. Through this evaluation, we chose fiber optic sensor technology. Once we determined the type systems, it was necessary to evaluate who and how we would install the sensors and test the system. Because of the complexity and expected work demand, we determined it would be best find a contractor who had experience and who had successfully installed and tested bridges using these types of sensors. Subsequently, we chose "Chandler Monitoring Systems" to provide a complete Strategic Health Monitoring System. The system was to include sensors, multiplexer, interrogator, Lap Top, Software, installation, training and deliver a "Strategic Health Monitoring System" to AUTC and the AKDOT&PF. The system was to provide real time monitoring and alarms to identify critical states. Choosing the contractor and identifying a scope of work were essential in selecting the types and number of sensors and the overall cost of the contract. Based this level of understanding, we formulated a plan to have power and phone service at the bridge site.

We are pleased the Princess Hotel agreed to provide the University of Alaska Fairbanks (AUTC) power at the bridge site. The Princess Hotel generates their own power and based on this allowed AUTC they generate their own power and allowed access to the power source. Prior to installing power and phone service, we requested an on-site planning meeting. Those present at the meeting included the engineer for Princess Hotels, AKDOT&PF Maintenance, AKDOT&PF Utility Permitting, Matanuska Telephone Association (MTA), and the Boring Contractor for MTA, the Electrical Contractor who would be given the contract to excavate a trench, install underground , install underground power, backfill and connect the power to the Princess junction box to the bridge. MTA was to provide underground fiber from their fiber source to the bridge and this was to be installed by boring across the private road to the Hotel and providing fiber in the same ditch as the power feed from the cross over point to the bridge, see Figure 3. It was MTA's responsibility to coordinate with the electrical contractor so that the fiber was placed in the trench prior to backfilling.

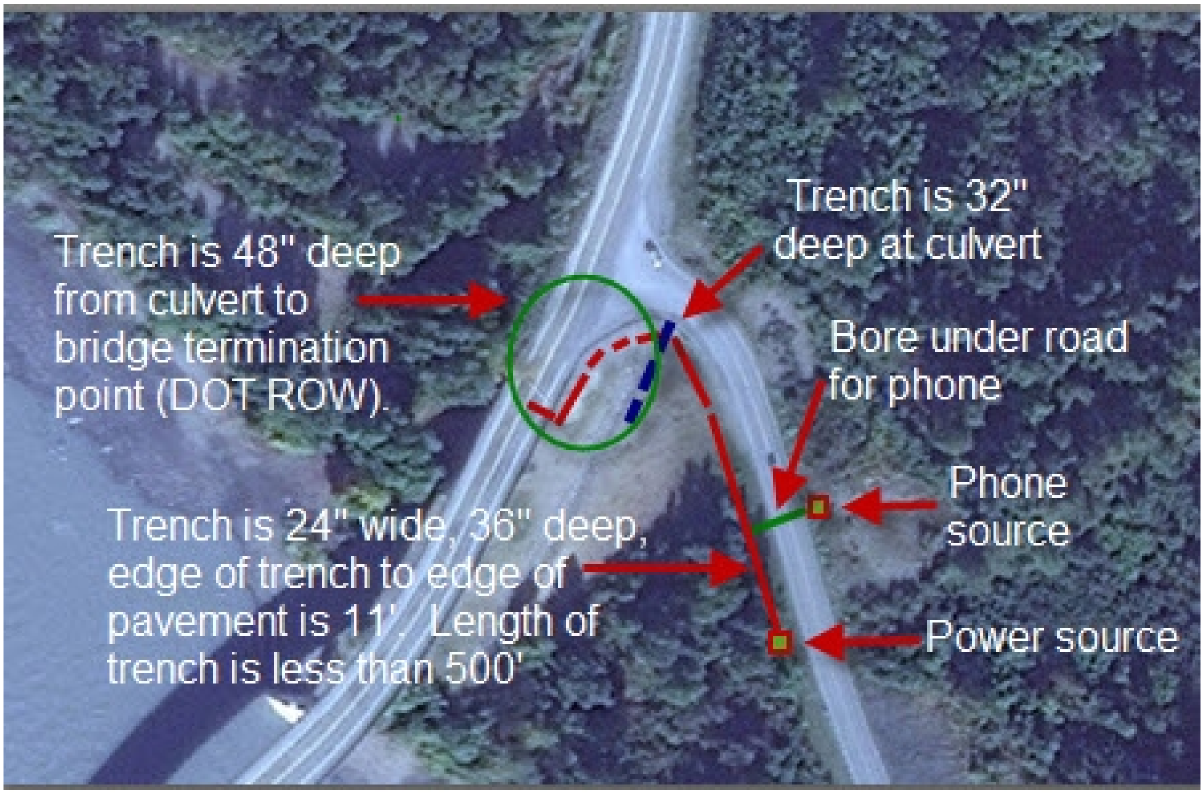

Figure 3. Plan View: Excavation for Installing Power and Fiber at the Bridge Site.

This plan was discussed at the field site and all parties agreed that this was an acceptable solution to get power and phone service to the bridge site. We also provided AKDOT&PF details for mounting and locating a NEMA breaker box at the bridge. Power, fiber, and multiplexer for the sensors were to be mounted in the NEMA sealed Breaker box mounted to the north abutment. These details were provided to AKDOT&PF in the permit application.

5. TESTING TO EVALUATE BRIDGE HEALTH

5.1 Testing Plan

We prepared two types of testing programs for this bridge. These were:

1. Ambient Accelerometer Tests (short term testing by UAF & AKDOT&PF); and
2. Strategic Health Monitoring Tests (long term testing by CMS/UAF & AKDOT&PF).

Ambient Accelerometer Testing. - "Ambient Accelerometer Tests" are used to establish a baseline of the bridge condition. These tests were developed using 15 portable highly sensitive accelerometers placed on the concrete deck of the bridge. This test was prepared by UAF in cooperation with UAA to establish a baseline of its condition on the day of the test. An ambient free-decay response approach is used to estimate the dynamic properties of the bridge. Both stationary and dynamic tests were prepared to determine the responses of the bridge recorded at different locations and in different directions while a traveling vehicle passes over the bridge. Modal properties identified during the testing of the Chulitna River Bridge may be used as benchmark in on-going health monitoring studies of this bridge.

Strategic Health Monitoring.- Unlike the previous tests, this system of tests are designed to provide real time evaluation of the bridge response to a given set of loads. For example, this system will continuously monitor structural response. It is particularly relevant as we can monitor when excessively large loads cross the bridge and during times of extreme temperature conditions, earthquake events, and etc.

5.2 Sensor Layout: Strategic Health Monitoring

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 study 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 BDI in a previous study. We prepared computer model to simulate truck loading using SAP2000 by Computers and Structures, Inc. 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. We than sent this placement plan to both AKDOT&PF and Chandler Monitoring Systems. This was followed by a teleconference to discuss the sensor layout. We then modified the sensor placement plan. Revised plans were subsequently reviewed and modified. Based on findings from the previous study by HDR[1], computer results, input from

AKDOT&PF and Chandler Monitoring Systems, Inc. a total of 73 sensors were selected to be installed to monitor the behavior of this bridge. The sensor arrangement (Figure 4) 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. We are attempting to measure flexural strain caused by moments near mid-span are to be monitored by twelve optic FBG strain sensors placed near mid-spans of the girders. To monitor the bending and the 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 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 accelerometers are used to monitor changing of stiffness's in the trusses and girders. The supports are monitored for rotation with 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 sensors are used to monitor the displacement of the truss bearings. The following table is a brief summary of sensor quantities.

