Final Report

NON-DESTRUCTIVE BRIDGE TESTING AND MONITORING WITH ACOUSTIC EMISSION (AE) SENSOR TECHNOLOGY

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SUMMARY

The proposed research at the Coast Guard Blvd. in the City of Portsmouth was according to the plan of action prepared in consultation with the VDOT. The major elements of the work are shown below:

- Research Preparation: review of the updated status of the bridge monitoring based on the feedback from VDOT
- Discussion of the Research Plan with VDOT/VTRC
- Site visits with VDOT for identification of the test objects on the bridge
- Planning of the equipment installation and data collection
- Collection of information of the bridge structural planning and changes from the original plans
- Acquisition of the latest average daily traffic data and determination of the percentages of light and truck traffics
- Planning of the research logistics in view of the change in structure
- Development of strategy and logistics for design, development of operational aspects of instrument installation/data collection

Bridge on Coast Guard Blvd.

The research preparations for the Route 164 bridge on Coast Guard Blvd. in the City of Portsmouth in Virginia were undertaken as proposed. The bridge is on the stretch between Cedar Lane and Norfolk Road. Passing below the Western Freeway is Coast Guard Boulevard (Figure. 1).

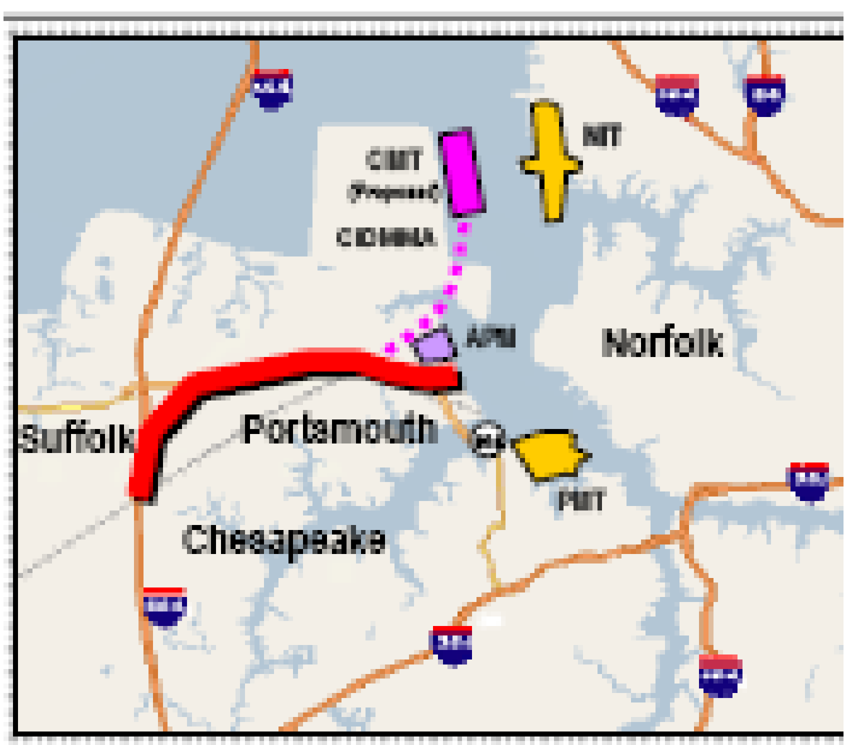

Figure 1: General Area in HR around Route 164

Such bridges use steel girders and devices such as pin and hanger assemblies as well as concrete in their structure (Figure 2). The structural plans of the two spans of the test bridge are shown in Figure 3.

Figure 2: Bridge girders at the tasked object.

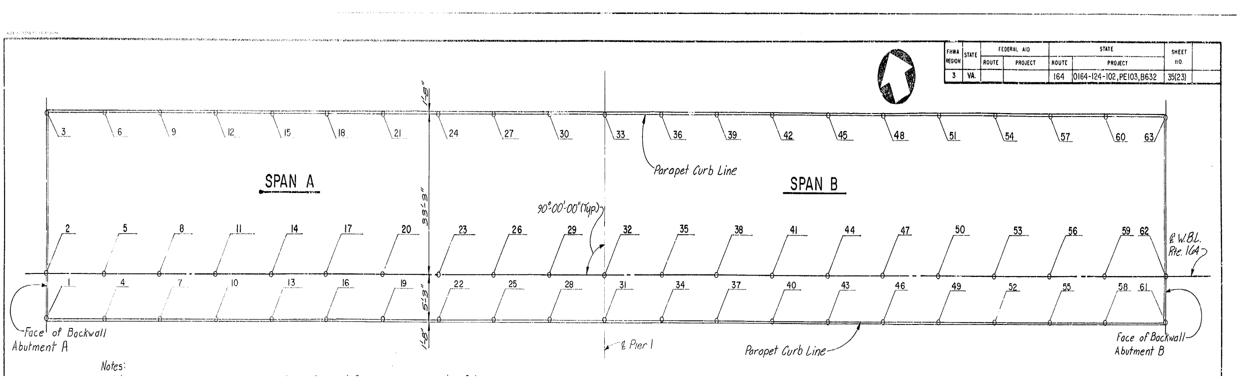

Figure 3: Structural plan of the two spans of the tasked object

Some of the problems with the pin and hanger assembly are attributed to deficiencies resulting in forces that were not accounted for in the bridge design. The hangers or links are designed for pure tensional forces. However, in practice, links are both tension and bending. Both in-plane and out-plane bending affect the bridge structure and its performance.

