Quarterly Report

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

Cooperative Agreement # RITARS11HUMD

Seventh Quarterly Progress Report

Period:
January 14, 2013 through April 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: April 29, 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 seventh quarterly financial and technical reports (Task 6 and Deliverable 11)
- Conducted Phase III Progress Review Meeting with Mr. Caesar Singh of RITA, USDOT on January 18th, 2013 (Task 6 and Deliverable 11)
- Presented at the TRB Conference and published several journal papers (Task 6 and Deliverable 12).
- Traffic loading data was collected and simulated to the bridge model. Finite element analysis based on the simulated loading has been conducted and reported in Appendix A.
- The proposed 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
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 7th quarter are partially fulfilled. They are still tested and modified by the NCSU team. The explanation of the delay is described and highlighted on page 9 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)

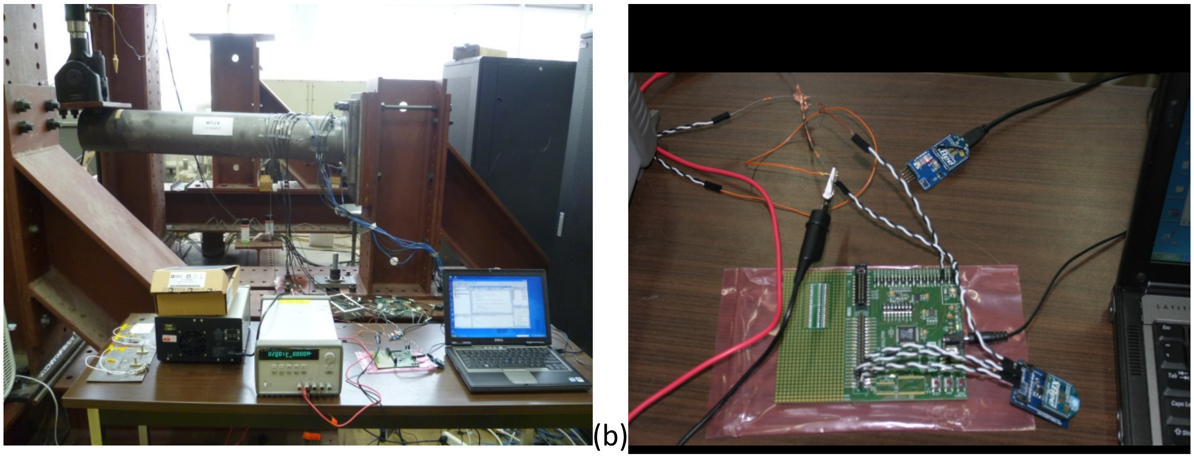
Link 2 to Remote AE sensor monitoring (link to http://166.143.163.215:8000/AE.html)
2) It will then ask you to download the Labview plug-in, and direct you to the webpage with the download.
3) After the plug-in is downloaded and installed, you should be able to view the file.

1.3 Pilot Bridge Second Test and following activities

- 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.
- Extracted about 40 days of stress and AE data from DAQ system and moved to cloud for storage.
  - Organized data in orderly segments to facilitate plots and rainflow analyses.
  - Processed data through detrend functions to remove drift.
- Configured Rainflow Counting to work with variable amplitude loadings
  - Set the settings to count stress levels above a user-specified threshold value
- Created Histograms of stress ranges using the variable amplitude counting methods
- 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 bridge to reset the system.