Table 1 Summary of Sensors

Sensor and locations	Number of sensors
Rosette Strain sensors	8
Strain Sensors on the Girders	12
Strain Sensors on the Composite Trusses	16
Strain Sensors on the Concrete Duck	4
Strain Sensor on the diagonal members	8
Accelerometers	5
Displacement Sensors	5
Temperature Sensors	11
Tilter meters	4
Total	73

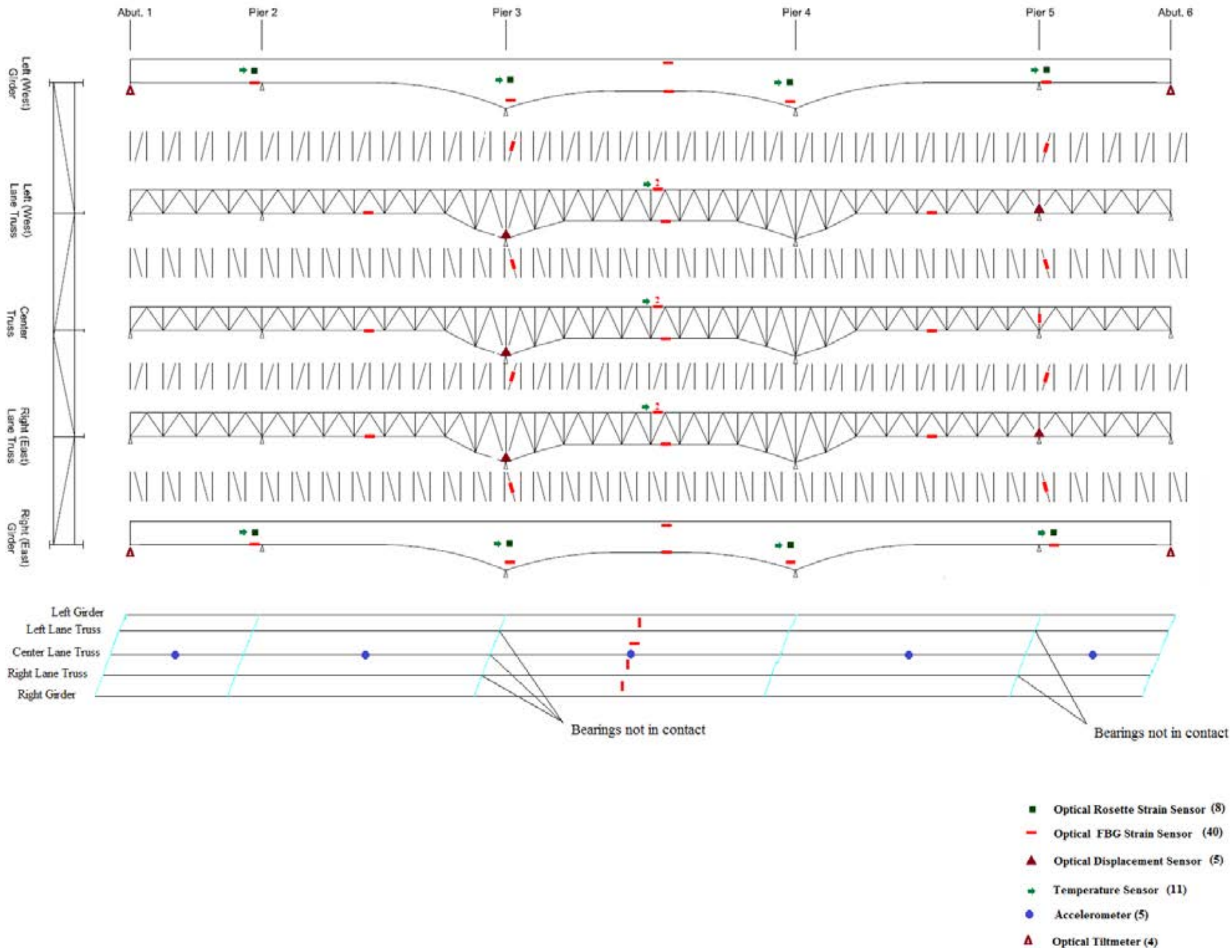

Figure 4. Sensor Layout

6. ISSUES PRIOR TO SENSOR INSTALLATION

Step 1. - The following tasks had to be completed prior to installing the sensors. First, we had to identify the types of sensors for use for long term monitoring. A sensor that didn't drift over time was an important consideration. Further, we wanted a sensor that would remain accurate in extreme temperature conditions. Thus, we selected fiber optic sensors.

Step 2.- Once we selected the sensors, we needed to identify supplier's, monitoring systems, and software. We also had to choose to a contractor who would install the sensors and who would test the system for compatibility and calibrate the equipment prior to testing. All of these issues were evaluated for the Alaska type exposure such as heavy loads in cold temperatures. Based on these factors, we selected Chandler Monitoring Systems (CMS) to provide a ready to use system and train both AUTC and AKDOT&PF in its usage.

Steps 3&4.-Because of limited time availability, we were on a critical path to award the contract for instrumenting the bridge. However, we were not able to begin until a permit was issued. The permit was affected by the number of sensors we proposed to use, how they were to be installed and how to get power and phone service to the bridge site. So, we developed a multi-tasking plan. Based on previous studies on this bridge, we selected a preliminary sensor layout plan that we planned to verify through computer modeling and input from both AKDOT&PF and Chandler Monitoring Systems, Inc.

The Princess Hotel offered to provide the University of Alaska Fairbanks (AUTC) power at the bridge site. Mantaskua Telephone Systems (MTA) agreed to provide fiber to the bridge site (DSL phone service). In order to implement getting both power and phone service, we were required to hire a contractor to install buried power and fiber. This same contractor provided electrical work to the Princess Hotel and therefore, he was chosen to install power at the bridge site. None of these options could proceed forward until we had a permit. Thus, early on in the project, we requested a site visit by the engineer for Princess Hotel, the engineer for, the electrical contractor, a boring contractor, AKDOT&PF environmental and utility permits, and AKDOT&PF maintenance and Dr. Hulsey at AUTC. At the site visit, we agreed on how the work was to proceed. Thus, we submitted the plan for use to obtain a permit that was acceptable to AKDOT&PF and FHWA.

Steps 5,6, & 7.- In cooperation with CMS and AKDOT&PF, we set a time for installation of the sensors, load testing, and training of AUTC personnel in Georgia, We also arranged to provide three AUTC personnel to assist with the sensor installation. As part of the effort, we made arrangements for a hotel, a "Porta Potty" at the project site, and contacted several possible contractors for setting up traffic control.

Steps 8 & 9.- Once we were notified that the permit had been issued, we were able to finalize our contract with CMS and finalize the matters with the electrical contractor, hotel, and supplier of the "Porta Potty". We subsequently awarded a contract for traffic control. The electrical contractor was Bridge Electric (John Bridge). The contract for Traffic Control was awarded to Northern Dames. We then made arrangements with AKDOT&PF to order the safe climbing equipment and to receive safety training.

Steps 10&11.- Prior to the date for installation AUTC traveled to Georgia and received a week of training at CMS and toured one of the supply manufacturers of the fiber optic sensors.

Step 12.- We worked with AKDOT&PF Bridge Design to have 2 belly dumps and 1 side dump loaded with sand for use during load testing. As part of this study, we made arrangements to load test following installation and calibration of the sensors.

Items to be considered in future studies. Any contractor who is installing sensors from areas outside of the state of Alaska should be asked to provide a shipping plan to the project manager (AUTC/AKDOT&PF). CMS did not provide sufficient time to allow for the equipment to arrive to its destination. Further, getting power and phone service is a challenge in remote areas and these items must be given priority. It is a challenge to get access to fiber for continuous monitoring of fiber optic sensors. Because of the temperature sensitivity of the interrogator and local computer (Lap Top), and because it is extremely expensive, it is very important to have this equipment in a temperature controlled environment and it should be off of the bridge and out of the reach of people who could damage it.

