Quarterly Report

Project Title:
Development of a Self-Sustained Wireless Integrated Structural Health Monitoring System for Highway Bridges

Cooperative Agreement # RITARS11HUMD

Ninth Quarterly Progress Report

Period:
July 14, 2013 through October 15, 2013

Submitted by:
The Research Team – University of Maryland with North Carolina State University and URS

Submitted to:
Mr. Caesar Singh, Program Manager, US DOT

Date: October 31, 2013

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EXECUTIVE SUMMARY

I — TECHNICAL STATUS

Accomplishments by Milestone

1.1. General

- Updated Project web site (http://www.ncrst.umd.edu/) (Task 1 and Deliverable 2)
- Delivered ninth quarterly financial and technical reports (Task 6 and Deliverable 11)
- Caught up with the progress on the subject of wireless sensor field testing.
- Conducted the time history analysis using updated traffic and truck information, and tried to match the simulated data with the summer and winter field test results for the remaining life estimation.
- Attended Conference of ASCE Engineering Mechanics Institute (EMI) conference and delivered two presentations.
- The revised work plan is shown below as Milestones/Deliverables. Dark Shading indicates Deliverable items and Tasks in which the Research Team has been engaged over the past quarters. Lighter shading indicates anticipated duration for Deliverables by quarters. Grid pattern shading means partially fulfilled.

Deliverables	Action	Quarter No.											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Form TAC and conduct kick-off meeting. Determine baseline field test procedure (Task 1)												
2	Establish and update project web site (Tasks 1 & 6)												
3	Conduct baseline field test and finite element analysis on pre-selected bridges (Task 1)												
4	Design, fabricate and characterize AE sensor and measure the performance (Task 2)												

5	Develop and evaluate T-R method for passive damage interrogation (Task 3)
6	Develop and experimentally evaluate wireless smart sensor and hybrid-mode energy harvester (Task 4)
7	Implement passive damage interrogation T-R algorithm in the wireless smart sensor on bridges (Task 4)
8	Integrate and validate AE sensors with wireless smart sensor and hybrid-mode energy harvester (Task 5)
9	Develop and conduct field implementation/validation of commercial-ready ISHM system with remote sensing capability (Task 5)
10	Recommend strategy to incorporate remote sensing and prognosis into BMS (Task 5)
11	Prepare and submit quarterly status and progress reports and final project report (Task 6)
12	Submit paper to conference presentations and publication to TRB meeting or other conferences (Task 6)

Note: Deliverables items 7, 8, 9 and 10 for the 8th quarter are partially fulfilled. They are still tested and modified by the NCSU team. The explanation of the delay is described and highlighted later under Section 1.6 - Future Plan.

1.2. Remote Health Monitoring System

- Real time strain and AE data monitoring is continuously viewed (, except two occasions due to thunderstorms and accidently pulled the plug by maintenance workers.) The following web address should display the BDI strain and AE data, both the graph and the properties.
  1) Try entering this web address into your browser (either Internet Explorer or Firefox should work fine)
  Link 1 to Remote BDI strain monitoring (link to http://166.143.163.215:8000/BDI.html)
  Link 2 to Remote AE sensor monitoring (link to http://166.143.163.215:8000/AE.html)
  2) It will then ask you to download the Labview plug-in, and direct you to the webpage with the download.
  3) After the plug-in is downloaded and installed, you should be able to view the file.
- Configured Microstrian™ Wireless Sensor Network
  - Installed software and hardware of Microstrain™ onto National Instruments Data Acquisition System (PXI)

- Configured and calibrated new Microstrain™ equipment to work with BDI strain gauge sensors.
- Began evaluating extrapolation and interpolation methods for acquired stress data
- Start implementing FEM bridge dynamic performance under truck loading using ANSYS APDL
  - Vehicle-bridge interaction
  - Analysis moving load on beam element
  - Analysis one truck passing solid and shell elements

1.3 Pilot Bridge Test and following activities

- 1st and 2nd Pilot Bridge tests: MD Bridge No. 1504200 I-270 over Middlebrook Road, was first tested on March 19-21, 2012 and then second tested on June 28 &29, 2012. Here is the list of troubleshooting and configuring hardware in the field in this quarter to alleviate problems with noise and interference (Task 1 and Deliverables 1 & 3; Task 2 and Deliverables 4 & 9).
  - **October 18, 2012** – Checked the connections of Amplifiers, and the DC Power Supply. Reset connections and powered off/on all equipment.
  - **November 2, 2012** – Looked for sources of interference in the field. Brought the PXI system back to the lab. Connected PXI to the laboratory sensors and found the PXI is operating correctly.
  - **November 9, 2012** – Brought the PXI back to the field and attached test panels to compare the plots of sensor data.
  - **November 15/16, 2012** – Visited the field with North Carolina State University graduate students. Replaced one inoperable amplifier with a specialty made amplifier: coated with waterproof epoxy. Replaced all sensors and covered with plastic to guard the sensors from moisture. Found there is still interference and brought the PXI back to the lab for more testing.
  - **November 30, 2012** – Cut wires in 100ft lengths to test if interference was coming from the wires. Consulted with National Instruments (NI) for grounding solutions and for field wiring and noise considerations for analog signals.
  - **December 4, 2012** – Reconfigured the ground so all equipment was grounded to the bridge. This solved the interference problem that was disrupting the AE sensors.
- 3rd Pilot Bridge test: Reconfigured hardware in the field after power losses.
  - **March 13, 2013** – Reset connections and powered off/on all equipment. Reset the AE hardware. Collected all the data from the data acquisition system.
  - **April 19, 2013** – Revisit the bridge to reset the system.
- 4th Pilot Bridge test: Wireless sensor integration test on May 29-30, 2013. Details of the test are listed in the report for the 8th quarter.
  - **June 19, 2013** – Reset connections and powered off/on all equipment. Attached Universal Power Supply (UPS) for temporary loss of power.
- 5th Pilot Bridge Test: Wireless sensor field tests on August 27 & September 26-27, 2013.Details of the test are listed in the following sections.

- August 27 - Conducted pencil break tests with new wireless piezoelectric sensor
- **September 26-27, 2013** – Went to the field on September 26th to install wireless sensor and collect 24 hours of data. Removed all testing equipment on the on the 27th.

1.4 AE Sensor

- Integrating wireless sensor node with piezo film AE sensor was examined in the lab test using pencil break tests on August 28 to 29, 2013 and another lab test on September 25, 2013. The wireless sensor node was brought by NCSU researcher and tested in UMD Structures lab before field test on the I-270/Middlebrook Bridge. The AE signal due to pencil break (a standard AE event simulation technique) was found to match those collected by wired data acquisition system.
- Field test of the wireless acoustic emission sensor was carried out in two events: August 27, 2013 and September 26 to 27, 2013. The field test bridge is the I-270 bridge near Germantown, Maryland. During this field tests, existing piezo film AE sensors installed in the late May 2013 were tested with wireless sensor nodes and the pencil break test signals were compared with those collected using wired data acquisition systems. One PZT sensor was found to malfunction in the September field test. Fatigue crack growth monitoring with piezo film AE sensor was terminated on I-270 bridge on September 27, 2013 and all field test equipment were removed from the bridge.

1.5 T-R Method, Energy Harvesting and Smart Sensor

Accomplishments of these tasks by NCSU team are summarized here:

- Redesign wireless piezoelectric sensor and base station.
- Solder the wireless piezoelectric sensor and test it with power.