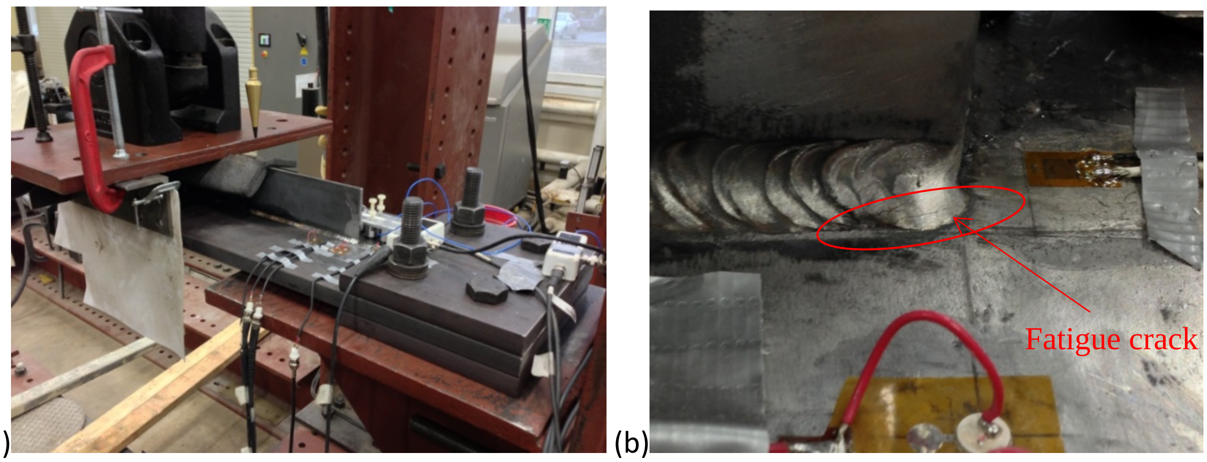
1.4 AE Sensor

- Integrating wireless sensor board with piezo paint AE sensor was examined in the lab test of welded tubular joint specimen and a stiffened web plate specimen, as shown in Figures 1 and 2. The AE signals were collected with wireless piezo film AE sensors of different sampling rate of 200 kHz. A close-up view of the wireless sensor node is shown in Figure 1(b). The feasibility of using piezo film AE sensor for continuous fatigue crack monitoring during fatigue test of steel test specimens in the lab has been demonstrated. Piezo film AE sensor made of piezo paint was found to be especially suitable for fatigue crack monitoring on tubular structure due to its flexibility. It can avoid noise introduced by imperfect bonding, which was seen for PZT based sensor. AE signals due to different source mechanisms were identified, including fatigue crack propagation and friction rubbing of the fatigue crack surface.
- For the stiffened web plate specimen shown in Figure 2, fatigue crack induced AE signals were collected (see Figure 4). This was proved by the delay of the time arrivals in the sensor array and the agreement between detected source location and the observed fatigue crack tip during the test. The sensor couple theory for AE source localization was experimentally verified using the data acquired from the fatigue test of the welded plate for both piezo film AE sensor and commercial AE sensor as shown in Figure 5. The localization results match that of the conventional Time of Arrival method.
- Long-term remote acoustic emission monitoring of the existing fatigue cracks has been carried out on the I-270 bridge near Germantown, Maryland since July 10, 2012. In the last quarter, unexpected power-down happened in the middle of March and a field trip was arranged on April 19, 2013 to bring the power back to the monitoring system at the bridge site. Continuous AE monitoring was done since December 9, 2012 to March 14, 2-13. Based on analysis results of the triggered AE signals collected by the piezoelectric film AE sensor signals and AE feature analysis, it is believed that the recorded AE signals are likely related to the AE activities associated with fatigue crack growth. The high stress level (peak value up to 17 ksi) in the BDI strain gage data also support this observation that the fatigue crack is growing. The UMD team discussed with Dr. Ed Zhou of URS on the crack geometry (orientation, shape) and stress intensity factor for the crack being monitored. From fatigue tests reported by others as well as the writer's own experience from lab fatigue testing, fatigue crack development should be in regime II (Paris law regime, or stable crack growth regime). The sensor couple theory for AE source localization was also verified with a limited number of piezoelectric film AE sensor data. However, many AE data do not show the space phase shift induced trough frequencies although this does not suggest these AE data are not related to the active fatigue cracking. This deserves further study.



(a) (b)

Figure 1. (a) Test setup for validation test of wireless piezo film AE sensor on welded tubular joint fatigue test and (b) close-up view of zigbee based wireless sensor node



(a) (b)

Figure 2. (a) Test setup for characterizing piezo film AE sensor on stiffened web plate specimen; (b) fatigue crack in the test specimen at load cycle number N =182,000

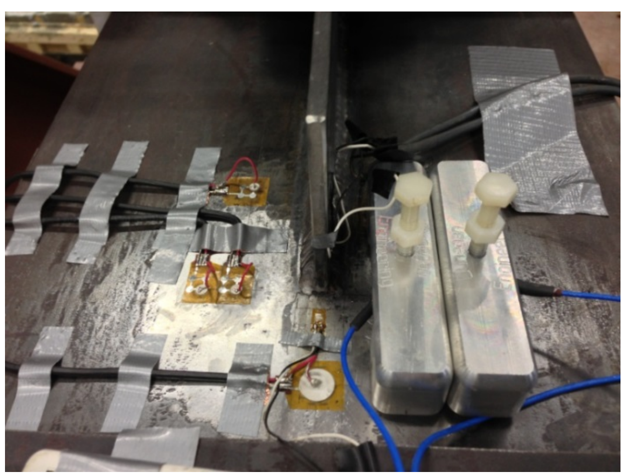


Figure 3. Configuration of piezo film AE sensors and commercial AE sensors on the stiffened web plate test specimen

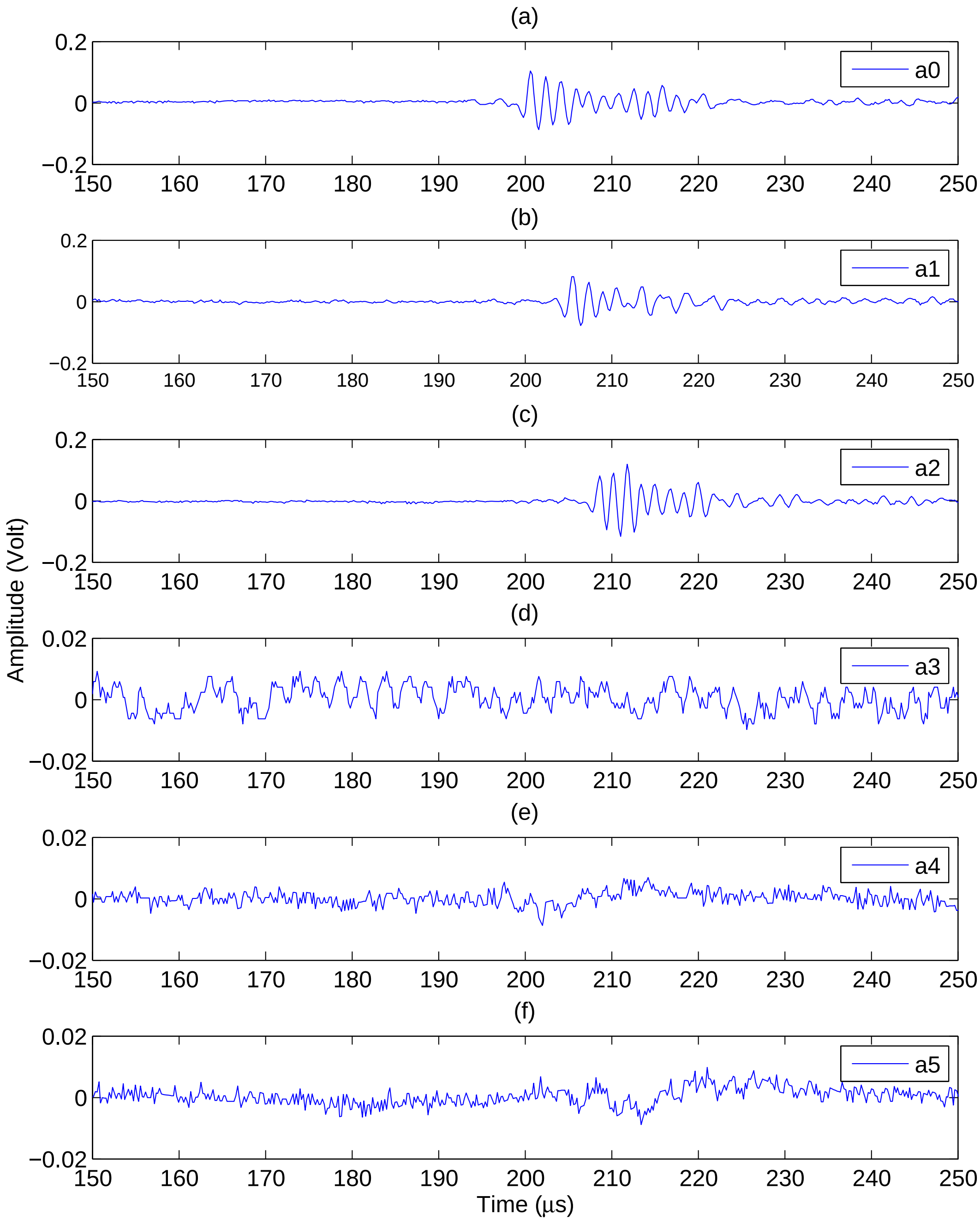


Figure 4. AE signals measured by piezo film AE sensors and commercial AE sensors on the stiffened web plate test specimen