7. SYSTEM OVERVIEW: STRATEGIC HEALTH MONITORING

The structural health monitoring system is composed of five parts: sensors, sensor multiplexer, sensor interrogator, local computer and remote computer (Figure 5). 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 (Figure 6). The sensor interrogator and local computer are located in control panel at the Mt. McKinley Princess Wilderness Lodge (Figure 6).

The sensor interrogator sends four optic signals (lasers) from the Utility room at the Mt. McKinley Princess Wilderness Lodge to the sensor multiplexer at the bridge via four fiber optic channels. The multiplexer is composed of four switchers; these four switchers 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).

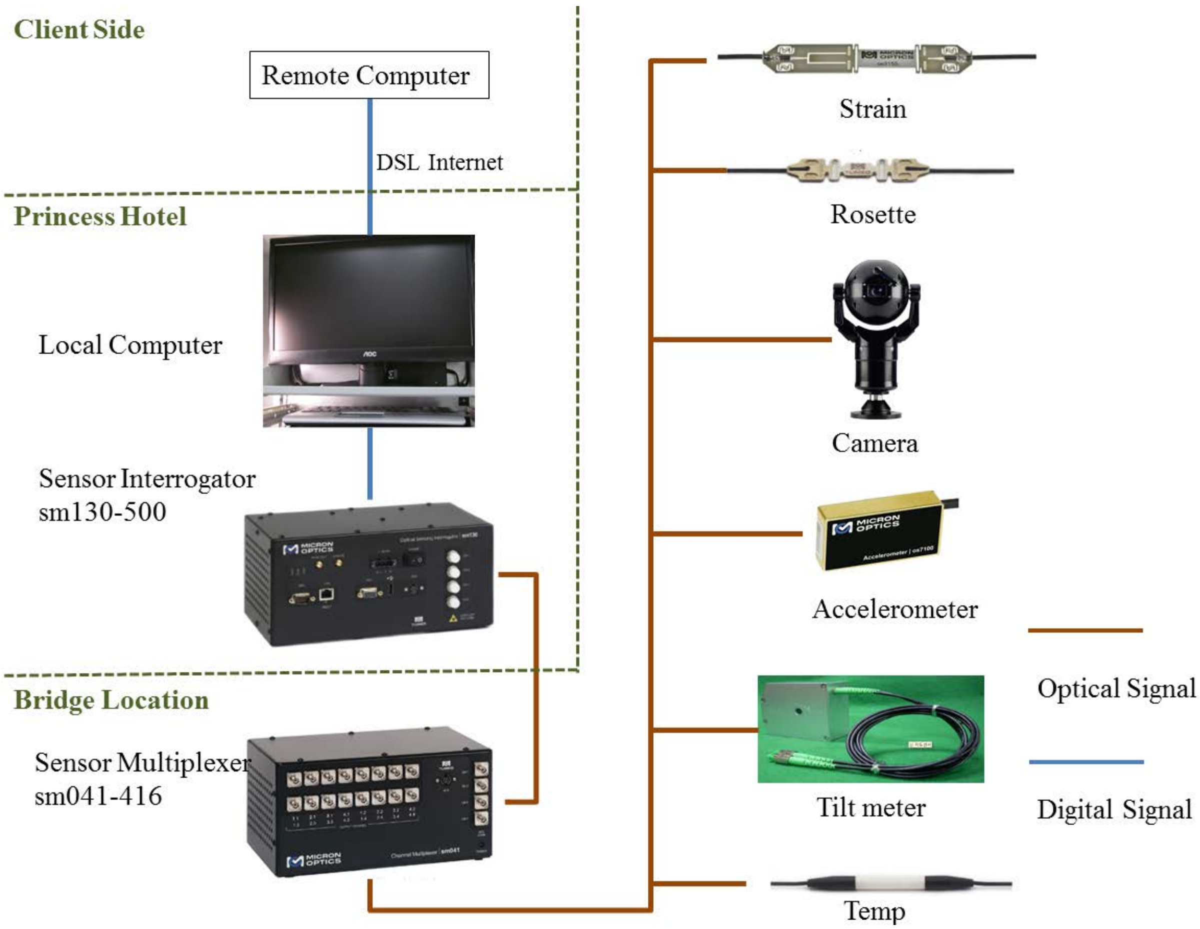

Figure 5. System Configuration

8. SENSOR INSTALLATION

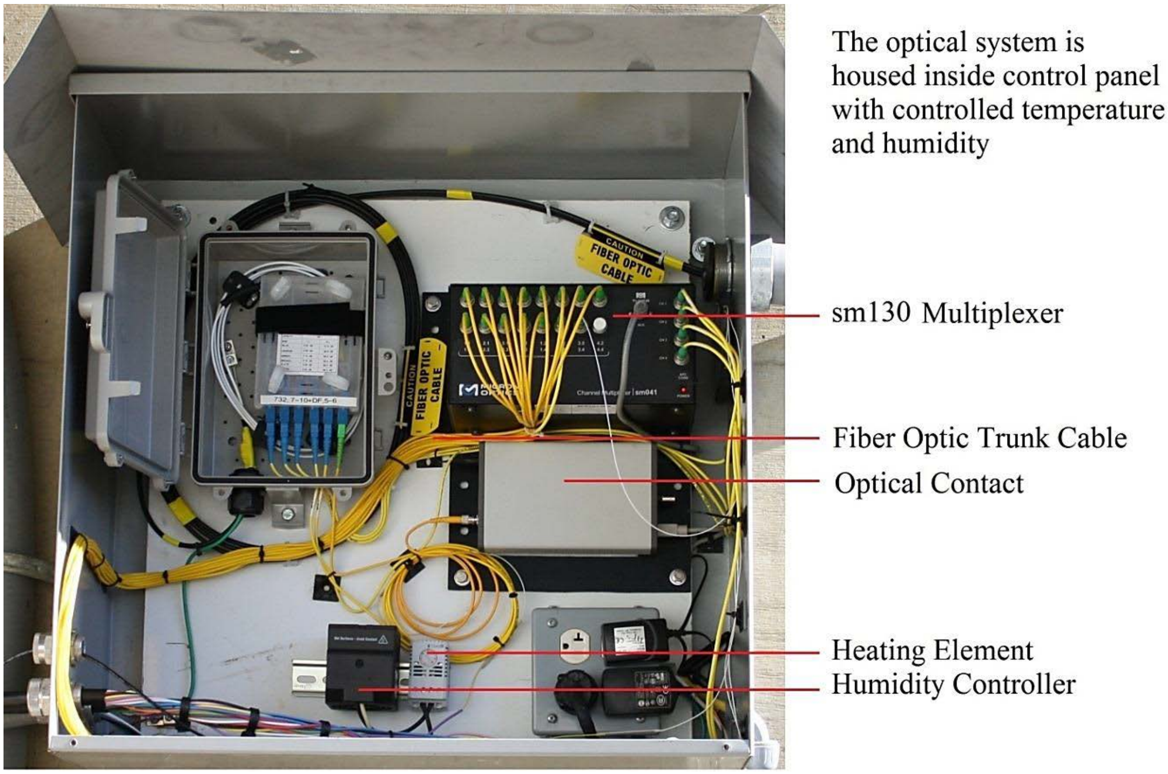

Figure 6. Control Panel at the Bridge

8.1 Sensor Protection

Both the rosette strain sensors and the conventional strain sensors require protection from exposure to moisture and ultra violet light. CMS currently uses a protective covering that appeared to be composed of a modified bituminous material. The actual formulation of the material was not known as it was proprietary information. Due to the extreme arctic environment of this installation, AUTC cautioned that this conventional sensor protection method could become brittle and vulnerable to cracking and delamination during winter months. Furthermore, the manufacturer's data sheet indicated a lowest allowable operating temperature of -40C (AUTC anticipated site conditions to reach temperatures as low as -50C). AUTC and CMS worked jointly to develop a list of possible alternative coating systems. AUTC then tested these proposed alternative protection materials at temperature ranging from -20C to -50C in their labs at the University of Alaska Fairbanks. The tests showed that asphalt based materials become brittle and loose adhesion under arctic conditions.

