Alaska Department of Transportation & Public Facilities
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Structural Health Monitoring and Condition Assessment of Chulitna River Bridge: Training 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)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		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)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		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. EXECUTIVE SUMMARY

In July of 2012, Alaska University Transportation Center (AUTC) was invited by Chandler Monitoring Systems Inc. (CMS) to Atlanta, Georgia to provide training: a) in the operation of structural health monitoring systems and b) sensor installation. The objective of this trip was to develop a thorough understanding of fiber optic sensing technology, data acquisition software and the installation and maintenance of the system as a whole.

While in Georgia, the AUTC group, comprised of AUTC's Associate Director Dr. J. Leroy Hulsey, Ph.D. student Feng Xiao and undergraduate student Patrick Brandon worked closely with CMS and Micron Optics, the developers of the strain gauges, data acquisition hardware and software to develop a structural health monitoring (SHM) system that would meet the needs of the Chulitna River Bridge SHM Project.

AUTC met with CMS in mid-July at their headquarters outside Atlanta. The first three days of training consisted of covering the fundamental theories behind fiber optic sensing systems. Once the AUTC team had developed a basic understanding of the system, CMS gave the team members hands on training including fiber splicing, sensor installation and sensor calibration.

AUTC also toured the Micron Optics manufacturing facility in Atlanta Georgia. Micron Optics was the manufacturer selected to provide the strain gauges, interrogator, multiplexer and the data acquisition software called IntelliOptics.

The following report outlines the selected structural health monitoring system configuration and a description of how t optic sensing technology is used to monitor bridge behavior.

3. STRUCTURAL HEALTH MONITORING SYSTEM OVERVIEW

The structural health monitoring system used on the Chulitna River Bridge is composed of five parts: sensors, sensor multiplexer, sensor interrogator, local computer and remote computer (Figure 1). The interrogator is the main component of the optics system.

The sensor interrogator sends four optic signals (lasers) via four channels from the McKinley Princess Wilderness Lodge communications room to the sensor multiplexer which is located at the bridge. The multiplexer is composed of four switchers; these four switchers distribute the incoming four laser 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 grating (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 1). In this study, the local computer and the sensor interrogator is located 1.3 miles from the bridge in a controlled environment utility room at the McKinley Princess Wilderness Lodge at MP 133 North Parks Highway. This is the first time, the local computer system and sensor interrogator has been placed off of the bridge. The idea is to provide better long term stability through a controlled temperature environment and to minimize chances of damage to the equipment by weather, people, animals or other factors.

