TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): ____IOWA DOT____________________________________

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *TPF-5(449)*		**Transportation Pooled Fund Program - Report Perio** Quarter 1 (January 1 – March 31, 2022) x Quarter 2 (April 1 – June 30, 2022) Quarter 3 (July 1 – September 30, 2022) Quarter 4 (October 1 – December 31, 2022)
Project Title: Robust wireless skin sensor networks for long-term fatigue crack monitoring of bridges		
Project Manager: Khyle Clute	**Phone:** 239-1646	**E-mail:** khyle.Clute@iowadot.us
Project Investigator: Simon Laflamme	**Phone:** 294-3162	**E-mail:** laflamme@iastate.edu
Lead Agency Project ID:	**Other Project ID (i.e., contract #** Addendum 736	**Project Start Date:** May 15, 2020
Original Project End Date: May 14, 2023	**Contract End Date:** May 14, 2023	**Number of Extensions:**

Project schedule status:
x On schedule □ On revised schedule □ Ahead of schedule □ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Projec	Total Percentage of Work Completed
$ 540,000	$220,979	45%

Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
$153,104		

Project Description:

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

- ISU & USC worked together on achieving a paintable sensor for concrete applications and studied the use of a shielding layer on the sensor.
- ISU investigated the effect of shielding of sensors installed on concrete. Results are showed below from 3 different configurations. Overal, results showed that any shielding pattern can be used, with a preferred thickness of 0.34 mm and above. Sensor 3 readings are believed to be outliers.

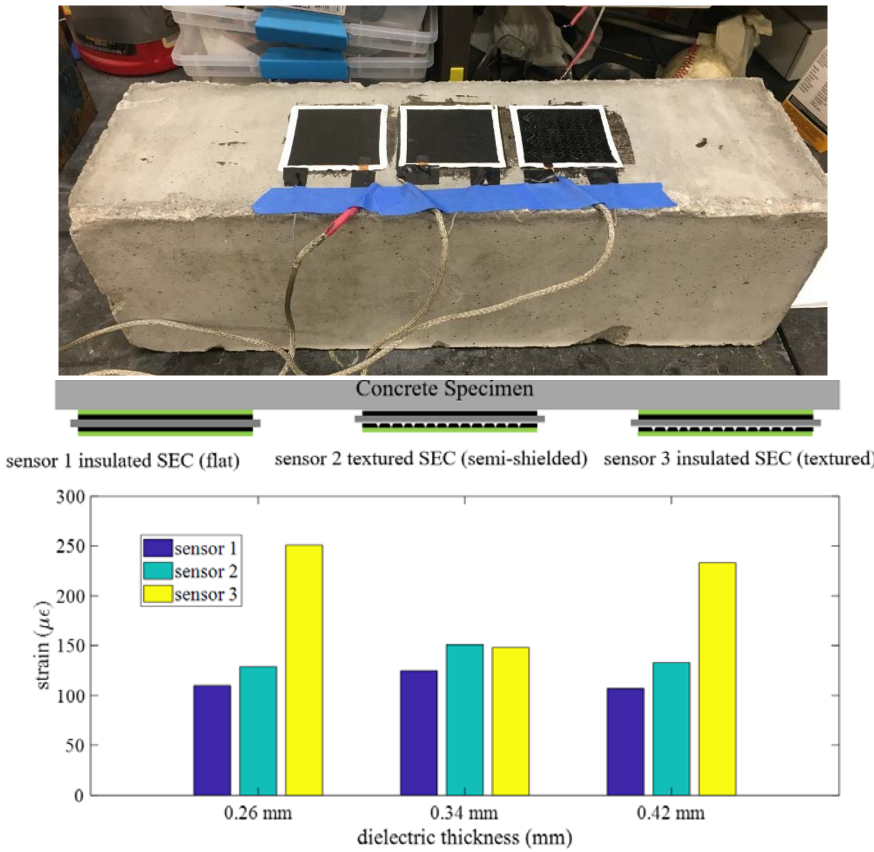


Figure: results from shielded SEC tests showing the setup (top) along with strain reading results.