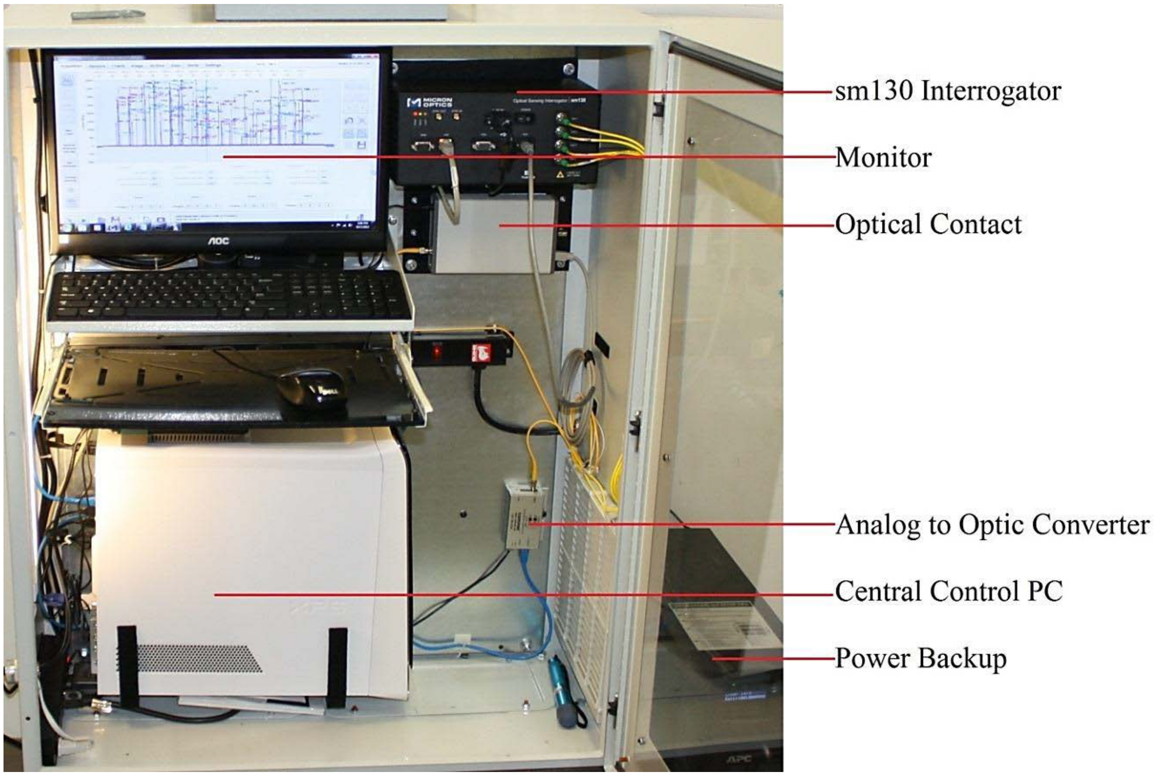

Figure 7. Inside of the Control Panel at the Princess Hotel

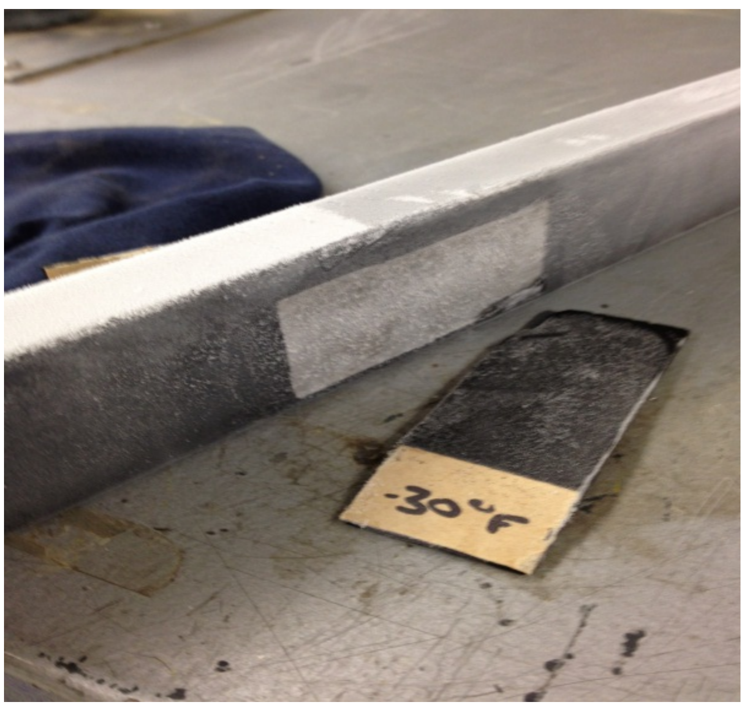

Figure 8. Bituthene Product Testing

AUTC suggested the use of 100% silicone coverings. These silicone coverings proved to keep their elastic properties and their adhesion to metal substrates at temperatures below -50C. AUTC suggested the use of a 1/32" rubberized silicone sheet with a Silpruf SCS2000 silicone paste top coat. The manufacturer's data sheet for Silpruf SCS2000 silicone paste claims that their product remains elastic in temperatures as low as -48C. Furthermore, Silpruf SCS2000 has a proven history of excellent performance on the North Slope of Alaska.

AUTC recommended the following protection system: 1) A 1/32" rubberized silicone sheet was to be placed directly over the sensor, providing a protective envelope that encapsulated the sensor. 2) A layer of Sulpruf SCS2000 silicone paste was then to be placed over the silicone sheet extending beyond the sheet in all directions. This silicone paste acts to seal the perimeter of the silicone sheet, cover any exposed base metal, and to add an extra layer of protection to the sensor. See Figures 16 to 22 illustrating the sensor protection process.

8.2 Installation Preparation

AUTC coordinated with AKDOT&PF and CMS to provide the necessary personnel, equipment, traffic control, and safety training in order to complete the installation.

AUTC contracted Northern Dames Inc. to conduct traffic control for the duration of the project. Northern Dames provided two flaggers throughout the installation and three flaggers for the load test (see Load Test Report).

AUTC aided by the direction of Simon Howell, AKDOT&PF Safety Training Specialist, purchased the necessary rope access harnesses, climbing helmets and positioning gear required to work at heights within the structure of the bridge. AUTC also attended job specific safety, fall arrest and rescue training at an AKDOT&PF facility conducted by Mr. Howell. Furthermore, all personnel working on the bridge attended on-site safety training specific to the UB-50 and A-30 boom trucks.

AKDOT&PF provided two articulating boom trucks capable of reaching the underside of the bridge structure while being parked on the bridge deck. One boom truck, the A-30 had a working platform that could accommodate four workers including the operator (Figure 27). The other boom truck, the UB-50, had an articulating basket that could accommodate up to three workers, including the operator (Figure 28). AKDOT&PF also provided personnel to operate the boom trucks. It is state policy that only AKDOT&PF personnel operate the boom trucks.