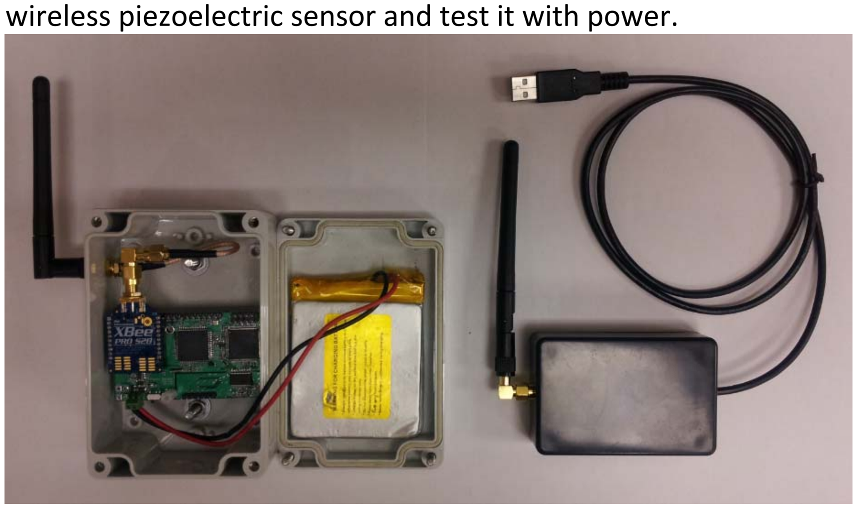

Figure 1 Redesigned Wireless Piezoelectric Sensor (Left) and Base Station (Right)

- Debug the piezoelectric acquisition program of the microcontroller and FPGA.
- Conduct five-peaked wave tests with new wireless piezoelectric sensor in the laboratory.

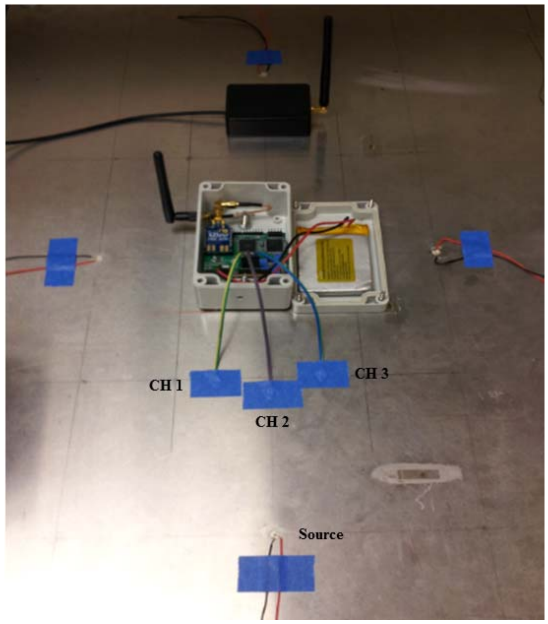

Figure 2 Five-peaked Wave Test Platform

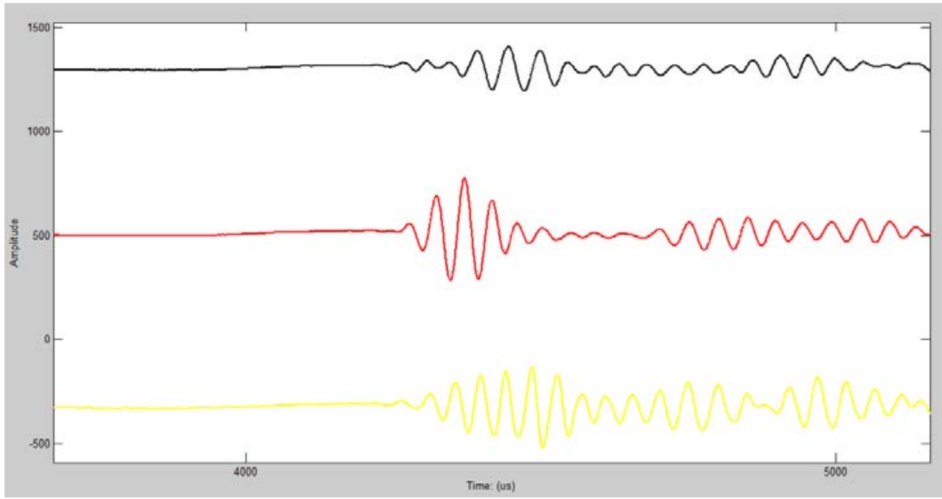

Figure 3 Five-peaked Wave Test 1 (CH1-Black, CH2-Red, CH3-Yellow)

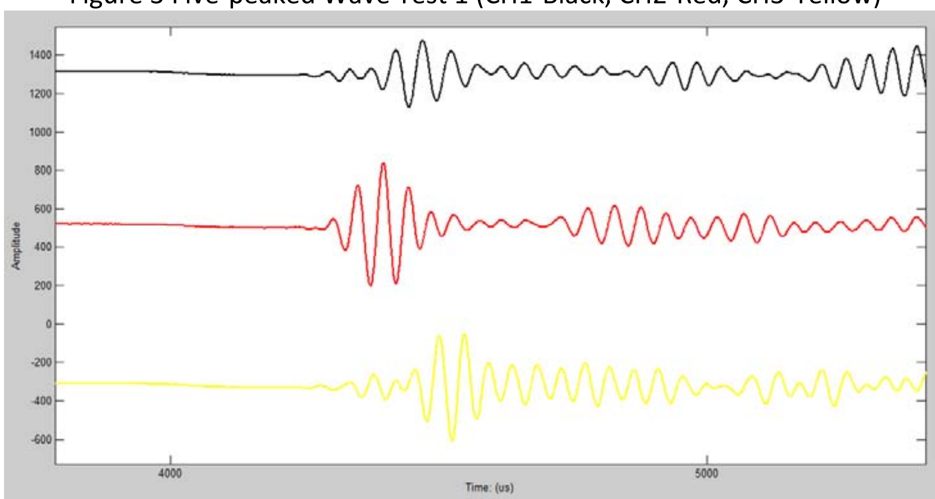

Figure 4 Five-peaked Wave Test 2 (CH1-Black, CH2-Red, CH3-Yellow)

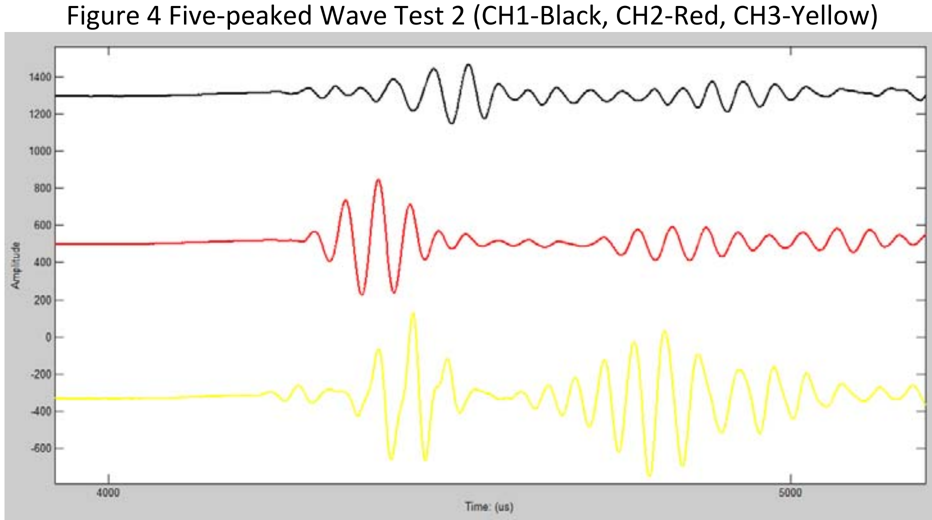

Figure 5 Five-peaked Wave Test 3 (CH1-Black, CH2-Red, CH3-Yellow)

- Conduct pencil break tests with new wireless piezoelectric sensor on the top of the abutment of No. 1504200 I-270 Bridge over Middlebrook road (2013-08-27).