- KU continued to collect and analyze data for the interior and exterior girders of the I-70 highway bridge near Kansas City using the deployed wireless large-area strain sensor network, WLASS.
- Using the proposed WLASS and automated algorithm, KU monitored fatigue cracks on the exterior girder, as shown in the figure below.

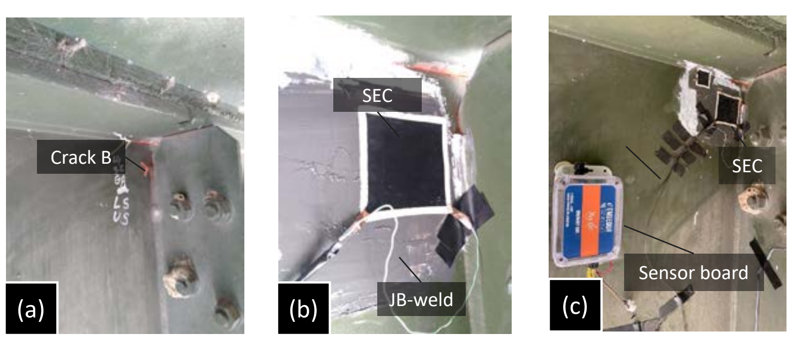


Figure. Installation of the WLASS for the exterior girder

Also shown below are results of the updated CGI results using 129 datasets. Similar to the previous result, the updated plot of CGI remained constant, indicating no crack growth.

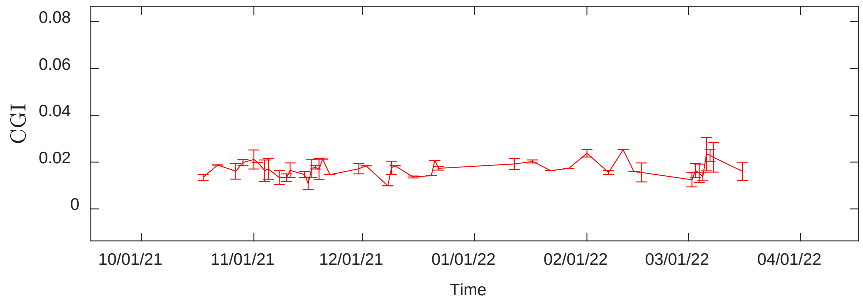
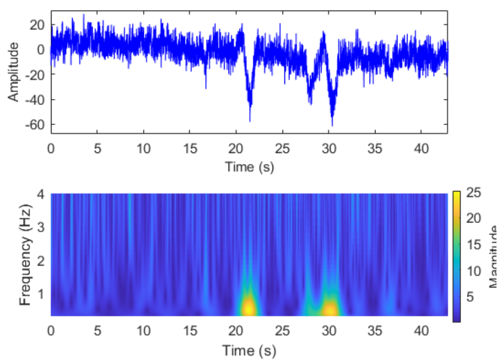
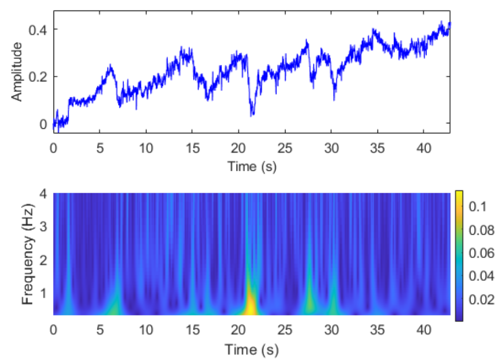


Figure. modified CGI results.