CMS provided all of the structural health monitoring equipment and all necessary installation tools. CMS also provided two full-time installers to install the system. AUTC provided back-up tools and supplies as needed by CMS. AUTC also provided two students to assist in the installation for the duration of the project and one faculty member to assist in the installation for the first week of the project.

8.3 Installation Processes

8.3.1 Installation of Main Infrastructure

TASK A: Place the control panel in the communications room of the Princess Hotel, confirm panel area placement, make cable connections needed, and bolt panel to the floor (Figure 9).

OBSTICLE 1: Communication between the Matanuska Telephone Association (MTA) and the CMS installers: The CMS installers had difficulty locating the fiber-optic lines that were installed by MTA. The lines were eventually located in the communications room of the Princess Hotel.

OBSTACLE 2: Communication with Princess Hotel.: Managers of the Princess were unaware of the amount of space required for the SHM control panel. It was determined that the location in which MTA ran the fiber-optic lines did not have enough space to accommodate the control panel. An alternate location was found in the electrical room of the Princess Hotel. CMS was required to relocate both the fiber-optic lines and the control panel to this new location.

OBSTACLE 3: Connector problems: CMS was unable to connect the control panel to the fiber-optic lines ran by MTA. CMS had inadvertently brought the wrong type jumpers needed to connect the interrogator to the main fiber optic lines. CMS quickly realized their mistake and ordered the correct jumpers. Due to the semi-remote location of the installation, the replacement jumpers took over a week to arrive. Upon arrival the CMS installers realized that the replacement jumpers were also incorrect. A second order of replacement jumpers was ordered. Because of these delays, CMS was forced to temporarily place the interrogator at the bridge site to test sensor arrays during the installation. This temporary configuration allowed CMS to connect directly to sensor arrays as they were being installed to ensure proper operation of the sensors. Final installation of the interrogator in the Princess Hotel occurred towards the end of the installation.

Figure 9. Control Panel at the Princess Hotel

TASK B: Install power for camera. Install camera and camera control panel (Figure 10).

OBSTACLES: Camera communications problems: Both the installation of the required 110 V. power source and subsequent electronics and hardware went smoothly. Ongoing communication issues with the camera control panel have prevented successful operation of the camera.

Figure 10. Camera and Camera Control Panel

TASK C: Install the main fiber optic trunk line. Secure the trunk line in place using epoxy, cable clips and industrial cable ties. Install splitter boxes along trunk line (Figure 11).

OBSTACLES: None.

Figure 11. Splitter Box

TASK D: Run main trunk line and two single fiber cables into the bridge control panel, punch out holes for cable entrance into the bridge control panel (Figure 12), install multiplexer in bridge control panel.

OBSTACLE 1: Due to the connection problems with the interrogator at the Princess Hotel, CMS was not able to install the multiplexer in the bridge control panel. A temporary solution to the connection problems was to install the interrogator to the sensor arrays directly, bypassing the multiplexer and Princess Control panel. This temporary setup did not provide the interrogator any protection from the weather or from vandals. Because of this, CMS was required to bring the interrogator home with them every night. This required the installation and uninstallation of the interrogator at the beginning and end of each work day.

OBSTACLE 2: Improper enclosure at bridge abutment: The bridge control panel, installed by Bridge Electric, on the north abutment of the bridge was not NEMA rated. Because the equipment required a controlled environment and the sheer value of the equipment, CMS specified the installation of a NEMA rated control box. The box installed lacked the gasketing material required to keep moisture from the environment out of the enclosure. CMS remedied the problem by using silicone sealant at the seams to seal the panel.

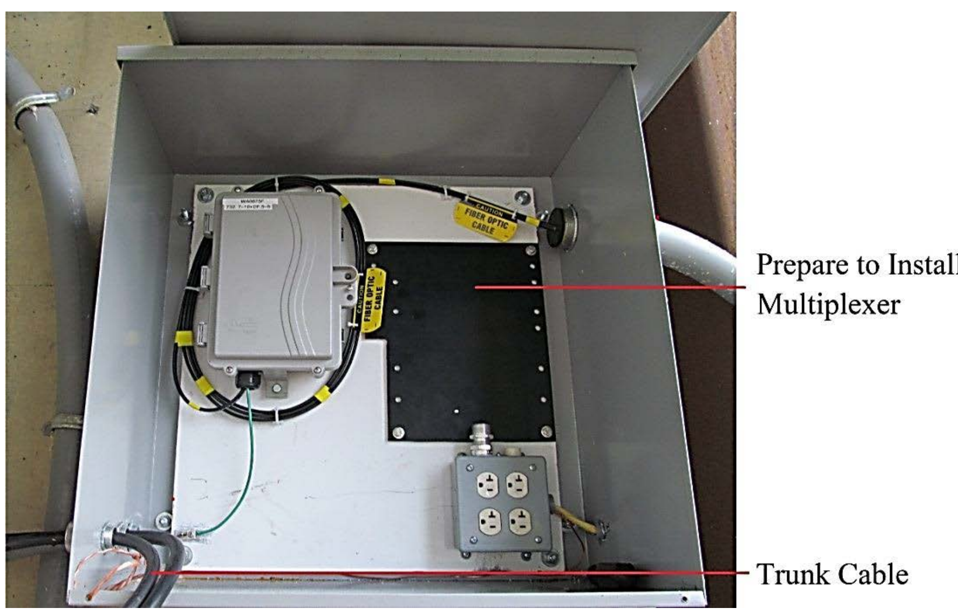

Figure 12. Control Panel at the Bridge

TASK E: Grind and prepare sensor locations for the installation (Figure 13). Cover with the temporary protective covering (Figure 14).

OBSTACLE 1: Many locations were impossible to access with the A-30 boom truck. While this piece of equipment was useful in pulling the trunk line, it lacked the articulation necessary to access many of the sensor locations. The sensor location, prepping and installation were predominantly done with the UB-50 boom truck.

OBSTACLE 2: Prepping of the sensor locations involved grinding off protective coatings. While AUTC anticipated the need for face shields, they did not anticipate the need for respiratory protection. The grinding of these coatings produced fine particulate matter cloud that encompassed both the person doing the grinding and the AKDOT&PF boom truck operator. AUTC made a trip to Talkeetna to purchase the necessary respiratory protection.

Figure 13. Metal Preparation: Grind and Mark the Sensor Location

Figure 14. Rust Prevention: Used a Temporary Protective Covering

8.4 Splicing-in Sensors and Sixteen Arrays

TASK A: Install sensor arrays (Figure 15). Arrays contain in part and/or in combination of the following sensors: steel strain sensors (Figure 16, Figure 17), concrete strain sensors (Figure 18, Figure 9 and Figure 20), rosettes (Figure 21, Figure 22), tilt meters (Figure 23), temperature sensors (Figure 24), displacement sensors (Figure 25), accelerometers.

OBSTACLE 1: Rosette sensors, specially ordered from Germany for this project, proved to be problematic. Unknown to the CMS installers, these rosettes were constructed with five micron fibers, not nine micron fiber that the system required. The issue was not discovered until CMS was on-site trying to splice them in. Ultimately the rosette sensors were not used. Alternative configurations of three small strain gauges were used in place of one rosette sensor.

OBSTACLE 2: The protective coatings prescribed by AUTC proved to be difficult and messy to install. The installers found that the application of the silicone paste took more time and produced more of a mess than their conventional sealing methods. This problem may be remedied in future installations with the use of caulking gun applied silicone in lieu of bucketed silicone applied by hand.