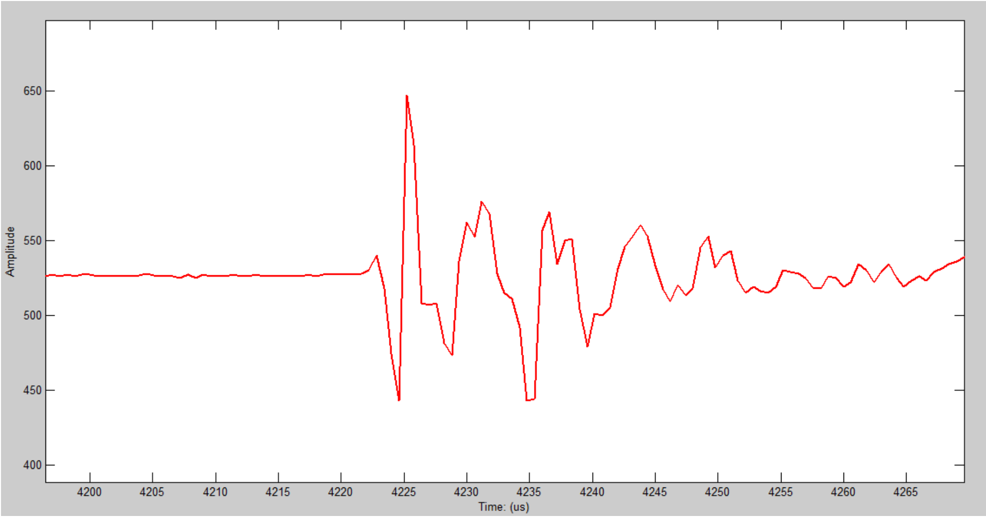

Figure 6 Pencil Break Test 1

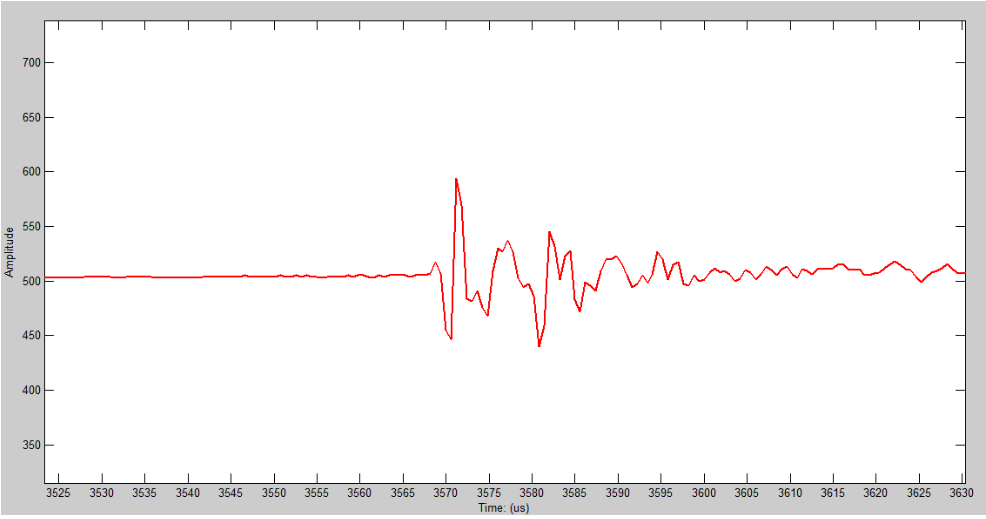

Figure 7 Pencil Break Test 2

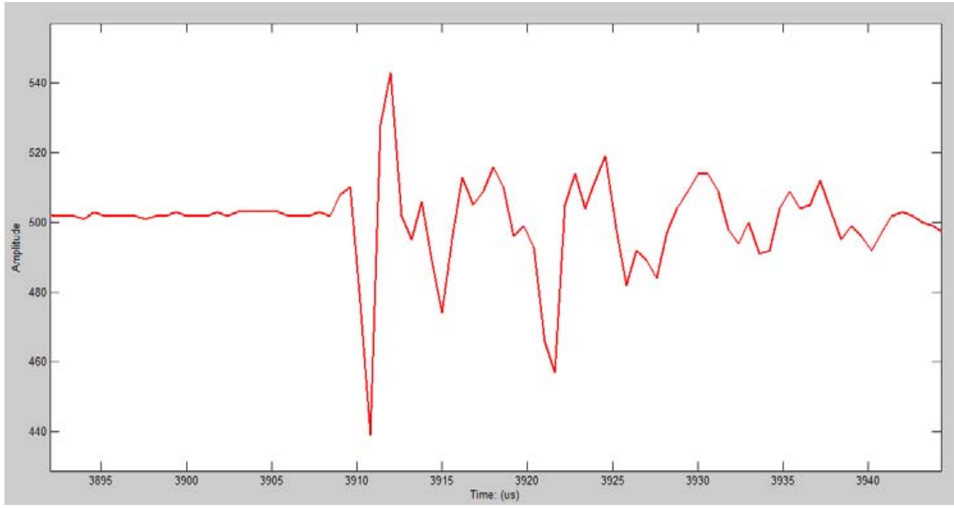

Figure 8 Pencil Break Test 3

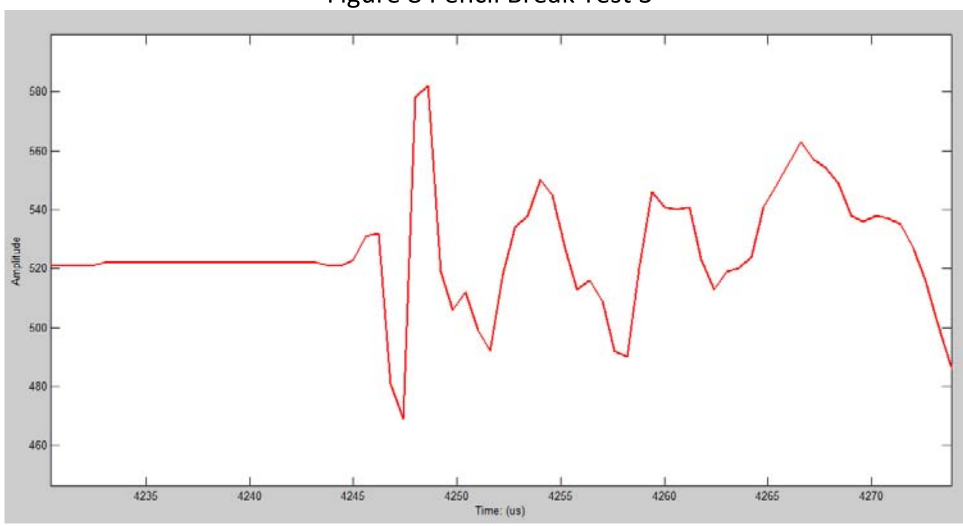

Figure 9 Pencil Break Test 4

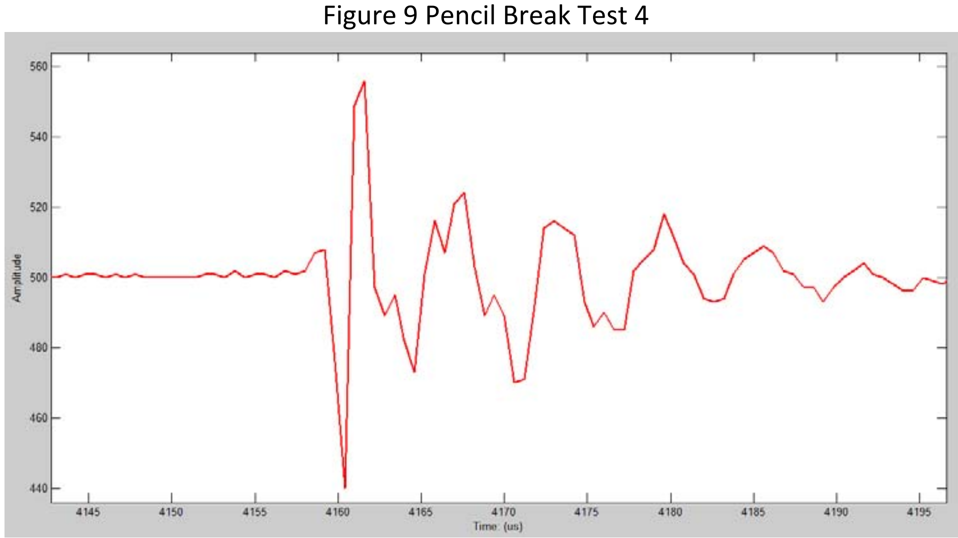

Figure 10 Pencil Break Test 5

- Conduct pencil break tests to simulate AE signals with new wireless piezoelectric sensor and wire data acquisition card in the lab (2013-08-27).