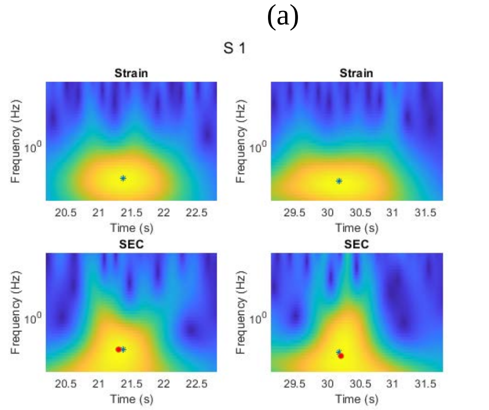
- KU monitored fatigue cracks on the interior girder using the three corrugated SEC. One of the corrugated SECs was installed on the exterior side of the interior girder, while others were attached to the interior side of the interior girder. Two strain gauges were installed on the diagonal members of the cross-frames, which were used along with the data from the corrugated SECs to compute the CGI. Promising data from the corrugated SEC installed on the exterior side of the interior girder was obtained, whereas data from other SECs experienced some fluctuations. The SEC data from the exterior side of the interior girder was analyzed using the CGI algorithm. The results are shown below. The algorithm identified the peaks and computed the modified CGIs. Overall, the CGI stayed constant.



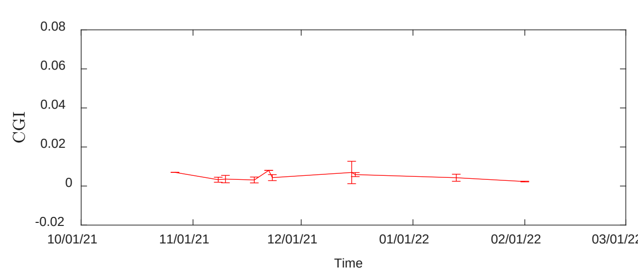
(a)



(b)



(c)

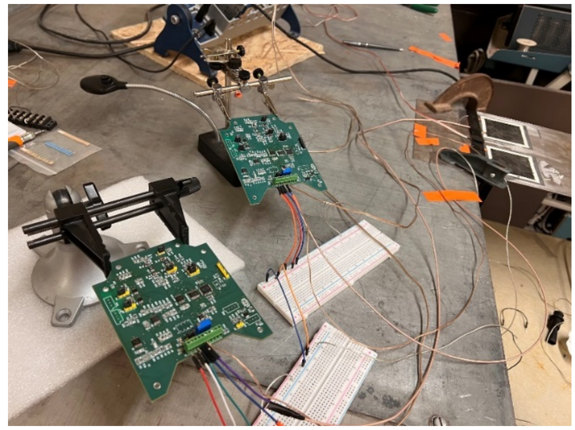


(d)

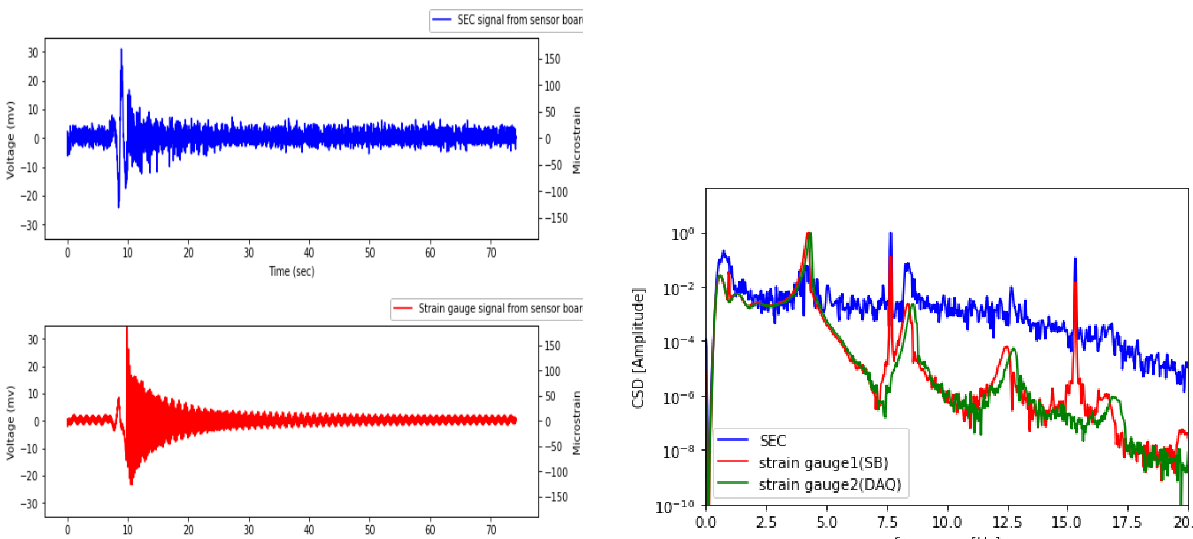
Figure. Data processing result using the corrugated SEC data: a) raw data and GM-CWT magnitude of the strain gauge, b) raw data and GM-CWT magnitude of the new SEC, c) WOIs of the strain and SEC with identified peaks, and d) the modified CGIs based on the identified peaks.