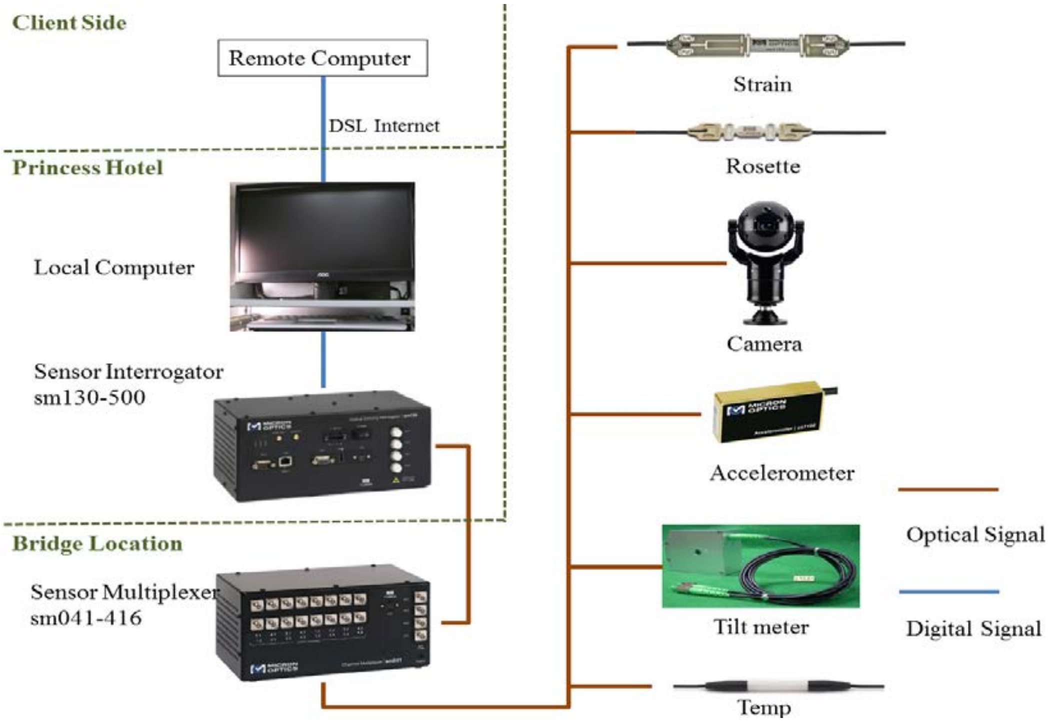

Figure 1. System Configuration

4. FIBER OPTIC CABLE

Fiber optic cable is composed of three layers: the core, the cladding and the buffer coating (Figure 2). The core is made from a high density glass and is the part of the fiber optic cable that conveys the light signals. The main cladding is made from a lower density glass that acts to contain the light signal within the core (Figure 3). The buffer coating is a protective coating that encapsolates the cladding fiber. This buffer coating can be ordered in varuis compositions depending on the required protection requested by the customer. Some common coatings include metal jacketing, kevlar lined plastic and low temperature plastics.

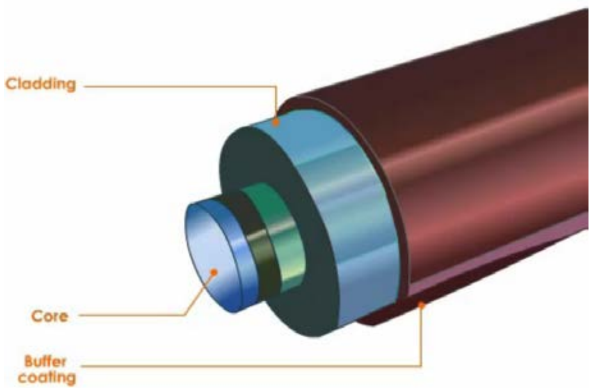

Figure 2. Fiber Optics

The glass core has higher refractive index than the glass cladding. Because of this, signal light is reflected back to the glass core. The glass cladding works to limit light loss from the core (attinuation). Because of this cladding, signal light can travel great distance in the glass core with relativly low light attinuation.

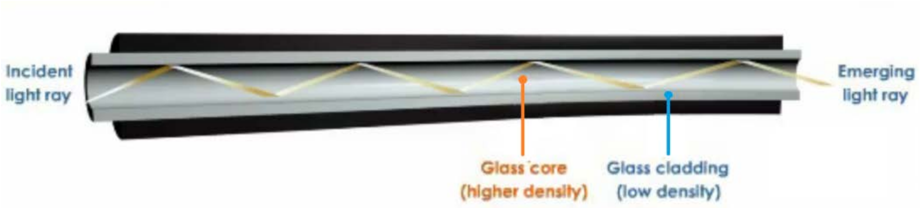

Figure 3. Light Transmission in Fiber Optic Cable

Modern fiber optic cable is durable, light and cheap; a far cry from fiber from the past. The fiber being used on the Chulitna River Bridge is a nine-micron, carbon fiber weaved, cable. This cable is capable of being bent into a six inch radius without any light attenuation.

5. FIBER BRAGG GATING

All optic sensors measure temperature, strain, acceleration, displacement and rotation by measuring strain within the fiber optic strand at the sensor. The strain developed within the fiber strand is produced in many ways, thermal strain (temperature sensor), strain due to stress produced by the base material (strain sensor), mechanical systems within the sensor (displacement sensor), and many more.

The strain experienced by the fiber is made apparent by changes in the dimension of the fiber Bragg Grating (FBG). This grating is composed of evenly spaced imperfections in the fiber cable core. These imperfections act as small mirrors that reflect select wavelengths of light back to the data interrogator (Figure 4). Each grating reflects only pre-determined light wavelengths, allowing the rest of the light to pass uninhibited.