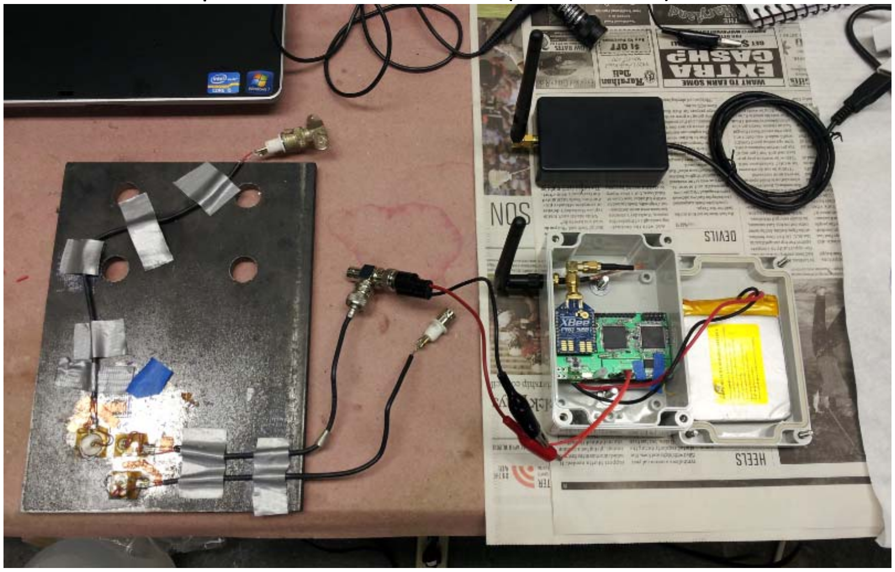

Figure 11 Pencil Break Test Platform

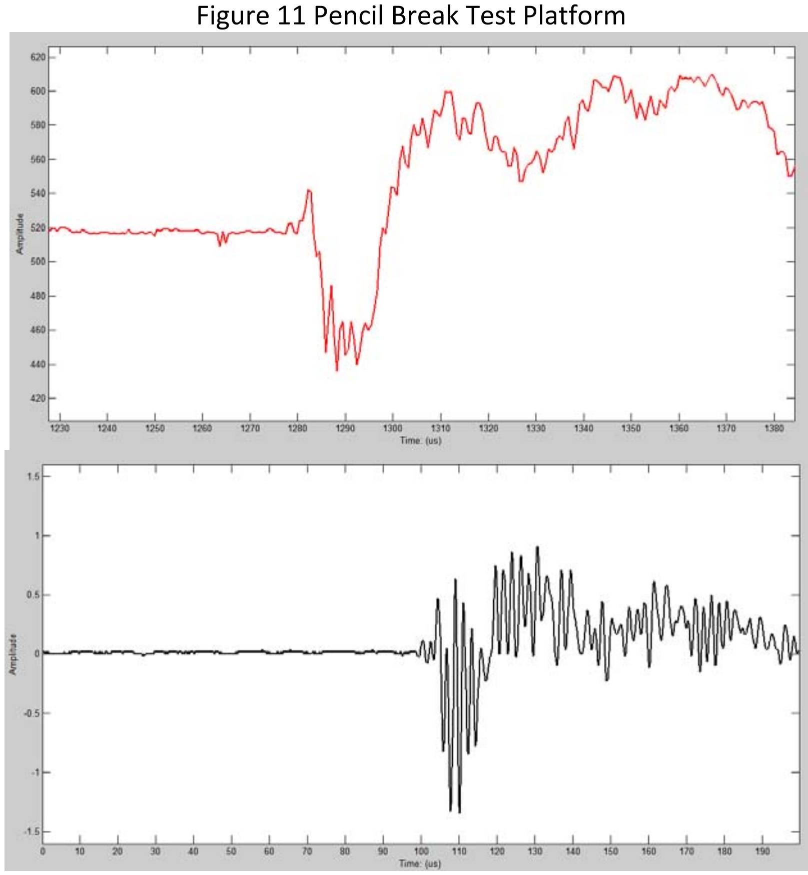

Figure 12 Wireless Sensor (Red, Sample Rate: 1.67 MHz) and Wire Data Acquisition Card (Black, Sample Rate: 5 MHz) Results 1

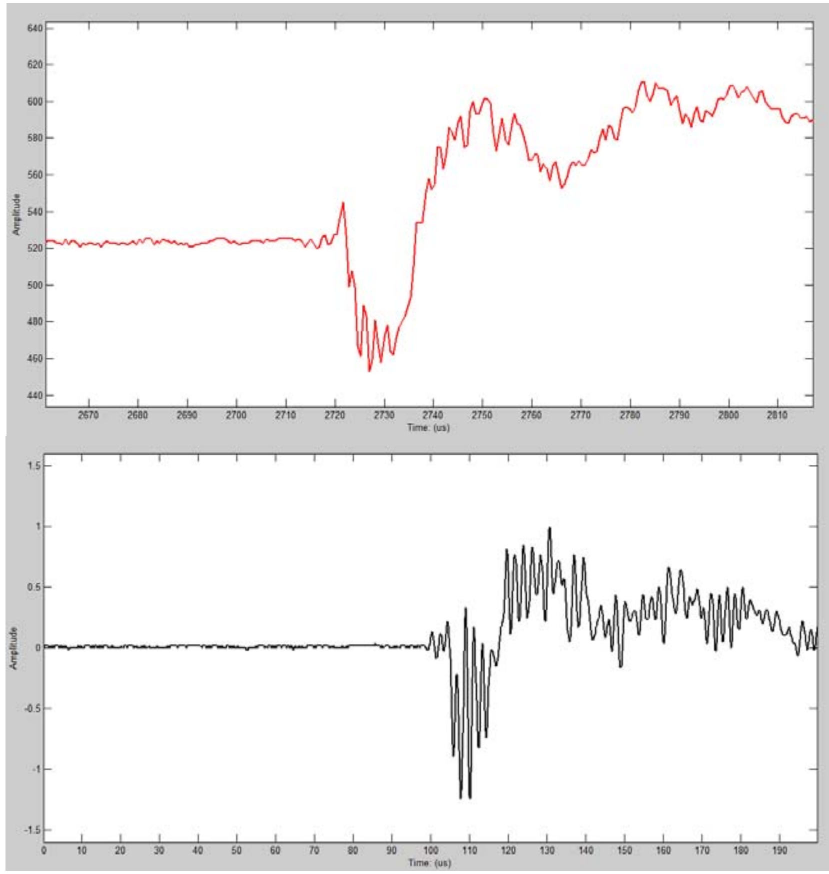

Figure 13 Wireless Sensor (Red, Sample Rate: 1.67 MHz) and Wire Data Acquisition Card (Black, Sample Rate: 5 MHz) Results 2

