Quarterly Progress Report:

Project Number and Title: 2.10 Durability Evaluation of Carbon Fiber Composite Strands in Highway Bridges
Research Area 2: New materials for longevity and constructability

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Co-PI(s): *Keith Berube and Andrew Goupee, University of Maine*

Reporting Period: *09/01/2020 to 12/31/2020*
Date: *12/31/20*

Overview:

Work performed during the reporting period:

Task 1: Upgrade Data Acquisition System

1. Hardware installation plan

   The hardware installation plan was submitted to MaineDOT Bridge Engineering and it was approved. MaineDOT contracted the electrical work to provide power for the systems at the Penobscot-Narrows Bridge (PNB) site based on our instrumentation plan. Keith Berube met with two engineers from Campbell Scientific, MaineDOT engineers and electrical contractor at the PNB site. The recommendation was to have two independent systems: MaineDOT (air temperature) and UMaine (wind speed and air temperature). Keith Berube met with the electrical contractor to explain the installation work. The electrical installation work was completed.

   We coordinated with MaineDOT having the network switch installed at the PNB site, which would provide online access for our monitoring systems.

   We conducted weekly trips to the PNB site to install the necessary hardware for the implementation of the wireless system. The fiber optic sensor conduit installation has been completed on both spans of the bridge. Installation on the Prospect side is shown in Figure 1. We have completed approximately 40% of the hardware installation work.

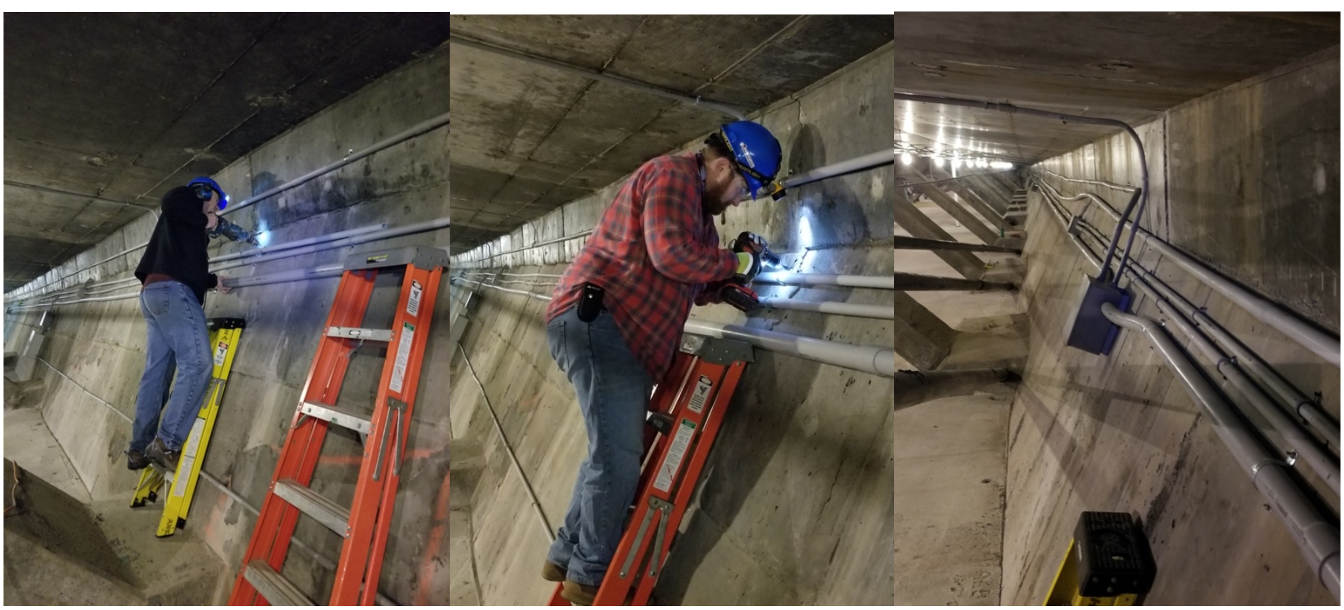

Figure 1 Fiber optic sensor conduit installation on the first span (A anchors) from the Prospect side of the PNB

2. Wireless data acquisition system

The minimum requirements of the wireless data acquisition system for the sensor system upgrade at the Penobscot Narrows Bridge were:

- 4 analog input channels at ±10 Vdc
- 2 full-bridge differential input channels
- 16-bit analog to digital conversion (ADC) resolution
- 100 Hz sampling rate
- 200 m wireless transmission range
- System must automatically reset after power outage
- System must integrate with National Instruments Labview software
- Operate in temperature conditions of 0°F to 100°F
- Ethernet connection for base unit
- Ability of base unit to interface with computer via USB
- Remote system operating 24 hr/day, 7 days/wk, 365 day/year, etc.