- UA assembled two new sensor boards and tested them to validate their performance. A cantilever plate test was conducted. A typical result is shown below.

a. The two new sensor boards



b. Test setup for the sensor boards



c. Sensorboard 2 test results - comparison to conventional strain gauge with NI DAQ in time domain (left) & frequency domain (right)

Figure: cantilever test result for new sensor boards.

- UA updated the sensor board operating software to add a scheduling function to control the frequency of the onboard calibration process (i.e. bridge balancing, signal amplification, and shunt calibration). The frequency can be preset in the software. With this, once the sensor board carries out the onboard calibration process, it stores the calibration information (i.e. optimized resistor values in the digital potentiometer) in the non-volatile memory and uses those stored calibration data for next sensing process. As such calibrated setup will be valid for substantial period unless significant change occurs in the SEC, sensorboard, and environment condition, there is no need to repeat the onboard calibration process each sensing event. Adding this function can save up to 40 seconds of time required for the onboard calibration each sensing event and reduce unnecessary power consumption of the sensor board. The sensor board signals from two consecutive turns are shown the figure below indicates the scheduling function is working as expected; first one carried out the onboard calibration process, but following event skipped that calibration process.

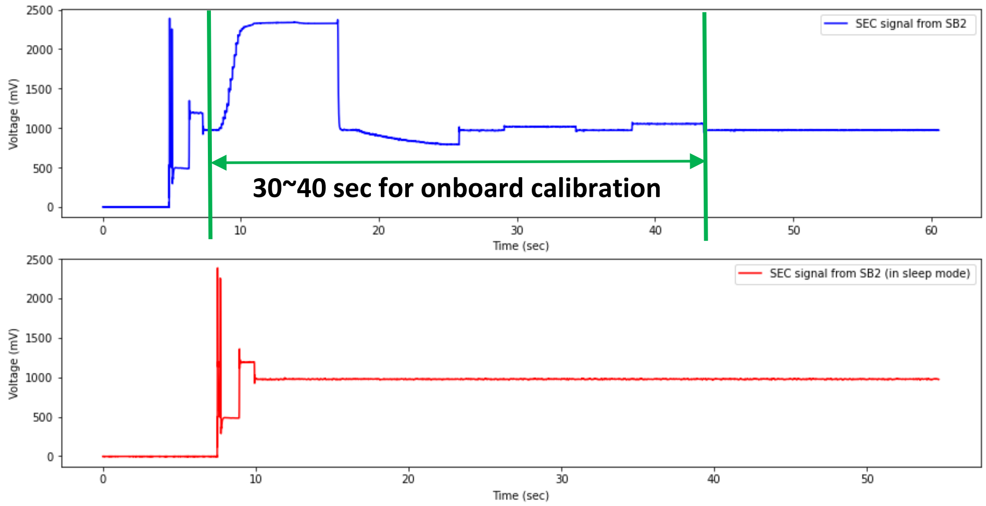


Figure: SEC signal with the scheduling function in sensor board after powering on the board