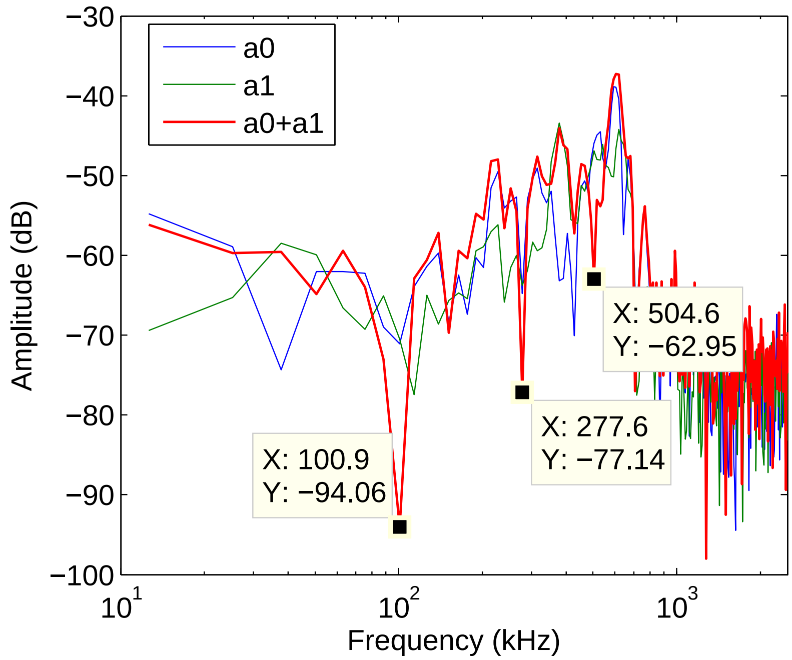


Figure 5. Frequency spectra of AE signals in sensor couple (a0+a1) comprised of two piezoelectric film AE sensors

1.5 T-R Method, Energy Harvesting and Smart Sensor

Accomplishments of these tasks by NCSU team are summarized here:

- Test the new piezoelectric sensor board with power.
  Test the JTAG function of the microcontroller and FPGA, and the program can be downloaded correctly.
  Test the CC2420 and SST25VF032B IC, and the wireless communication and serial FLASH can work well.
- Modify the enclosure to install the new sensor board and battery.

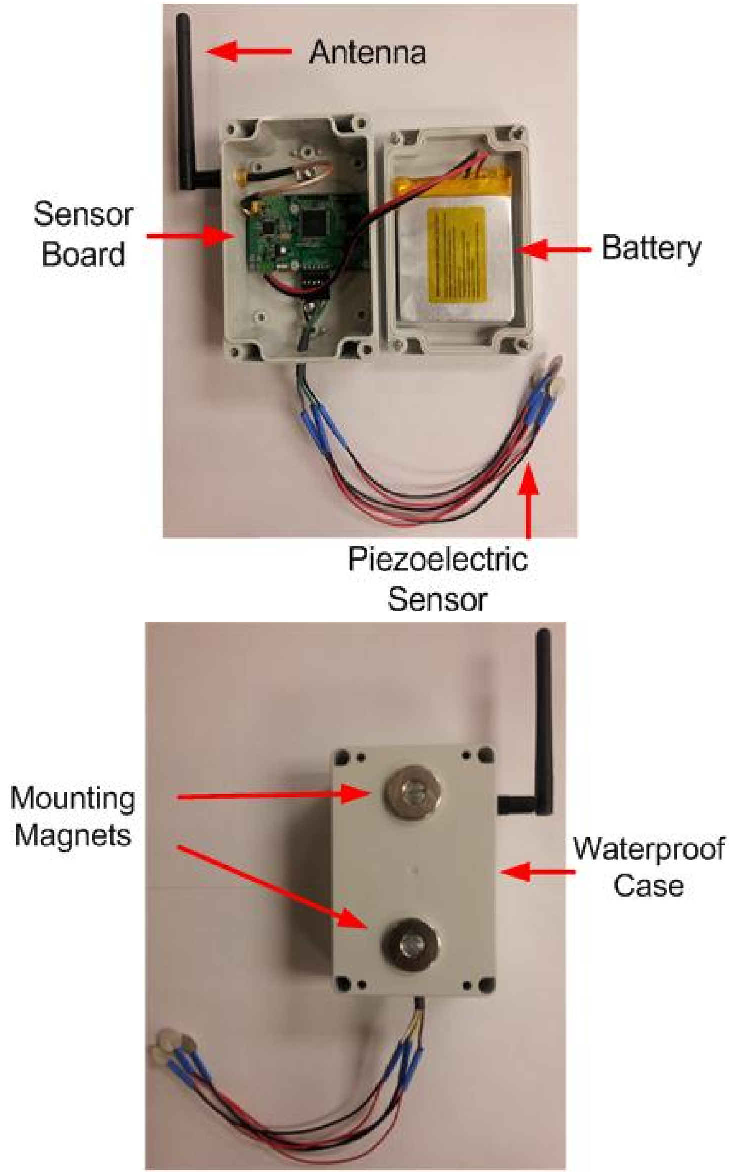


Figure 6. The new enclosure of the piezoelectric sensor

- Redesign the piezoelectric amplifier circuit for better piezoelectric signal reception.