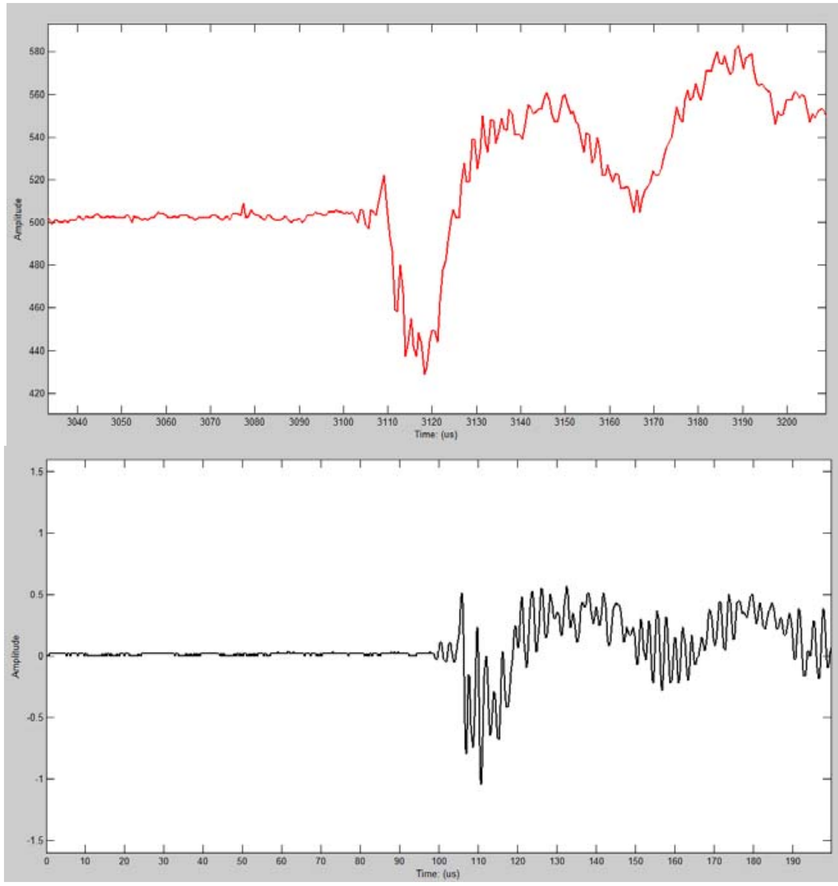

Figure 14 Wireless Sensor (Red, Sample Rate: 1.67 MHz) and Wire Data Acquisition Card (Black, Sample Rate: 5 MHz) Results 3

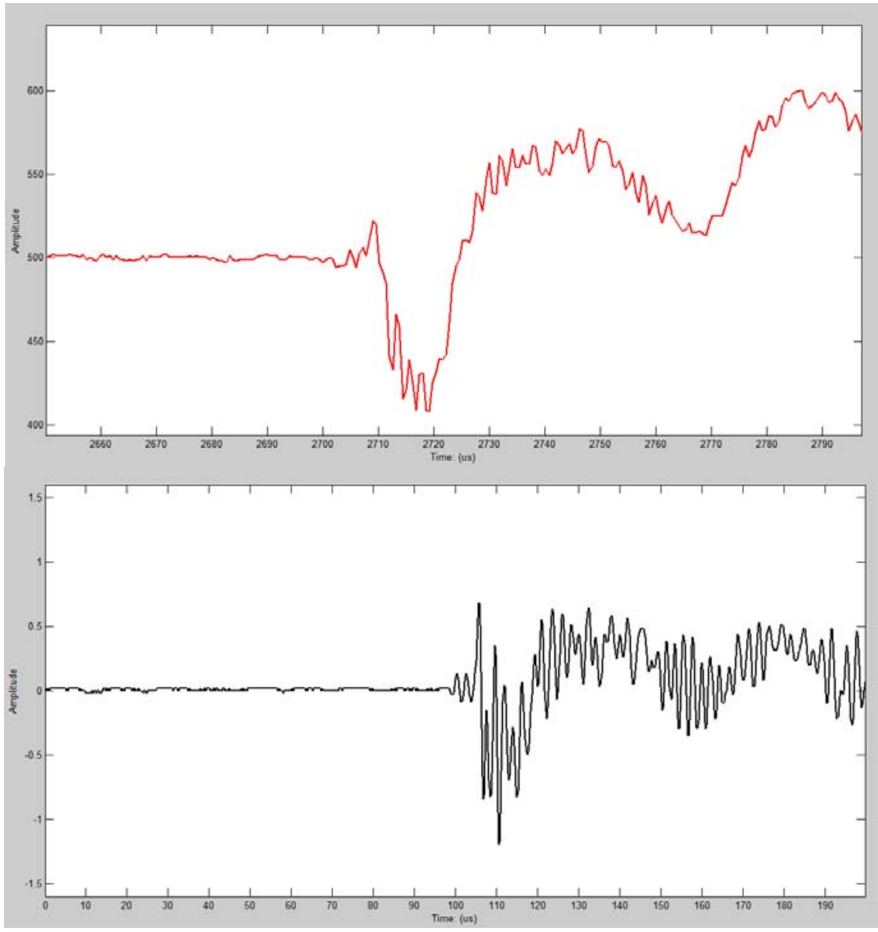

Figure 15 Wireless Sensor (Red, Sample Rate: 1.67 MHz) and Wire Data Acquisition Card (Black, Sample Rate: 5 MHz) Results 4

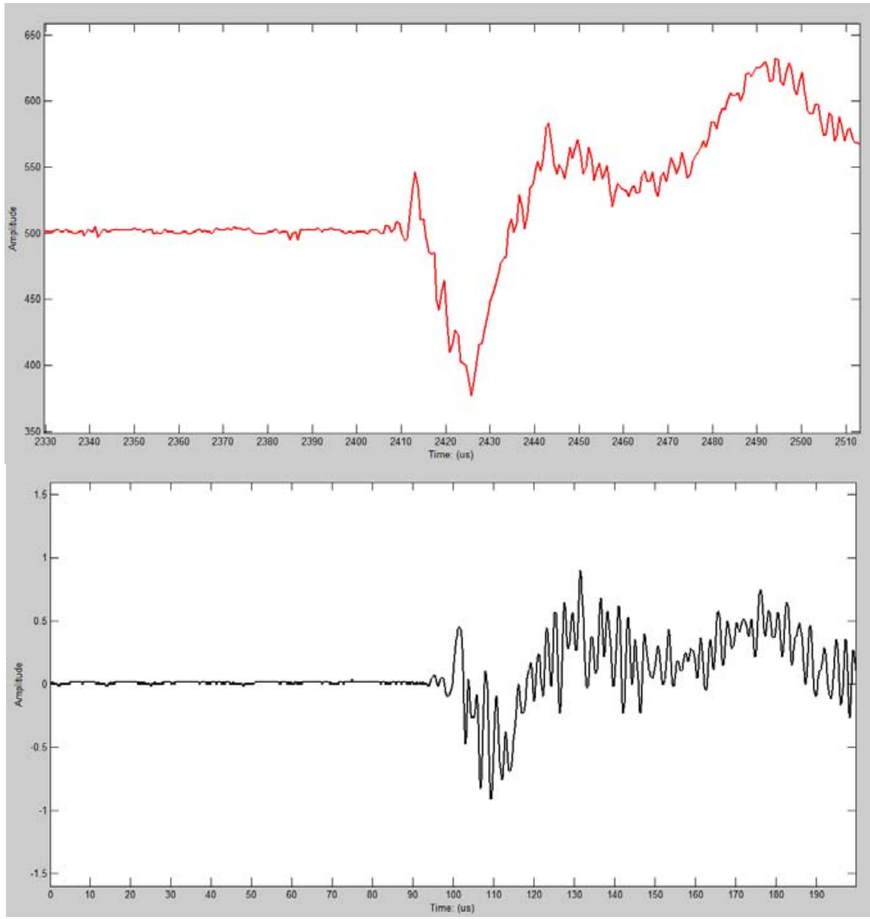

Figure 16 Wireless Sensor (Red, Sample Rate: 1.67 MHz) and Wire Data Acquisition Card (Black, Sample Rate: 5 MHz) Results 5