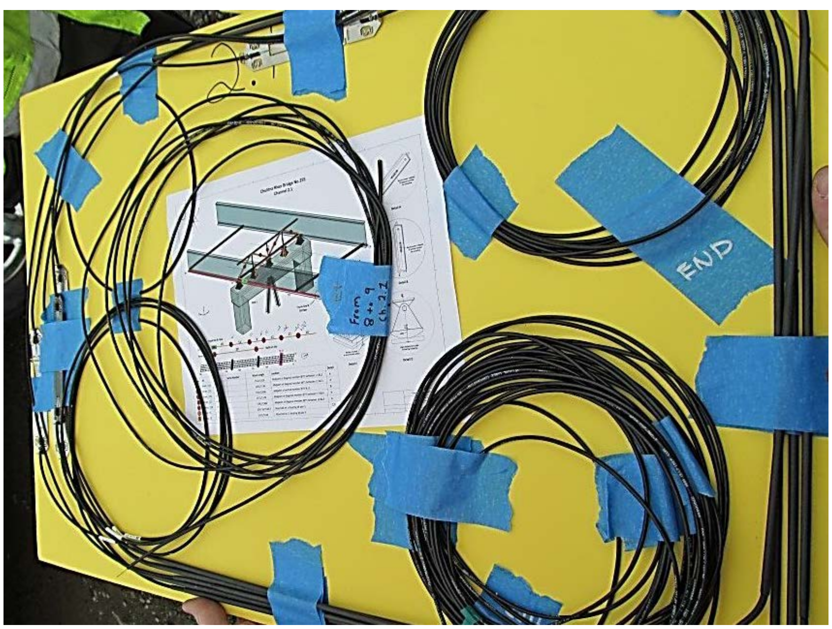

Figure 15. Sensor Array

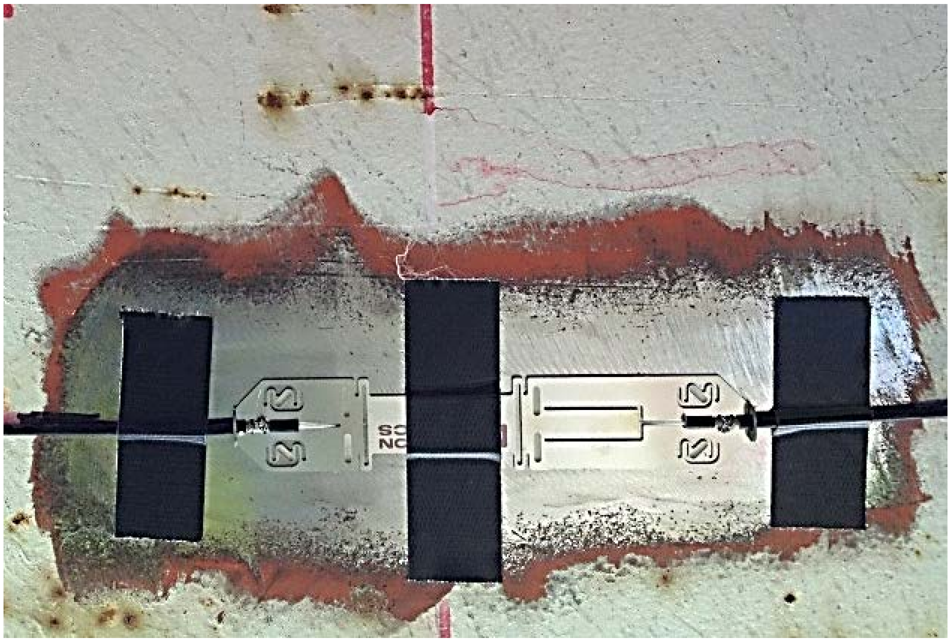

Figure 16. Spot Weld Strain Sensor

Figure 17. Strain Sensor Cover with the Protection Coating

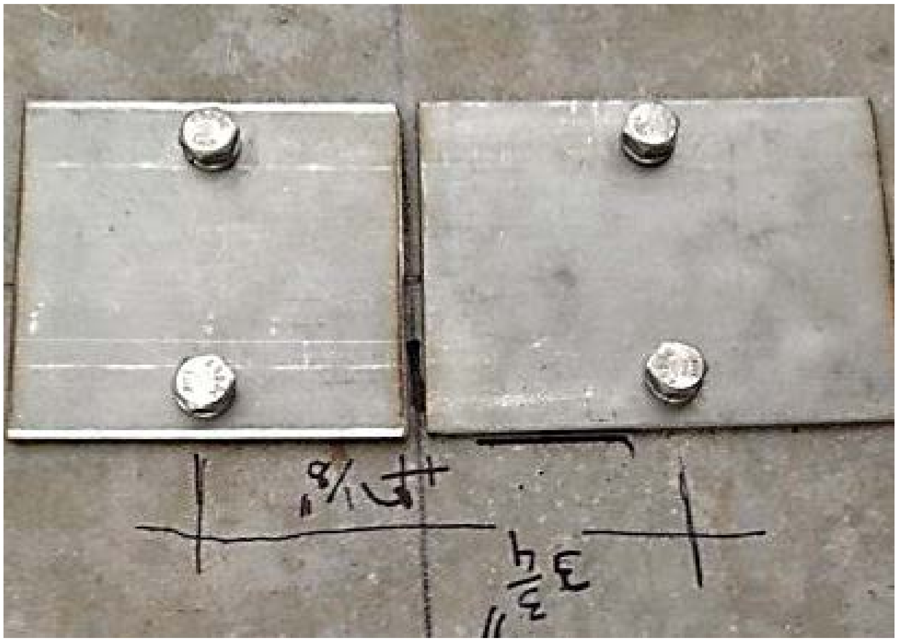

Figure 18. Bolted Steel Plate to the Concrete Deck

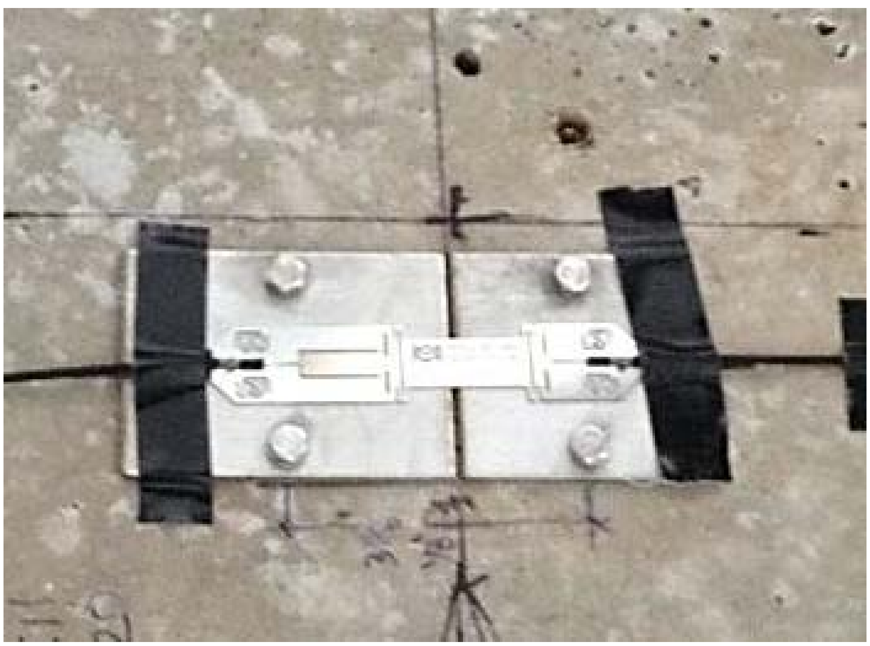

Figure 19. Spot Welded Strain Sensor on Steel Plate

Figure 20. Strain Sensor with Protective Cover

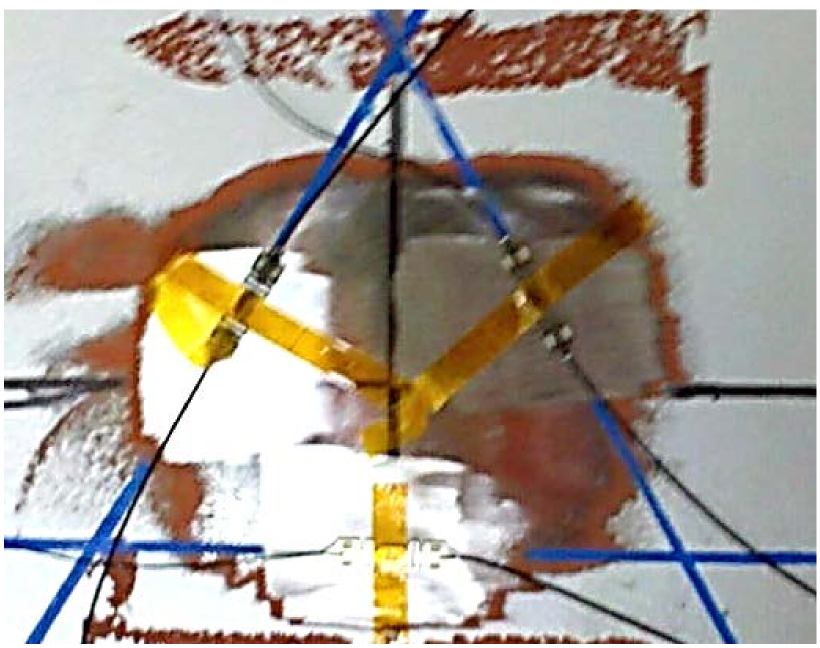

Figure 21. Spot Welded Rosette to Girder

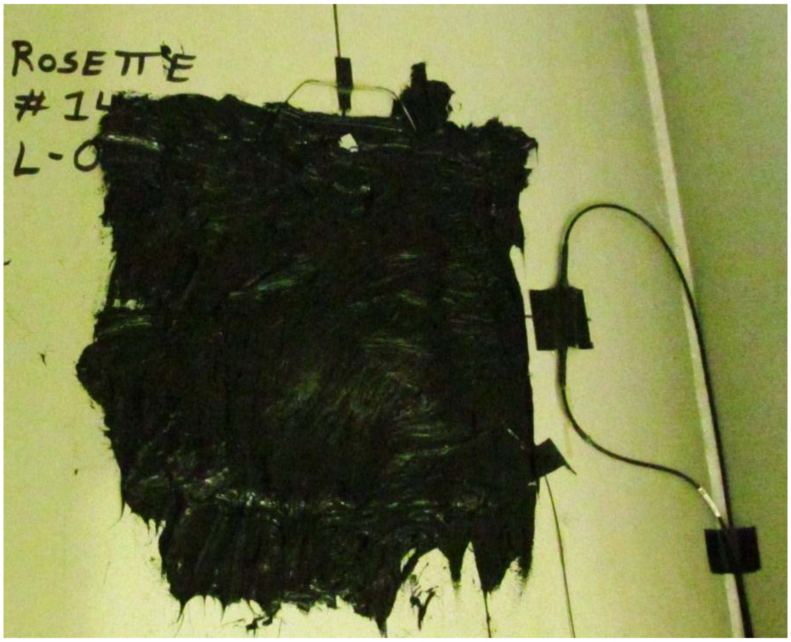

Figure 22. Rosette with Protection Coating

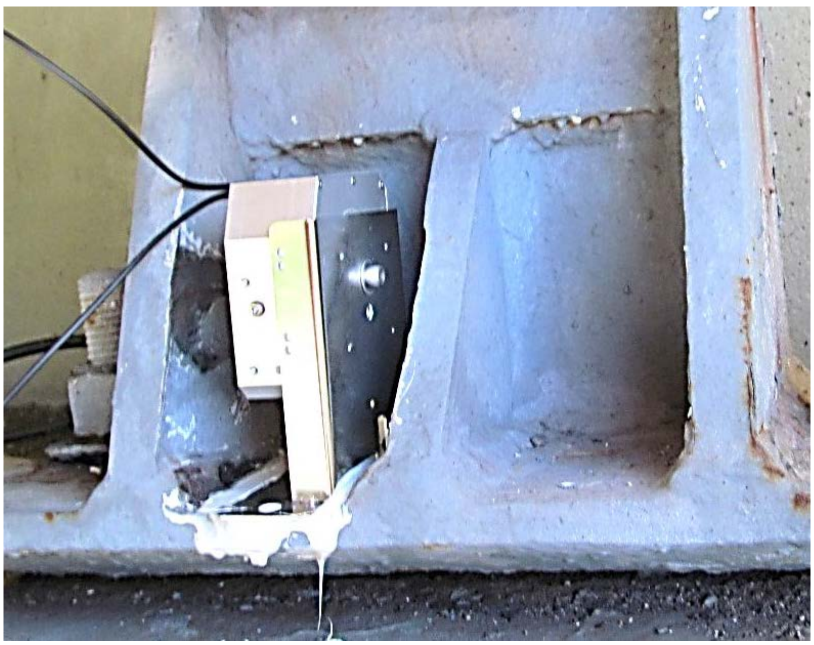

Figure 23. Tilt Meter at a Roller Support

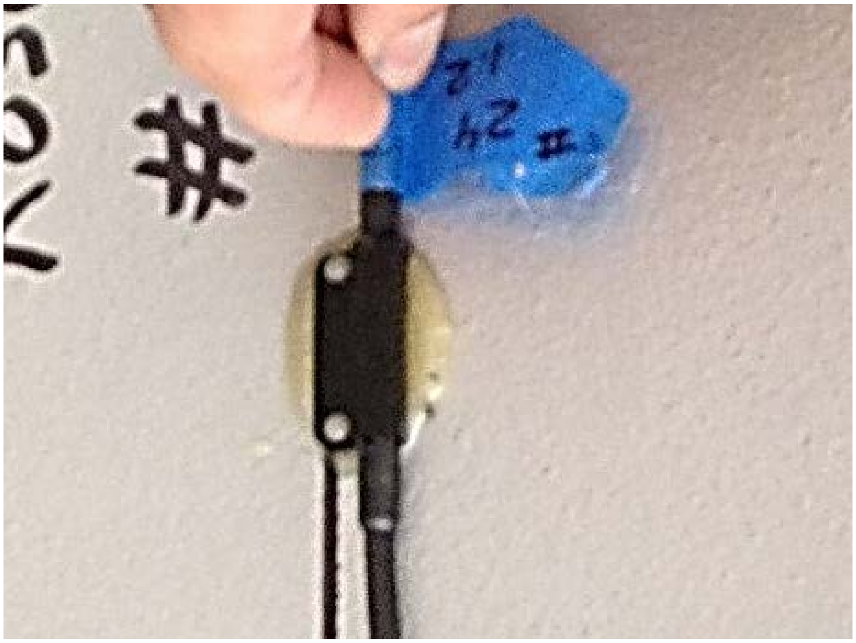

Figure 24. Using Epoxy to mount Temperature Sensor

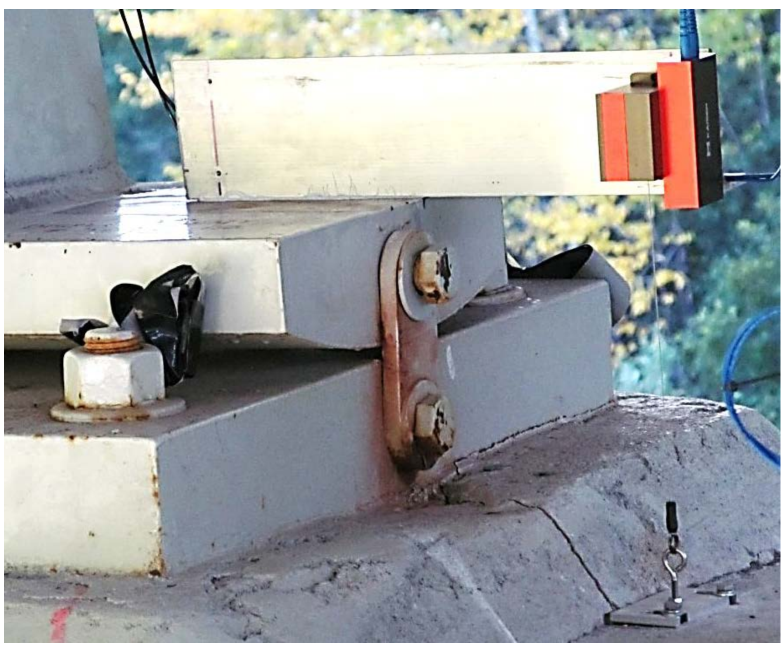

Figure 25. Displacement Sensor at the Support Bearing

TASK B: Test all connections and power levels (Figure 26).

OBSTACLES: Power level testing was done with the sensor arrays being directly hooked up to the interrogator. This was due to previous difficulties mentioned earlier in this report.

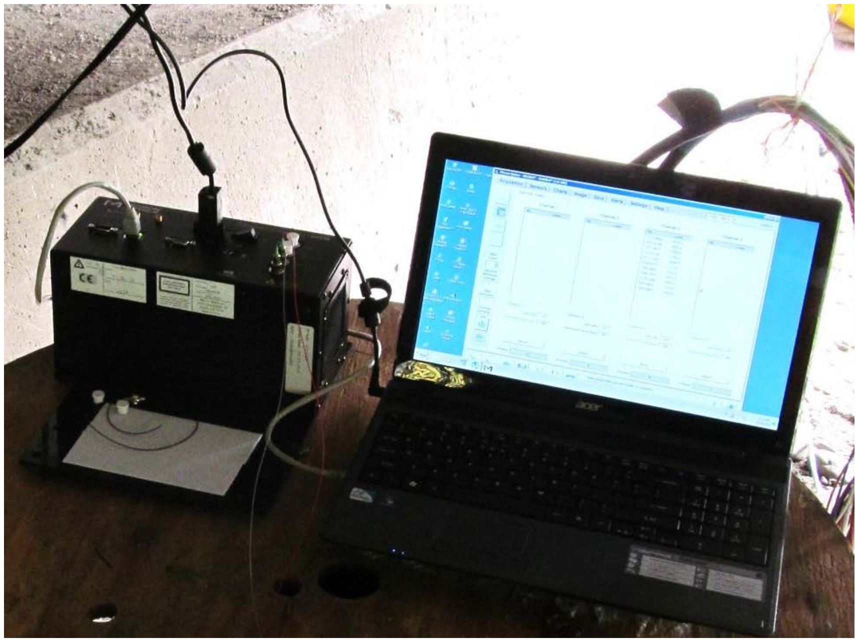

Figure 26. Test Each Array and the Power Level

9. ON-SITE CALIBRATION

TASK A: Calibrate all sensors and observe them for setting the first zero point.
TASK B: After load test, a second zero is given archiving the pervious data. Throughout the completion of this project, IntelliOptics SQL will be functional to save and run reports.
OBSTACLES: None.

10. CLIMBING EQUIPMENT

10.1 A-30 and UB-50 Truck

Truck mounted work platforms and the operators were provided by AKDOT&PF. CMS and AUTC personnel were safety trained and were required to wear the proper safety gear (harnesses, safety glasses, ear plugs and hard hat. During installation, CMS and AUTC personnel with the assistance of AKDOT&PF operators used an A-30 and UB-50 truck (Figures 27 and 28) to access structural members, prepare and install sensors. The A-30 has large platform and it is convenient for a worker for accessing equipment and to walk on the platform, however, it has limited extension and it couldn't reach some parts of the bridge. The UB-50 has a small platform, but it can extend longer than A-30 and it makes up for the shortness where the A-30 couldn't reach.