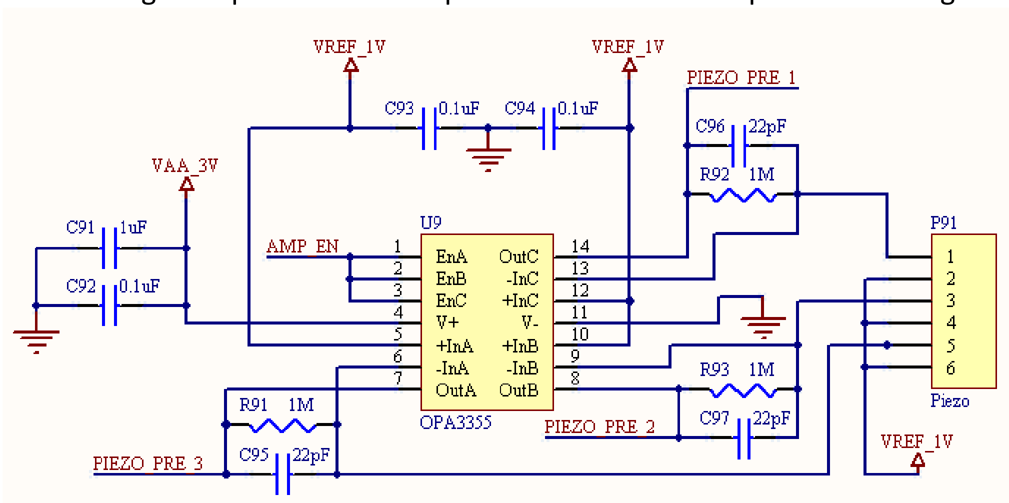


Figure 7. The new design amplifier circuit of the piezoelectric sensor

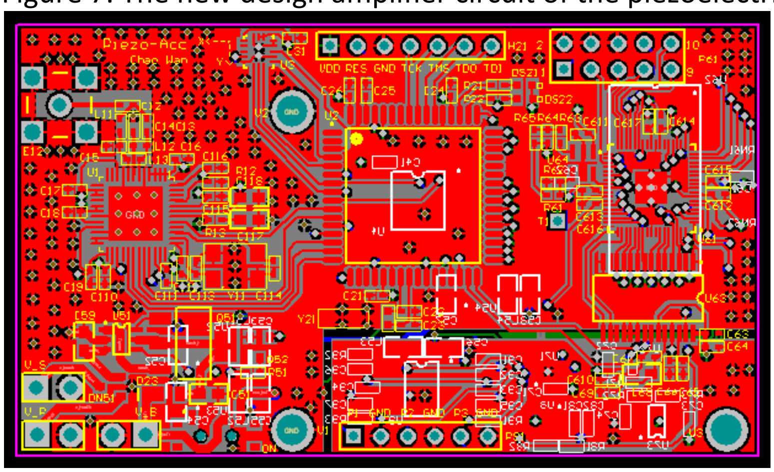


Figure 8. The top view of the new sensor PCB design

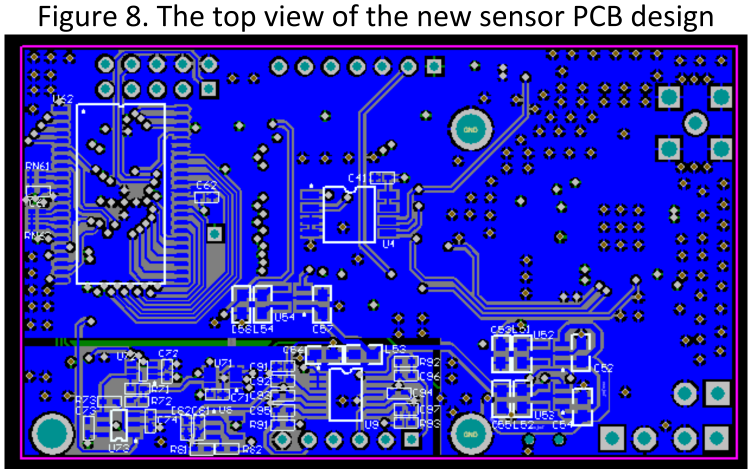


Figure 9. The bottom view of the new sensor PCB design

- Finish the piezoelectric acquisition program of the microcontroller and FPGA.