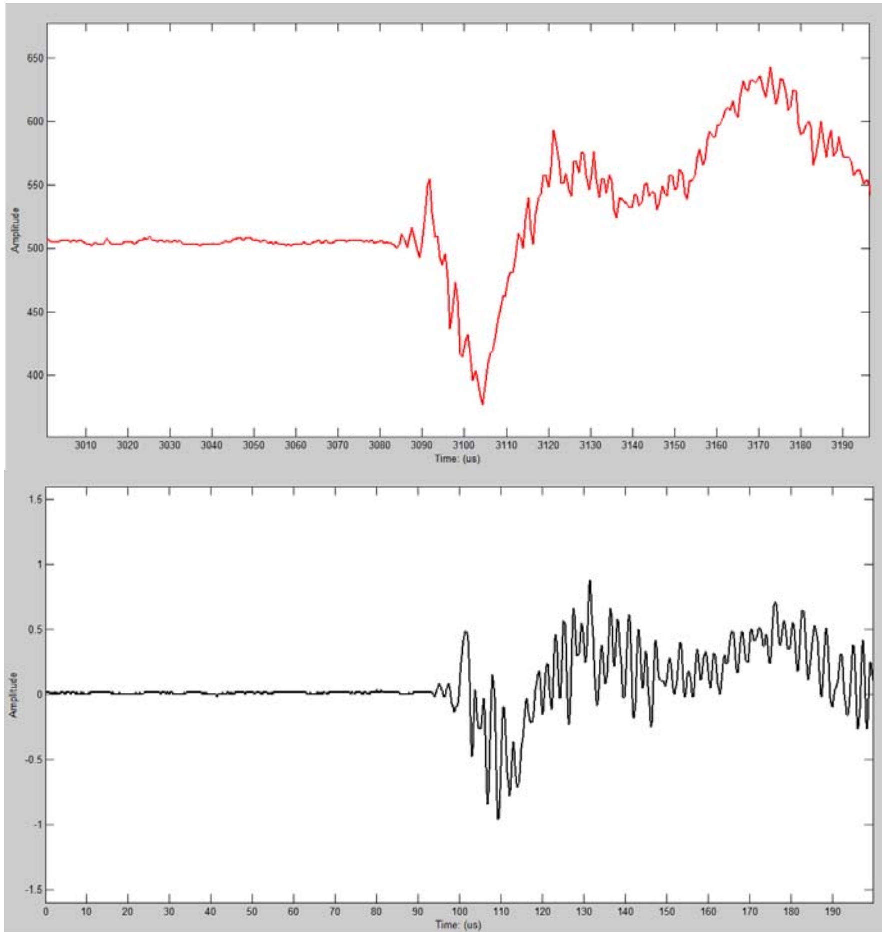

Figure 17 Wireless Sensor (Red, Sample Rate: 1.67 MHz) and Wire Data Acquisition Card (Black, Sample Rate: 5 MHz) Results 6

- Conduct pencil break tests to simulate AE signals with new wireless piezoelectric sensor on No. 1504200 I-270 Bridge over Middlebrook road (2013-09-26).

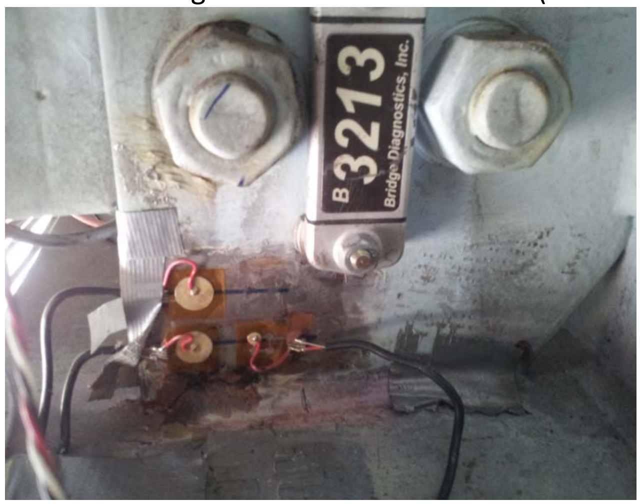

Figure 18 Piezo Film Sensors and PZT Sensor on the Bridge Deck
(Piezo Film Sensors: Left Two, PZT Sensor: Right One)

Figure 19 Test Platform (Left: Wireless Piezo Sensor, Right: Base Station and Laptop)

a. Pencil break tests with PZT sensor on the bridge deck

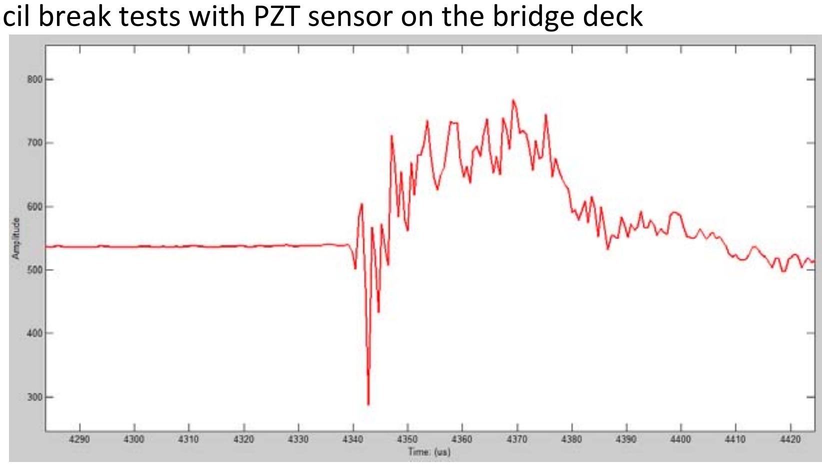

Figure 20 PZT Sensor Pencil Break Test 1 Result

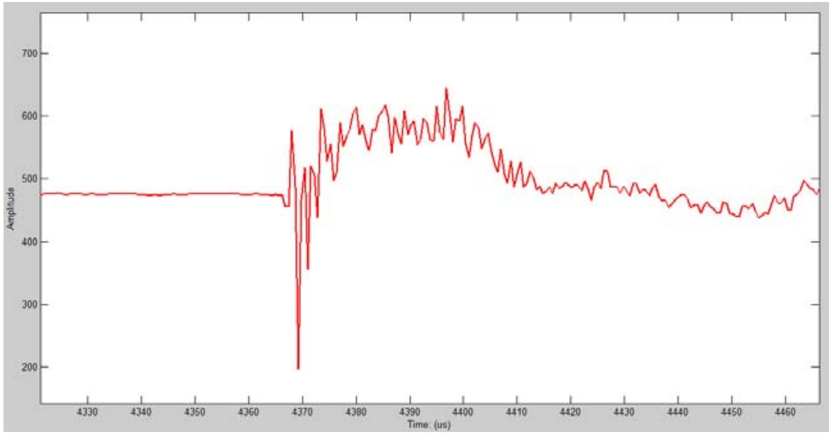

Figure 21 PZT Sensor Pencil Break Test 2 Result

b. Pencil break tests with PZT sensor and piezo film sensor on the bridge deck. (using PZT sensor for triggering)