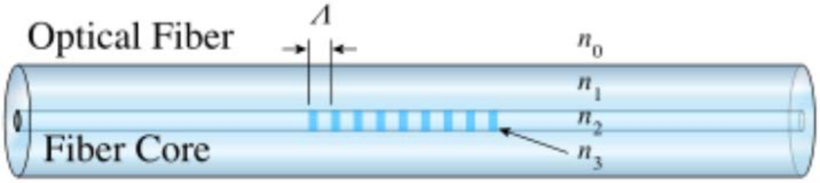

Figure 4. Fiber Bragg Gating

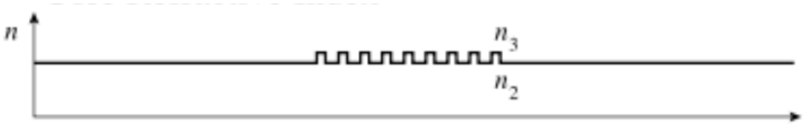

Figure 5. Core Refractive Index

The optic signal originates at the sensing interrogator. The interrogator sends out discrete light wavelengths in cycles that range from 1510 nm to 1590 nm. The interrogator used on the Chulitna River Bridge Project has a cycle rate of 1 kHz (1,000 cycles per second). This cycle capacity is reduced by the multiplexer to 250Hz (250 cycles per second). This reduction by the multiplexer is necessary to expand the signal from four channels to sixteen. In simple terms, the 250 Hz speed means that data from every sensor on the project can be recorded 250 times a second. These light signals are then reflected back to the interrogator by the sensor's FBG (Figure 6). From that point the interrogator interprets the incoming light signals and transfers them to digital data that is recorded by the on-site computer.

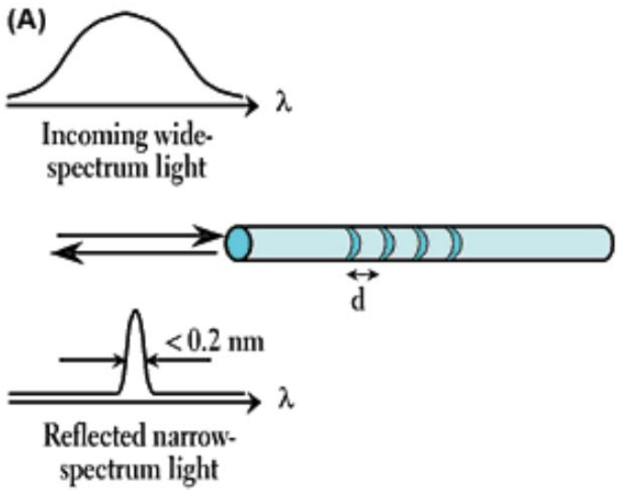

Figure 6. Fiber Bragg Gating Light Reflection

There are several external factors which can change the distance between each Bragg reflector, such as strain, temperature, etc. All of which affect the wavelength of the reflected light. Expansion of the FBG will result in longer reflected wavelengths. In the same way, compression of the FBG will reduce the wavelength of the reflected light (Figure 7).