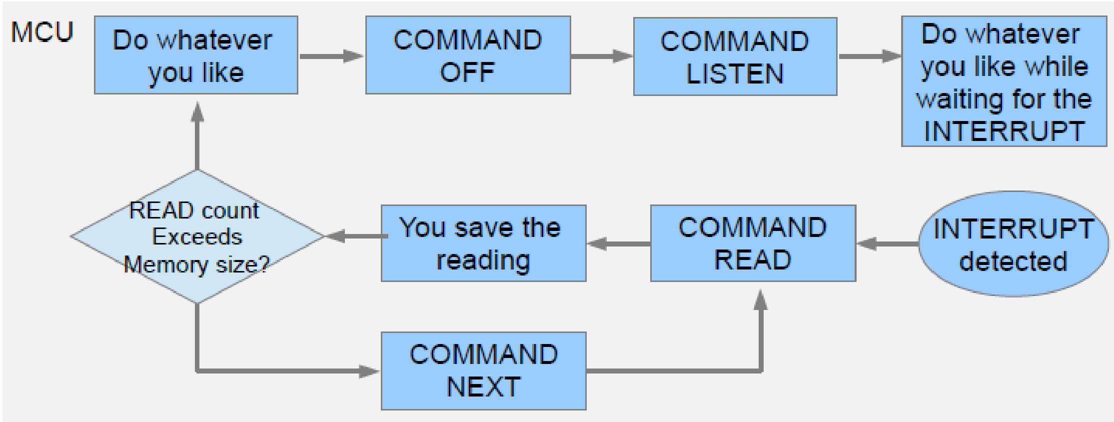


Figure 10. The scheme of the MCU program

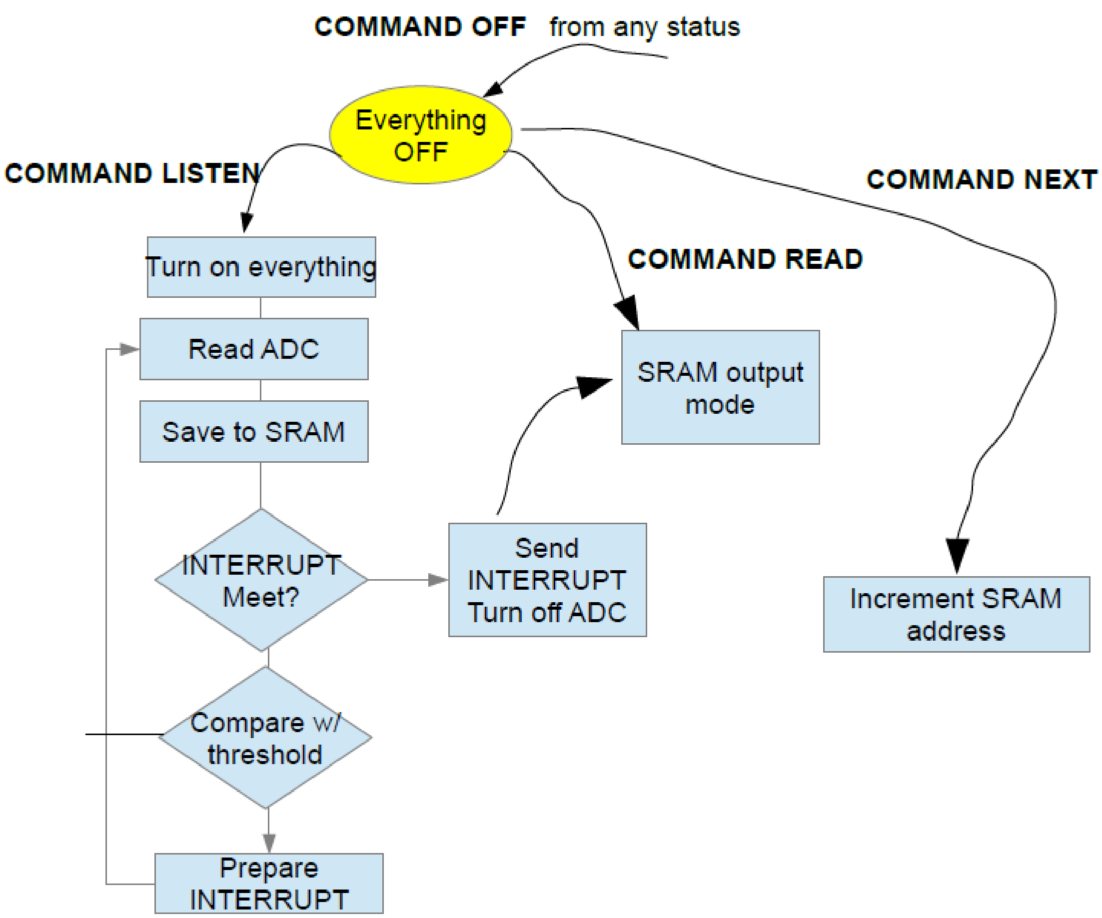


Figure 11. The scheme of the FPGA program

- Test the piezoelectric sensor in the lab.

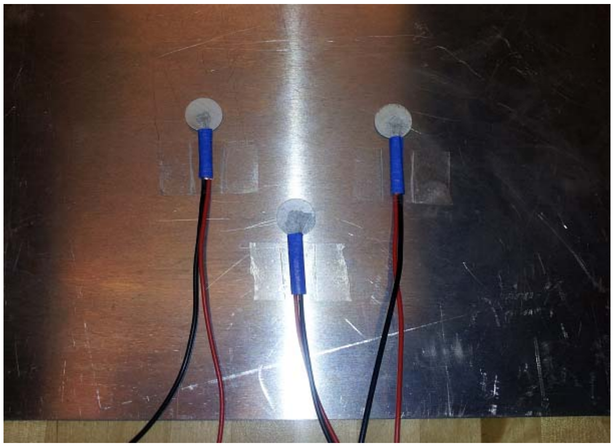


Figure 12. The test platform

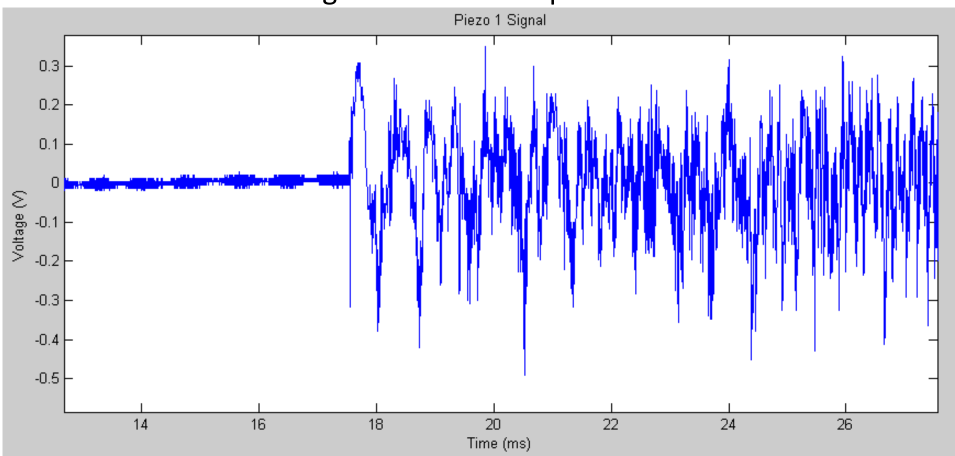


Figure 13. The test result

1.6 Future Plans

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

- Continue AE monitoring, evaluating and validating results on the pilot test bridge in Maryland (MD Bridge No. 1504200 I-270 over Middlebrook Road)
- Preparing field testing the proto-type ISHM system on the pilot test bridge.
- Collecting more W-I-M data to simulate more traffic through FEM models for all pilot test bridge in Maryland and validating test data with FEM results for the cause of fatigue.
- Coordinate with MDSHA on the demo bridge candidate.