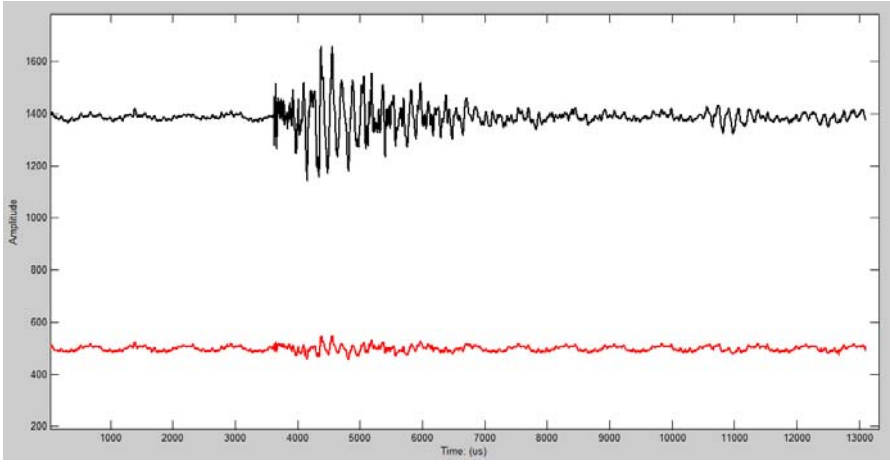

Figure 22 Pencil Break Test 1 Result (Black: PZT Sensor, Red: Piezo Film Sensor)

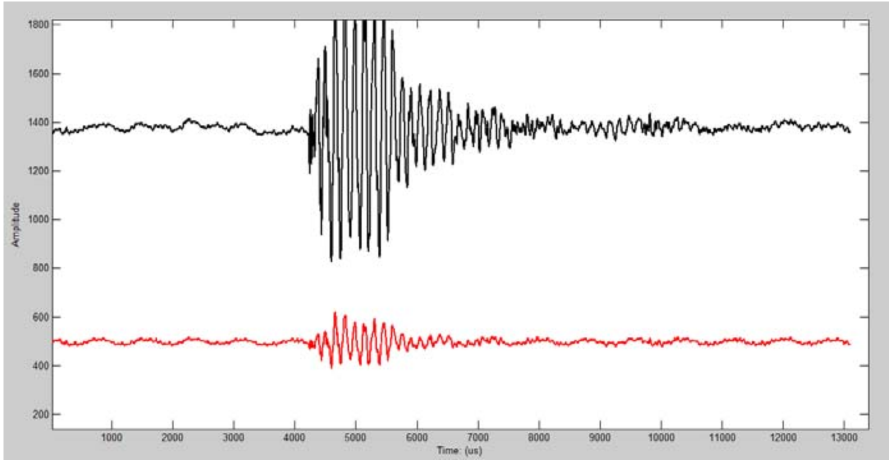

Figure 23 Pencil Break Test 2 Result (Black: PZT Sensor, Red: Piezo Film Sensor)

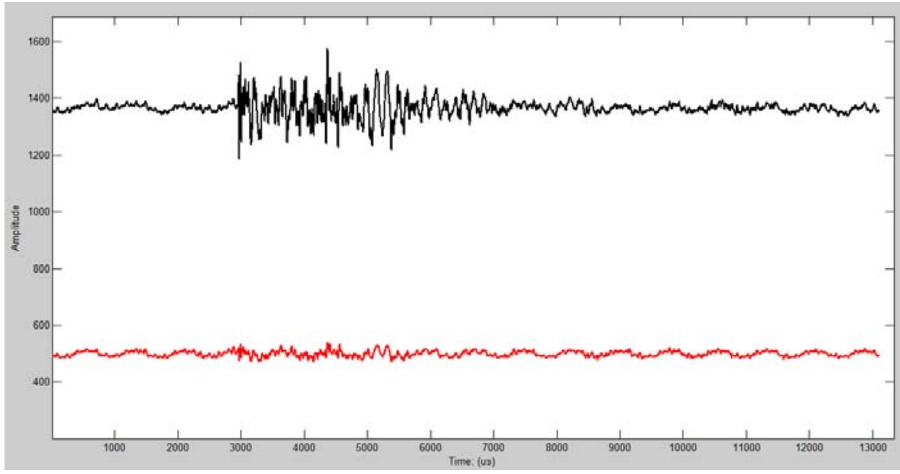

Figure 24 Pencil Break Test 3 Result (Black: PZT Sensor, Red: Piezo Film Sensor)

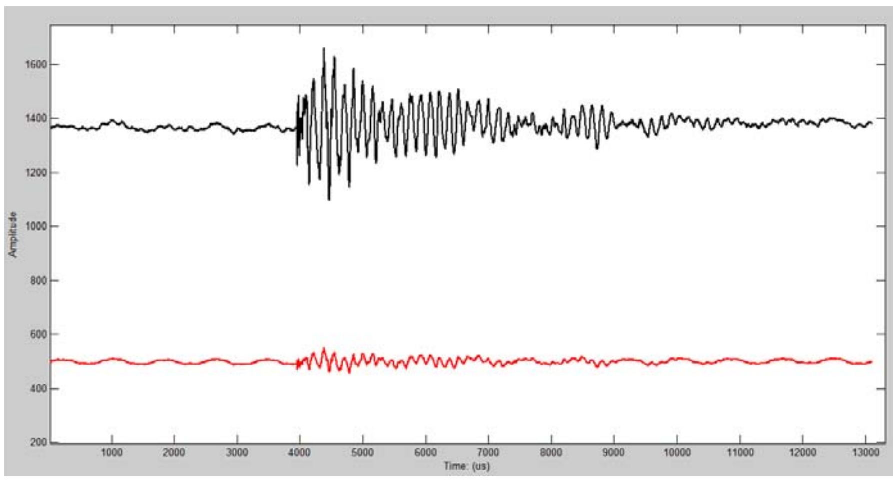

Figure 25 Pencil Break Test 4 Result (Black: PZT Sensor, Red: Piezo Film Sensor)

c. Conduct an overnight traffic test (2013-09-26 3:00 PM – 2013-09-27 9:30 AM) on the bridge deck (PZT sensor).