- For mass production of up to 10-15 sensor boards, all the necessary parts have been purchased.
- USC investigated the corrugated SECs with different dielectric thicknesses using SECs attached to concrete using off-the-shelf epoxy and the corrugated SEC painted onto the surface of the concrete specimen. SECs of different layers were attached with off-the-shelf bicomponent epoxy on the. The investigation is conducted for different thicknesses of SEC's dielectric layers for thicknesses of 0.28, 0.36, 0.48, and 0.56 mm, as shown in the figures (a) - (d) below. The results show higher strains recorded by the SEC at 0.28 mm, and the strain slowly reduces as the dielectric layer increases. Therefore, an optimal dielectric layer thickness can be obtained between 0.36 mm and 0.48 mm. Beyond a thickness of 0.48 mm, the SEC will underestimate the strain on the monitored surface

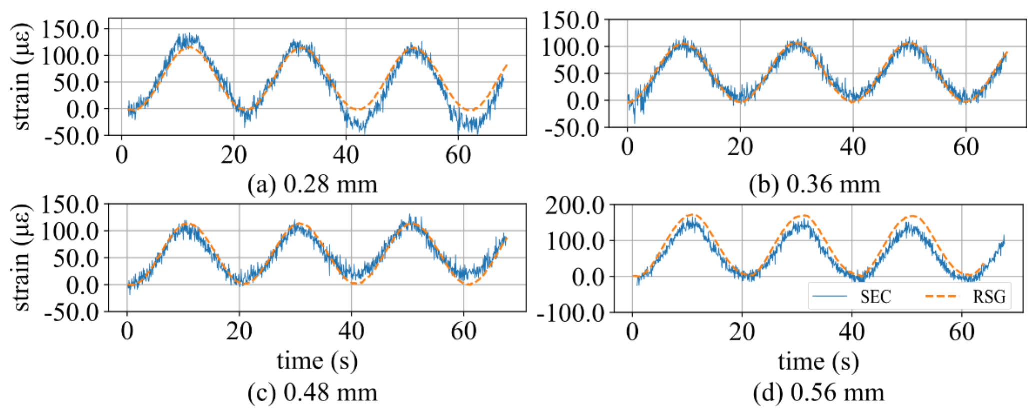
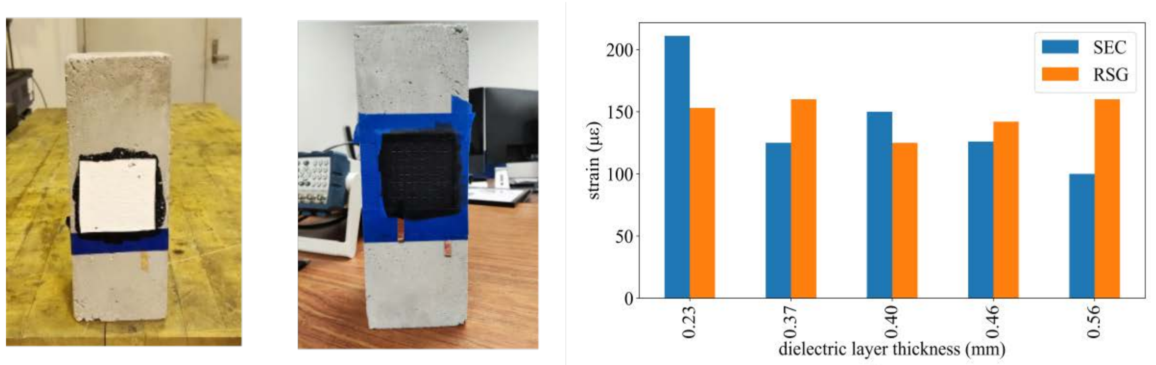


Figure: Strain results from textured SEC adhered with off-the-shelf bi-component epoxy at: (a) 0.28 mm; (b) 0.36 mm; (c) 0.48 mm; and (d) 0.56 mm thicknesses.

- Investigations were carried out on SEC painted onto concrete surfaces. This method of application ensures that the SEC is in direct contact with the monitored surface. The painting process is shown in figure (a) below, and the investigation results are shown in the subsequent figures. Similar to strain data obtained from SEC attached with epoxy, the SEC measured strain reduced as the dielectric layer thickness increases. The exception in this data is seen at thicknesses of 0.37 and 0.40 mm, where the strain recorded by the SEC is higher than that of RSG, as detailed in the histogram in figure 3(c). The results show that the textured SEC behaves the same with either method used to adhere it to the concrete surface.