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

- Continue the long-term fatigue crack growth monitoring with piezo film AE sensor and remote sensing features on I-270 bridge in Maryland. Focus will be placed on integrating wireless sensor node with the piezo paint AE sensor. A field trip is planned for May 2013.
- Testing and validating high-sensitivity piezo film AE sensor couple in the lab to characterize its performance for fatigue crack localization. Based on the lab test and

field monitoring results, the sensor design has been modified again and will be sent to piezoelectric circuitry manufacturer in summer 2013. Piezo film AE sensor will also be used for AE monitoring of prestressed concrete beam cracks in another lab test in this quarter. The test specimen is a 8 ft long reinforced concrete beam and a total of six beams have been casted. The AE monitoring performance of wireless piezo film AE sensors will be tested on these concrete beam specimens.

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

- Solder the new design piezoelectric sensor board. Test it with power and debug it.
- Set up a web server and database to manage the acquisition data and achieve the function of remote data acquisition via internet.

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) - $563,799.72 (49%)
- Cost sharing committed - $1,525,063 & Cost shared (3/31/13) - $769,566 (50.5%). The increase in non-federal cost share was due to the UMD waived IDC from 50% to 25% ($197,153) was finally reported in January of 2013.

Appendix A - Traffic Loading Simulation and Bridge Finite Element Analysis

Appendix A - Traffic Loading Simulation and Bridge Finite Element Analysis

By Gengwen Zhao and Chung C. Fu

1. Traffic Data

This is a continuing study of the traffic loading simulation contained in Appendix C of the 5th progress report. The data that has been used to simulate traffic flow is the time varying vehicle count data from Internet Traffic Monitoring System operated by Maryland Department of Transportation State Highway Administration. (http://shagbhisdadt.mdot.state.md.us/ITMS_Public/default.aspx)

However, there are some problems with these vehicle count reports. The dates of these vehicle count reports are long time ago, from 2001 to 2008, mostly in spring or October. The durations of these reports are all less than 24 hours. That cannot match with our field test.

The data mostly met our need is the continuous Weigh-In-Motion data for trucks on the bridge of I270 (Southbound) over Middlebrook Road near Germantown, Maryland, probably lasting more than one week during summer and winter 2012. Since the nearby station -Hyattstown southbound station does not have what we want; we have to contact other institutions trying to get continuous traffic flow data. Further search on traffic data is still ongoing and further study will be made once the data is received.

Figure 1 shows the schematic view of a truck on the Middlebrook Bridge FE model.

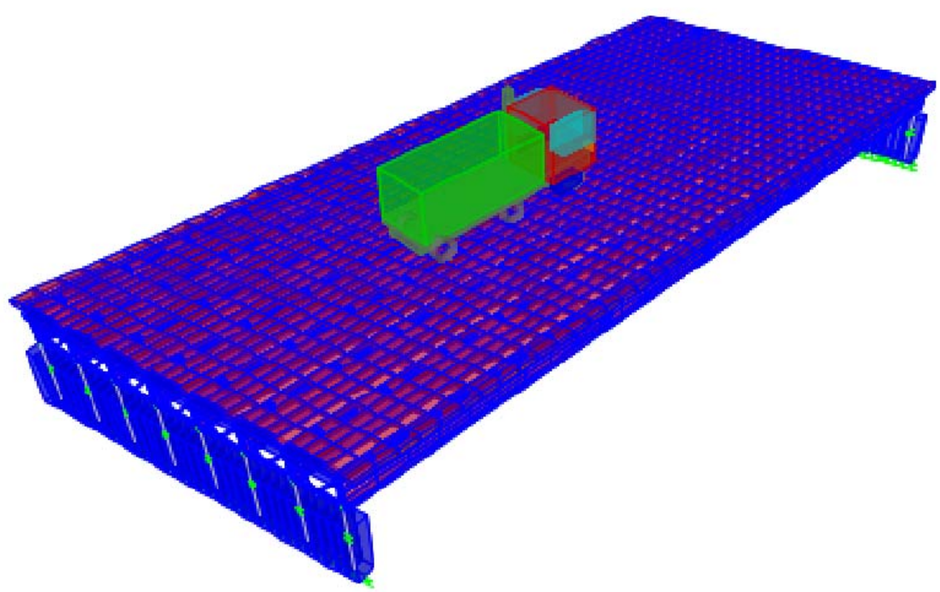


Figure 1. Bridge under Traffic Loading

2. Finite Element Model

Once the traffic data is collected, it will be simulated to the bridge model by the CSiBridge program. This part is to refine the global and local models for the crack locations of the Maryland Middlebrook Bridge contained in Appendix C of the 5th progress report. Figure 2 shows the displacement time history of midpoints at the bottom flange for Girder 3 and Girder 4. The maximum differential displacement is 0.08 in under simulated traffic loading. Figure 3 shows the time history curves of two hot spots of the connection plate, located at Girder 3 Diaphragm 3. Shell element 252 is on the G3crack side, and shell element 250 is on G3 uncrack side. Both of them are on the same face.

Graphic results are shown below. Figure 4 shows the crack locations on Girders 3 and 4 on the bridge model. Figures 5 and 6 show zoom-in stress contours of connection plates on Girder 3 Diaphragm 3 at T=597second and on Girder 4 Diaphragm 3 at T=283second, respectively.