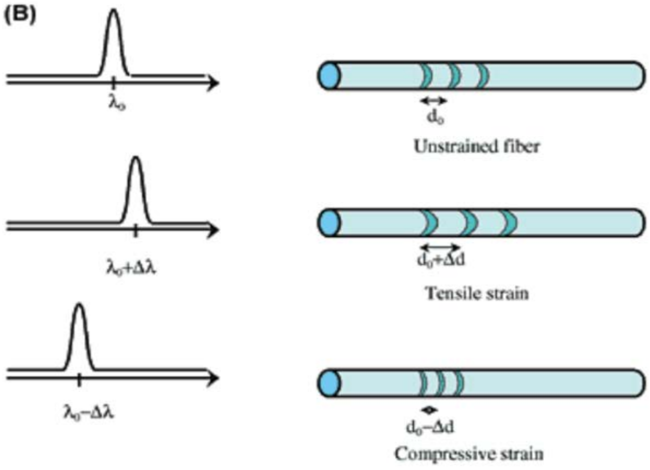

Figure 7. Fiber Strain & Corresponding Wavelength Change

Sensor wavelengths are sent by the Multiplexer on the bridge by buried dark fiber to the sensing interrogator located at the Mt McKinley Princess Hotel. The optic sensing interrogator interprets changing wavelengths and transfers them to digital signals. The local computer then stores the incoming data via IntelliOptics software (produced by Micron Optics Inc.) on-site and also sends the data to a remote server via DSL internet. In this study, the remote server is located at the University of Alaska Fairbanks at the Institute of Northern Engineering about 350 miles from the bridge. The University, AKDOT, and Washington State University have real time access to the system and can obtain reports. At this point, five users are provided “User name and password” privileges. Three users are at AKDOT and two users are on the research team at UAF (J. Leroy Hulsey and the PhD student, Feng Xiao).

6. FIBER OPTIC SENSOR ARRAYS

The optic sensing interrogator sends out a wide-spectrum of light in wavelengths ranging from 1510 nm to 1590 nm. Optical sensors only reflect pre-determined wavelengths back to the interrogator. The wavelengths returned by each individual sensor are unique to that specific sensor in that array. These specific wavelengths act as digital fingerprints, identifying what sensor the returned light belongs to and its’ corresponding strain.

Each optic sensor occupies a 5 nm wavelength range within an array. There is an available wavelength range of 80 nm within the 1510 – 1590 nm signal range. This means that a series of sensors can be installed in an array using one continuous fiber. The sensors downstream of the initial sensor reflect other ranges of wavelength light to the interrogator. It is standard practice to “space” the sensors 5nm apart to avoid any possible signal overlap. This means that there is a 5 nm wavelength range that is unused between each sensor’s reflectable light range. In this configuration, around eight fiber optic sensors can be put into use in one fiber optic cable and work as one sensor array (Figure 8).

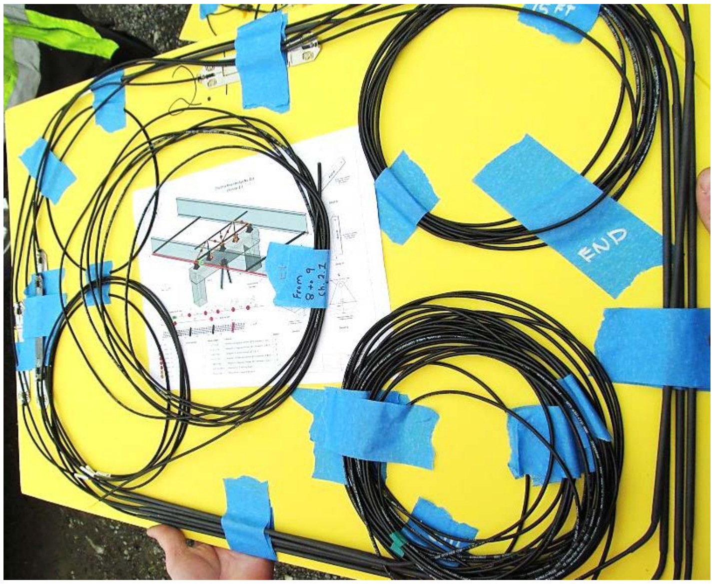

Figure 8. Seven Fiber Optic Sensors in One Array

7. ADVANTAGES OF FIBER OPTIC SENSORS

a) Stability

Fiber optic sensors are stable compared with the traditional foil strain gage. Light signals are capable of being transmitted over very long distances with low signal transmission loss. Fiber optic sensors are composed of mainly glass and protective coverings, if sealed properly; they are practically corrosion free generating long-term stability.

b) Non-conductive

Fiber optic sensors have the advantage of using non-conductive signal transmission. This means they are free from electromagnetic and radio frequency interferences. Fiber optic sensors have practical applications in urban areas where serious signal interferences are present.

c) Convenience

The fiber optic sensors and their cabling are very small and light, making it possible to permanently incorporate them into the structures. Also, several sensors can be installed on one array, meaning up to eight times less cabling as with conventional sensors. Much less than their electric counterparts; foil strain gauges which require a minimum of two cables per sensor. Fiber optic sensing systems simplify cable layout, shortening the installation period and saving on installation costs.