The system chosen was a Parker/Lord Microstrain wireless system. The system consists of a base station receiver (the WSDA-2000) and six wireless DAQ modules (the V-Link 200). The WSDA-2000 base station allows reception from up to 127 DAQ modules, has both USB and Ethernet interfaces, and 4 GB data storage. The V-Link 200 modules have:

- 4 full-bridge differential input channels
- 4 single-ended analog input channels with 0-5 V, +/-5 V, 0-10 V, or +/-10 V DC voltage input ranges
- 18-bit ADC resolution
- Sampling rates up to 4 kHz
- RF range up to 800 meters
- –40 to +175 °F operating temperature range

The system includes a rechargeable battery backup, it fully resets after a power outage, and comes with Labview drivers and sample code.

The wireless system is currently being integrated with the LabView data acquisition program and undergoing environmental sensitivity testing. A thermal verification of the V-Link 200 DAQ modules is being conducted to determine each units' sensitivity to temperature variations. This is required since the wireless DAQ modules will be located inside the PNB where temperatures vary year-round. This will allow the recorded outputs from the DAQ modules to be modified to account for DAQ temperature sensitivity.

Each module is being tested through the range of 0°F to 105°F, in increments of 15°F in a controlled environmental chamber at the Advanced Structures and Composites Center (ASCC). The temperature is held constant at each increment for a period of two hours to allow the DAQ units to equilibrate. A constant voltage power supply provides a constant 5 Vdc to each of the single-ended voltage input channels of the wireless DAQ module.

A sample graph of the results of the temperature testing is presented in Figure 2. The graph includes the temperature of the chamber where the wireless DAQ unit was located and the change in voltage recorded by the four single-ended voltage channels. The graph indicates that the recorded values of voltage change with temperature variation of the wireless DAQ module in the range of -0.5 to 2.5 mVdc over the 0-105°F temperature range.

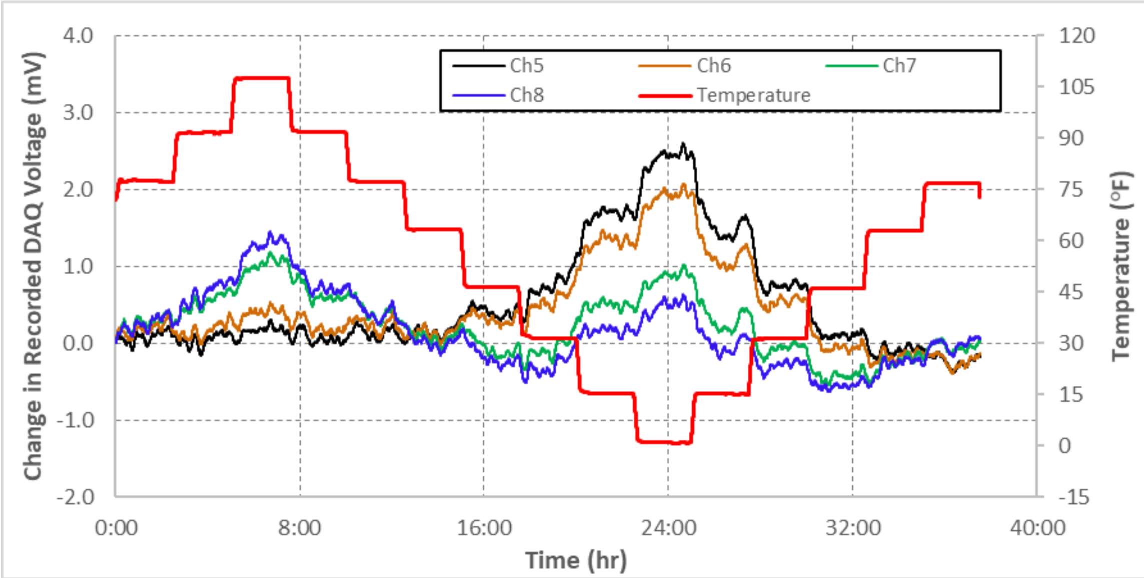

Figure 2: Temperature sensitivity results for the four voltage input channels of a V-Link 200 wireless DAQ module

Task 2: External Environmental Sensing

- The instrumentation interface was removed in September for implementation of the new wireless system. Continuous data will resume after the wireless system installation is completed.
- We drafted the outline for a journal paper to tell the story of the work that has been done on external environmental sensing. We identified two potential journals: a) Journal of Civil Structural Health Monitoring https://www.springer.com/journal/13349, and b) Structural Health Monitoring https://journals.sagepub.com/home/shm

Task 3: Implement Analytical Model

- We have started analyzing the data acquired from continuous monitoring at one stay anchorage location at the PNB site during July and August. The data being analyzed is: force vs time and temperature vs time. The data acquired is being correlated with a numerical model (example shown in Figure 3).