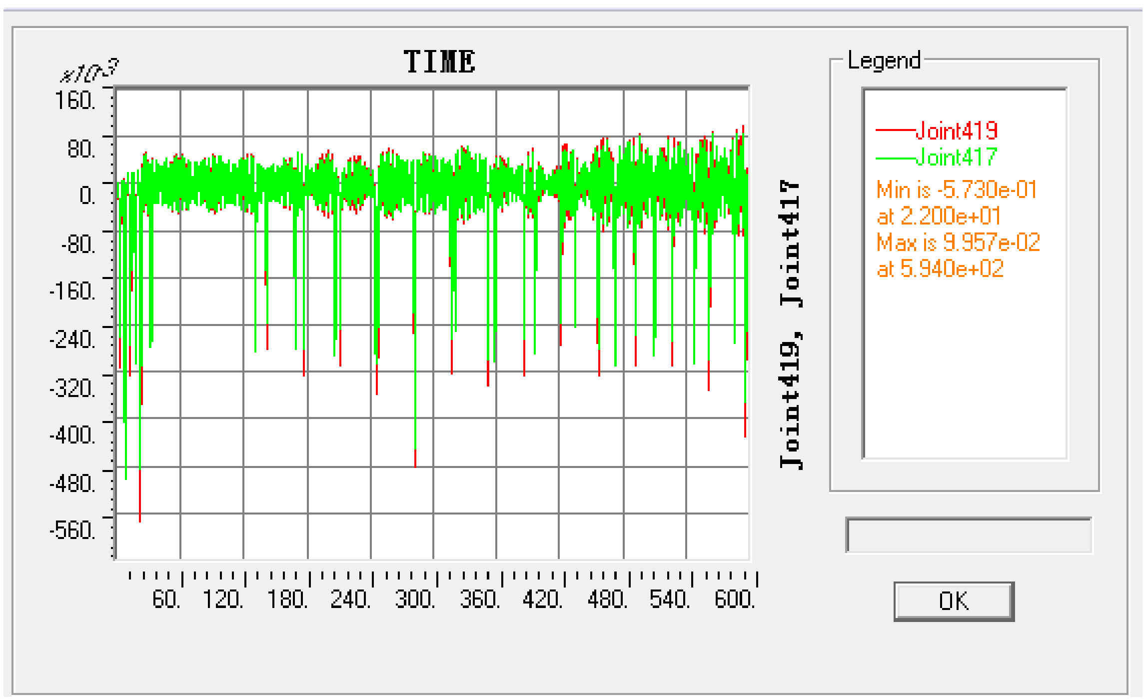


Figure 2-Midpoint displacements for G3(Joint 419) and G4(Joint417),unit - inches

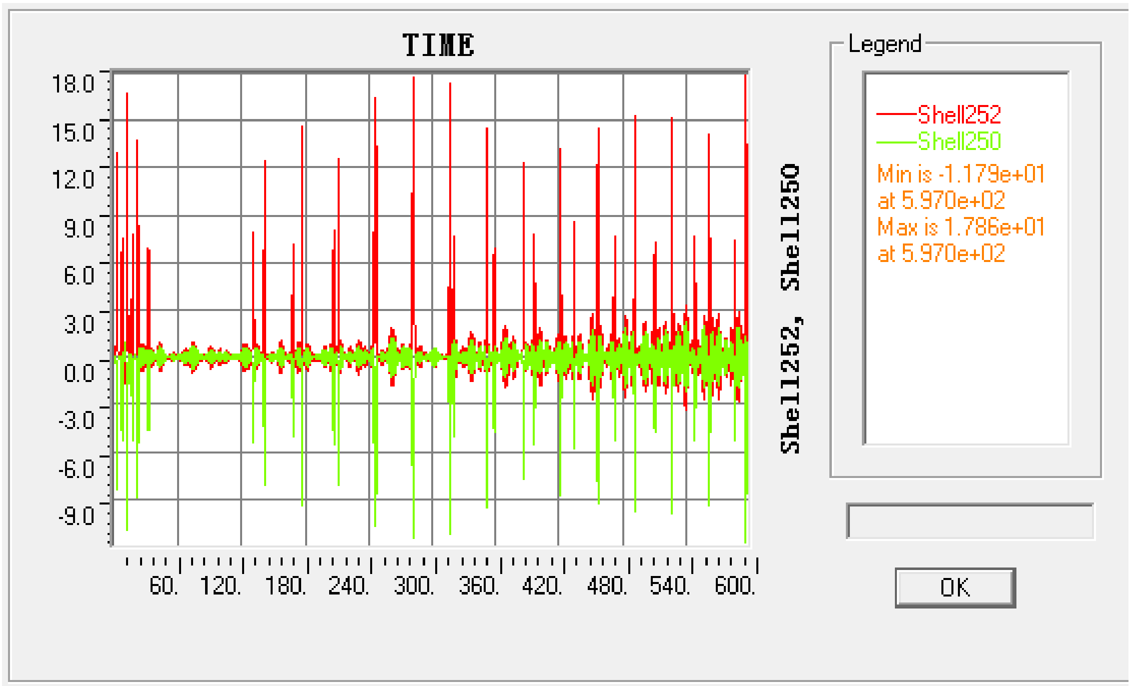


Figure 3-Stress of Hot Spot (Shell252-G3crack side, shell250-G3uncrack side) unit-ksi