Figure 27. A-30 Truck Mounted Safety Equipment

Figure 28. Truck Mounted UB-50 Safety Equipment.

11. RESPONSIBILITIES

1. AUTC developed a work plan to schedule and coordinate with AKDOT&PF and various agencies, departments, material and equipment availability, personnel etc.
2. AUTC evaluated the plans for the structure to determine critical location for installation of the SHM sensors.
3. AUTC assisted CMS in the layout and design for location of various monitoring and equipment points.
4. AUTC provided 3 people on site to assist in the installation for a period of minimum one week and two people for the duration of the install.
5. AUTC ensured power and internet communications were on site and functional.
6. AUTC provided a modem on-site for internet communications.
7. AUTC provided a lift to access the upper part the of bridge truss.
8. AUTC traveled to CMS facility for training, and SHM system development.

CMS assisted in the design, development, fabrication and installation of a SHM system on the Chulitna River Bridge that included and was capable of the following:

1. Structural Health of the bridge is monitored independently by each individual sensor as well as in combination with other sensors.
2. The installed sensing technology can be monitored constantly such that changes in behavior and potential problems shall be identified in real time.
3. The system is robust and durable and will not require any calibration beyond the initial installation unless a major failure occurs.
4. The sensors are immune to electromagnetic interference and operate in an unprotected outdoor environment at ambient temperatures from -40°C to +120°C.
5. The SHM System is able to monitor strain, tilt, temperature and acceleration of the structure, all contingent on choices that were determined by AUTC.
6. Because of budgetary limitations, single axis accelerometers were used for modal response.
7. Strain gauges were welded to the structure using a Vishay spot welder. Each gauge was to have a range of plus or minus twenty five hundred (2,500) micro-strain or better. The