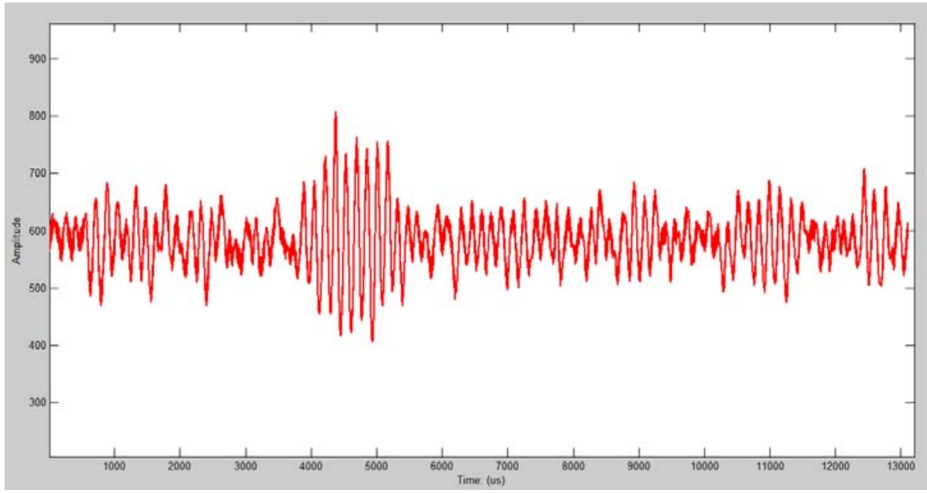

Figure 26 Traffic Test Result 1

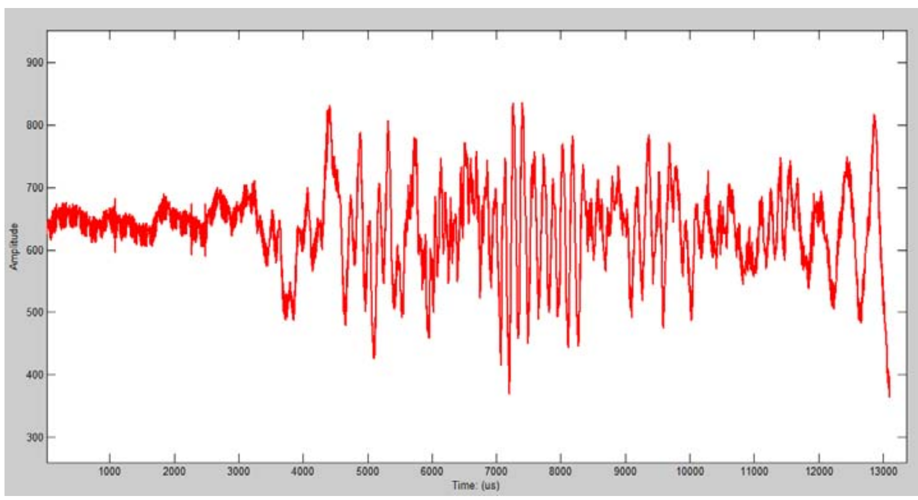

Figure 27 Traffic Test Result 2

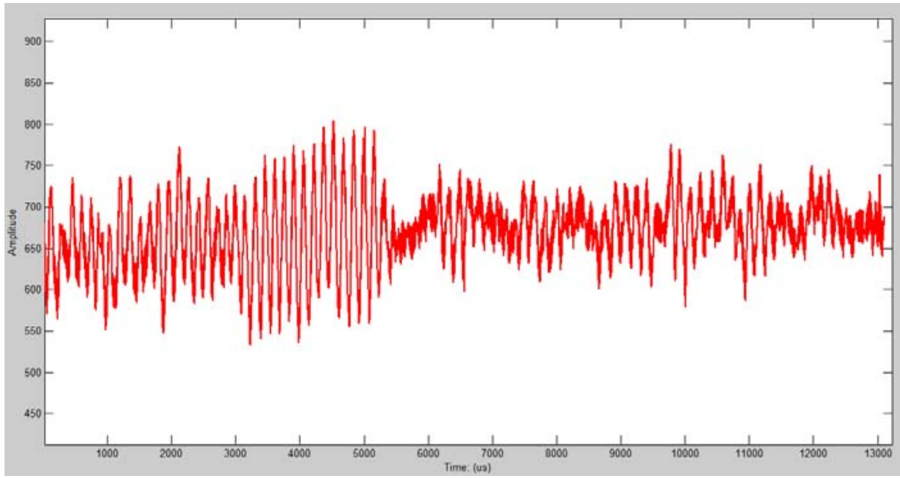

Figure 28 Traffic Test Result 3

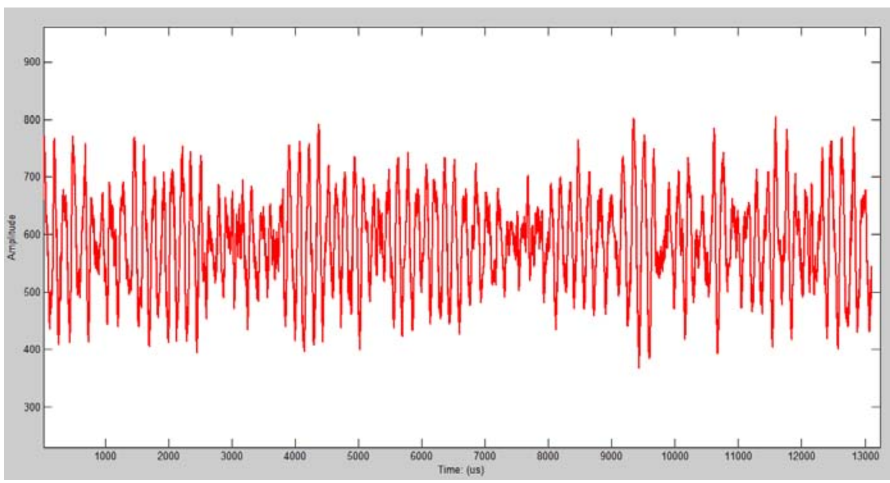

Figure 29 Traffic Test Result 4

1.6 Future Plans

Pilot Bridge Testing (UMD team led by Dr. Fu) –

- Coordinate with MDSHA on the demo bridge (currently I-95 over Patuxent River was selected) and testing schedule.
- Collecting W-I-M data on I-95 Bridge to simulate traffic through FEM models for all pilot test bridge in Maryland and validating test data with FEM results.
- Establish the local finite element model of the crack location, do the same analysis with the global model, compare the results and discuss the necessarily of local model for our studies.
- Discuss which of the four possible crack configurations has the highest SIF at the crack tip and thus most likely to occur using finite element model.
- Estimate fatigue failure using Wohler Curve (S-N curve) where their results are currently undergoing analysis and comparisons with a probabilistic model for fatigue damage.

AE Sensor (UMD team led by Dr. Zhang) -

- Field test is planned to test the long-term fatigue crack growth monitoring with wireless piezo film AE sensor and remote sensing features on a steel highway bridge along I-95 near Laurel in Maryland. This bridge is selected to implement full scale integrated structural health monitoring system.
- A 54-dB gain preamplifier with a bandpass filter (1 to 400 kHz) will be designed for piezo paint AE sensor to increase its signal strength.
- Professional grade piezo film AE sensor has been designed and will be sent to flexible circuit manufacturer for enhanced weathering and environmental impact protection in November so they will become ready in the next field test. After receiving the orders from the manufacturer, these sensors will be tested first in the lab to characterize its performance for fatigue crack localization.

T-R Method, Energy Harvesting and Smart Sensor (NCSU team led by Dr. Yuan) -

- Test the noise amplitude of the wireless piezoelectric sensor.
- Test the solar panel for the wireless piezoelectric sensor.
- Improve and test the wireless accelerometer sensor for Bearfort #25 Bridge in North Carolina. And prepare to install them on the Bearfort #25 Bridge
- Prepare testing on the demo bridge (tentatively I-95 over Patuxent River)

II — BUSINESS STATUS

- Hours/Effort Expended – As the last reporting period, PI Dr. Fu worked one month paid by his cost sharing account for 167 man-hours. Three (3) UM and two (2) NCSU graduate assistants worked three months half-time (20 hours), the quarterly accounting deadline, for a total of 1,470 man-hours (one NCSU assistant is partially cost-shared by their University.)
- Total Budget - $1,151,169 & Invoiced (3/31/13) - $664,560 (57.7%) (not updated the exact figure due to University's delay in invoicing)
- Cost sharing committed - $1,525,063 & Cost shared (7/30/13) - $844,427 (55.4%).