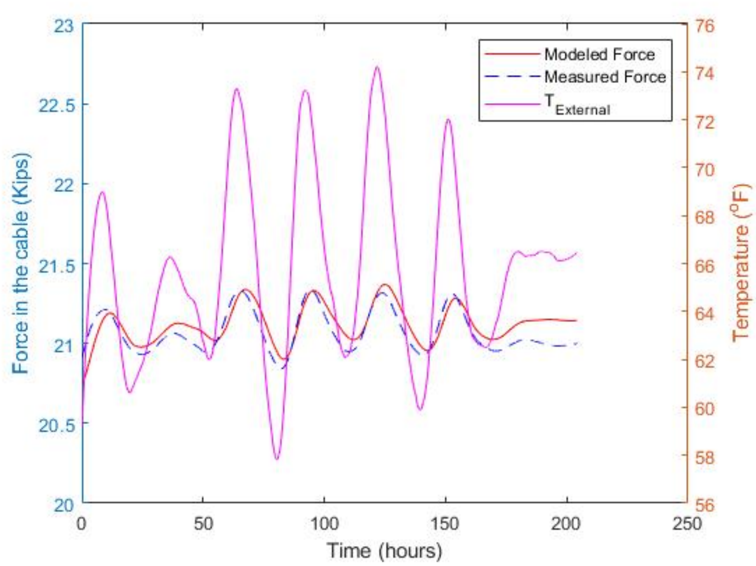

Figure 3 Comparison of predicted and measured force in left CFCC located in stay 10B

- A one-way coupled thermoelastic numerical model is being developed that predicts the range of forces in the CFCC strands for each stay using the measured external air temperature as an input. The numerical model consists of a transient heat conduction problem employing the lumped-parameter method applied to the components of the cable stays (i.e., the outer HDPE sheath, internal air as well as steel and CFCC strands) which is driven by the external air temperature via convection. The transient CFCC temperature is then used in a quasi-static linear thermoelastic calculation to determine the CFCC force by enforcing compatibility of the steel and CFCC strand deformations as well as equilibrium of the strand anchorage.

Task 4: Durability Assessment

- The literature review on existing use of carbon fiber cables/strands in civil infrastructure was drafted.

Table 1: Task Progress

Task Number	Start Date	End Date	Percent Complete
Task 1: Upgrade Data Acquisition System	6/1/2019	12/31/2020	70%
Task 2: External Environmental Sensing	1/1/2020	12/31/2020	30%
Task 3: Implement Analytical Model	11/1/2019	8/30/2021	35%
Task 4: Durability Assessment	11/1/2019	12/31/2021	25%

Table 2: Budget Progress

Entire Project Budget	Spend Amount	Spend Percentage to Date
To be completed by Grant/Fiscal Manager, Advanced Structures and Composites Center, UMaine		

Table 3: Presentations at Conferences, Workshops, Seminars, and Other Events

Title	Event	Type	Location	Date(s)
Durability Evaluation of Carbon Fiber Composite Strands in Highway Bridges	2020 TIDC Annual Conference	Abstract	Virtual	August 12-13, 2020
TIDC 2.10 Durability Evaluation of Carbon Fiber Composite Strands in Highway Bridges	2020 Student Poster Contest	Poster	Virtual	September 25, 2020

Table 4: Publications and Submitted Papers and Reports

Type	Title	Citation	Date	Status
N/A				

<u>Participants and Collaborators:</u>

Table 5: Active Principal Investigators, faculty, administrators, and Management Team Members

Individual Name	Email Address	Department	Role in Research
Roberto Lopez-Anido	RLA@maine.edu	UMaine Civil and Environmental Engineering	Project PI, Graduate student co-advisor, and Structural lead.
Keith Berube	keith.berube@maine.edu	UMaine Mechanical Engineering Technology	Project Co-PI and Data acquisition instrumentation lead.
Andrew Goupee	Andrew.goupee@maine.edu	UMaine Mechanical Engineering	Project Co-PI, Graduate student co-advisor, and Modeling lead.

Table 6: Student Participants during the reporting period				
Student Name	**Email Address**	**Class**	**Major**	**Role in research**
Braedon Kohler		Masters	Mechanical Engineering	Modeling, programming and data acquisition

Table 7: Student Graduates			
Student Name	**Role in Research**	**Degree**	**Graduation Date**
N/A			

Table 8: Research Project Collaborators during the reporting period						
Organization	**Location**	**Contribution to the Project**				
		Financial Support	**In-Kind Support**	**Facilities**	**Collaborative Research**	**Personnel Exchanges**
Maine DOT	Augusta, ME		x			

Technical Champion:
Name: Dale Peabody
Title: Director, Transportation Research
Organization: MaineDOT
Location (City & State): Augusta, ME
Email: Dale.Peabody@maine.gov

Changes:

The schedule has been affected by disruptions of day-to-day campus and field work due to the University restrictions imposed in response to COVID-19 health safety precautions.

Planned Activities:

The following activities are planned for the next three month period:

- Complete the hardware installation at the Penobscot-Narrows Bridge site.
- Integrate our LabView program with the wireless and fiber optic systems.
- Generate graphs summarizing the structural health monitoring data measured at the PNB site.
- Generate graphs correlating measured data with the numerical model predictions.
- Write the first draft of a journal paper to present the finding of the project. The questions to be addressed in the paper are: What is available in the literature for structural health monitoring of carbon fiber composite strands? How to implement a structural health monitoring system for continuous wireless data acquisition? What sending architecture and technology actually works at the bridge site? Why this system is valuable to assess durability and performance of the carbon fiber composite strands? Why a numerical predictive thermoelastic model is important to analyze the field monitoring data? Can we explain fluctuations in strand force over time? What is the value of having fiber-optic strain sensors?