sensors are to be compensated for temperature, humidity, and any other effects as necessary to provide accurate strain measurements.

8. Up to 70 to 75% of the investment for monitoring equipment can be used on future structures once research for the current bridge is complete.

12. LOOKING AHEAD TO FUTURE SHM INSTALLATIONS

12.1 Room for Improvement

From conception, this project was fast paced. This project went from proposal to complete installation in less than five months. Many difficulties with the installation of this system were born from this schedule. Future projects may benefit from extra time allotted for planning, material ordering and prior system testing. Many of the components used on this SHM project were shipped directly from various manufacturers to Alaska, completely bypassing an essential quality control check at CMS. Because of this, materials arrived on-site that were incorrect, didn't fit and didn't work with the SHM system. To encourage seamless installations in the future, complete systems should be fully tested for functionality and integration before being sent to the field.

The installation of the system could have been accelerated with the use of both boom trucks simultaneously. Production during every phase of sensor installation could have been improved with the use of both boom trucks. The sensor installation process proved to be more laborious than the installation team anticipated. Future projects would benefit from multiple boom trucks and an increased timeframe for sensor installation.

12.2 Successes

This project produced the first ever fiber-optic based structural health monitoring system with an off-site data interrogation and acquisition system. The continued commitments by AKDOT&PF, AUTC, and CMS will ensure that this system will provide real-time, accurate and ultimately cost saving information to the State of Alaska. A server at the Institute of Northern Engineering at the University of Alaska Fairbanks is used to provide access to AKDOT&PF bridge design personnel, the University of Alaska Fairbanks (AUTC) research team and Dr. David McClain at Washington State University.

12. REFERENCES

[1] HDR, Load Rating and Structural Assessment Load Rating Report-Bridge No. 255: Chulitna River Bridge, 2011