(a) (b) (c)

Figure: Investigations showing: (a) painted textured dielectric layer on concrete; (b) completed SEC painted on concrete; and (c) histogram chart for strain data on SEC and RSG at 0.23 mm, 0.37 mm, 0.40 mm, 0.46 mm, and 0.56 mm.

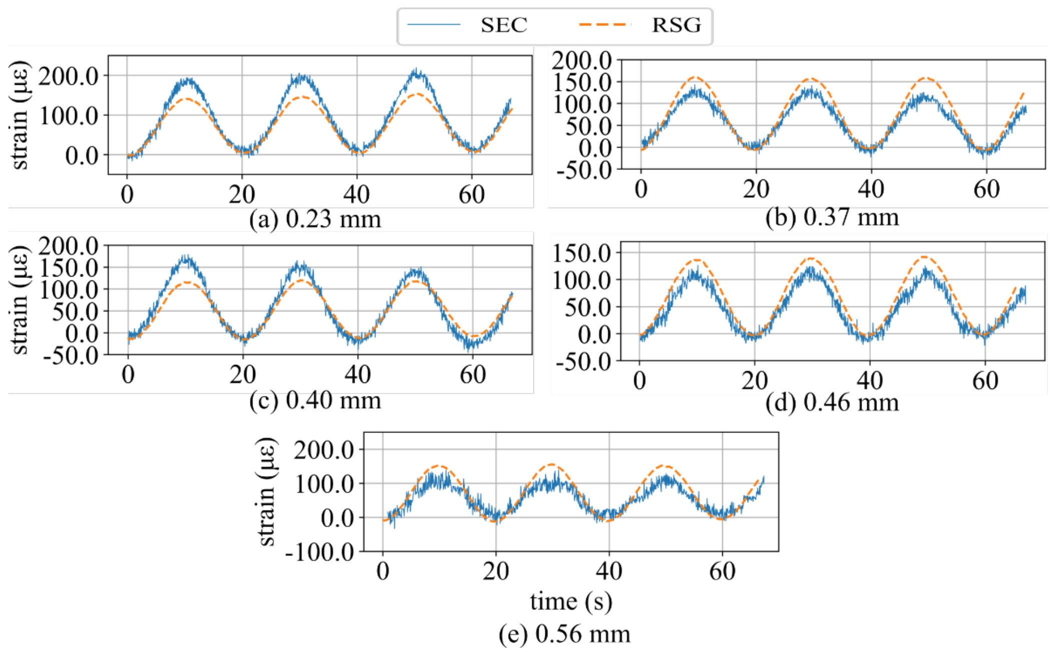


Figure : Strain results from textured SEC painted with carbon black on concrete at: (a) 0.283mm; (b) 0.37 mm; (c) 0.40mm; (d) 0.46 mm; and (e) 0.56 mm thicknesses.

Anticipated work next quarter:

- ISU will continue working with USC to establish fabrication and installation procedures for concrete applications, and extend to steel.
- KU is working with KDOT to schedule the next field visit to: 1) bring the WLASS back online, and 2) test strategies to improve the quality of data from the corrugated SECs.
- KU will continue to collect and analyze data from the WLASS using the developed algorithm.
- UA will continue to test the sensor boards in different test setup to further debug and to improve the performance of the boards.
- UA will start the PCB board printing and assembling process for mass production.
- USC will initiate the use of Digital Image Correlation for investigating crack propagation sensing for SEC painted and adhered onto the surface of a structure.

Significant Results:

- Demonstration that shielded SECs can be used in various configurations.
- Validated WLASS in the field.
- All three new sensor boards are working as designed with added scheduling function.

Circumstance affecting project or budget (Describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope, and fiscal constraints set forth in the agreement, along with recommended solutions to those problems). N/A