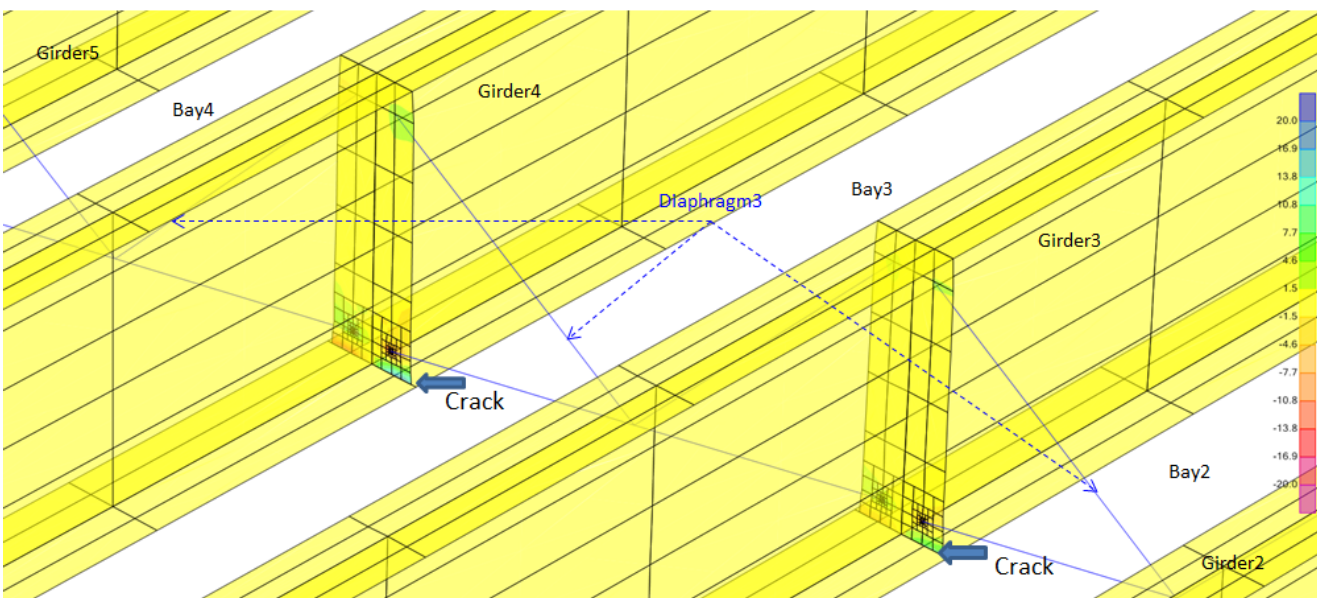


Figure 4 - Crack Locations

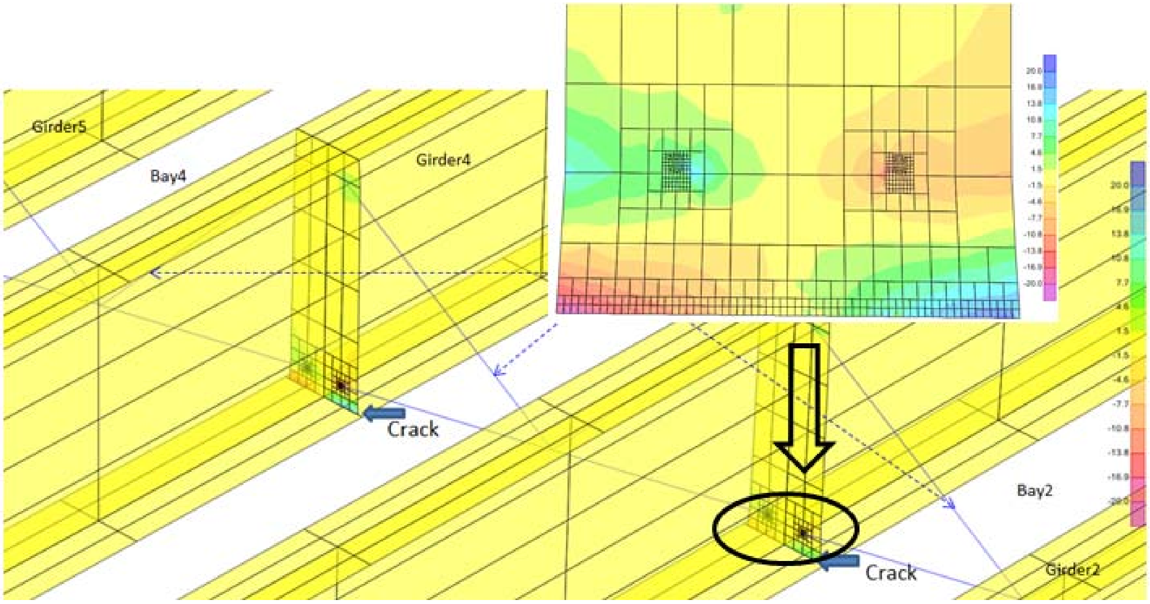


Figure 5 - Zoom-in Stress Contour of Connection Plate (Girder 3 Diaphragm 3) at T=597second

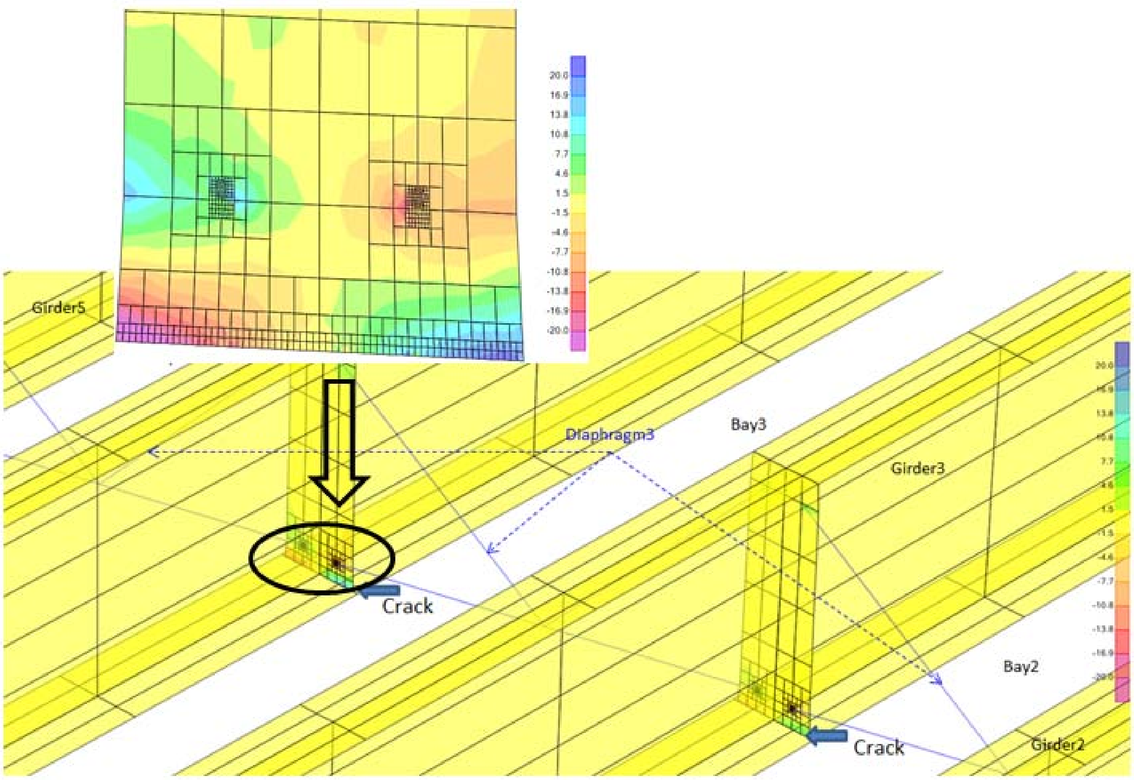


Figure 6 - Zoom-in Stress Contour of Connection Plate (Girder 4 Diaphragm 3) at T=283second