OBJECTIVES

The technique of AE was used with following objectives:

-If a bridge element broke, (friction) will cause AE to be generated when broke.
-If corrosion is taking place in the area close to sensor, AE will hear it.
-If micro cracking is taking place in the test element.

RESEARCH RESULTS

During the research period of January 1 – December 31, 2009, two bridges were identified as potential test candidates for NDT using the acoustic emission (AE) technology: 1. the bridge on I-164 at the Coast Guard Blvd. in the City of Portsmouth (built in 1991) that has an average daily traffic of 22,276 with 4% truck traffic according to the latest data in comparison to an average daily traffic of 11,337 with 4% truck traffic in 2004; and 2. the bridge located in the city of Williamsburg (VDOT Display structure 018 – 1917 (built in 1939) that has an average daily traffic of 2230 but with 5% daily average of truck traffic. Metal and non-metal bridge structure components were investigated using NDT of acoustic emission (AE) with the objective to monitor health of these bridges in collaboration with VDOT's District Structure and Bridge Engineering Department. It was proposed to develop accurate, reliable and durable NDT methods of structural health monitoring of highway bridges to help prevent spread of structural failures. In view of the changes made in the VDOT display structure 018 – 1917, research was focused on the bridge on I-164 situated near a cargo terminal at the Coast Guard Blvd. in the City of Portsmouth with the objective to investigate bridge structure element active defects during periods of low and/or no traffic and peak and/or heavy traffic in short areas of the AE sensors. Hence, the study focused on areas with higher potential of damage. Discussions were held with the VDOT/VTRC bridge engineers to finalize a plan of action to utilize AE sensors on the potential inspection sites, both on the Suffolk bound and Norfolk bound lanes of the Interstate. Potential test sites were identified based on the results from a monitoring system consisting of 2 AE sensors and the data acquisition (DAQ) system. The structural health monitoring of these involved metal and non-metal (e.g. concrete) bridge structural components using NDT of acoustic emission (AE). Future studies beyond this phase would require testing of approximately 50 bridges of different types for establishment of sorting or grading criteria. Bridges with problems can be monitored for longer time periods. The AE technology would be simplified for the DOT data review and decision making such that if problems are identified with AE, a dedicated system could be put into place for online monitoring.

Plan of Action

The latest traffic data on the bridge suggests a daily average traffic of 22,276 vehicles and 4% of these are trucks. This puts an enormous strain on the component plates. Accordingly, a plan of action was prepared in which the behavior of the component plates that are subjected to compression and shear, were selected for both the monotonic and cyclic loading conditions. According to the plan, the installed AE sensors are expected to provide information on local and global buckling of the test objects.

Figure 4: Potential Locations for AE Sensor Installation on the Bridge and the Back Wall.

AE responses from the test location were using 2-channel system were recorded during the research period of 2009. This period included both low traffic volumes (acoustically quiet) and high traffic volumes (acoustically noisy), as well as periods with the various ambient temperatures on the location.

Acoustic Emission Signatures

The recorded AE signals characterize the events that take place around the test area. These characteristics determine the source of the recorded signal. Two typical examples of detected AE signatures during this study are discussed in relation to the sensor that detected the signal.

1. AE signals related to a break are supposed to be dramatic. These will have high energy, high amplitude and very short duration. The AE amplitudes from sensors 1 and 2 installed on the test location are relatively feeble indicating their origin to be initiation and/or expansion of cracks in the concrete
2. The concrete walls are AE active and require further investigation using a portable higher channel AE system.

AE activity has been related to three types of activities in the concrete:

1. Expansion of the pre-existing cracks
2. Formation of new cracks
3. Friction due to rubbing of the two walls of a pre-existing or a newly formed crack

As a rule of thumb, the concrete crack expansion/formation are characterized by high energy counts, high amplitude, short duration and short rise time. The crack friction due to rubbing, on the other hand are of low energy counts, low amplitude, longer duration and longer rise times.

Typical examples of AE responses during a cracking event are detailed in Figures 5 – 8 where the energy counts (in mV) are plotted against response times (in microseconds).

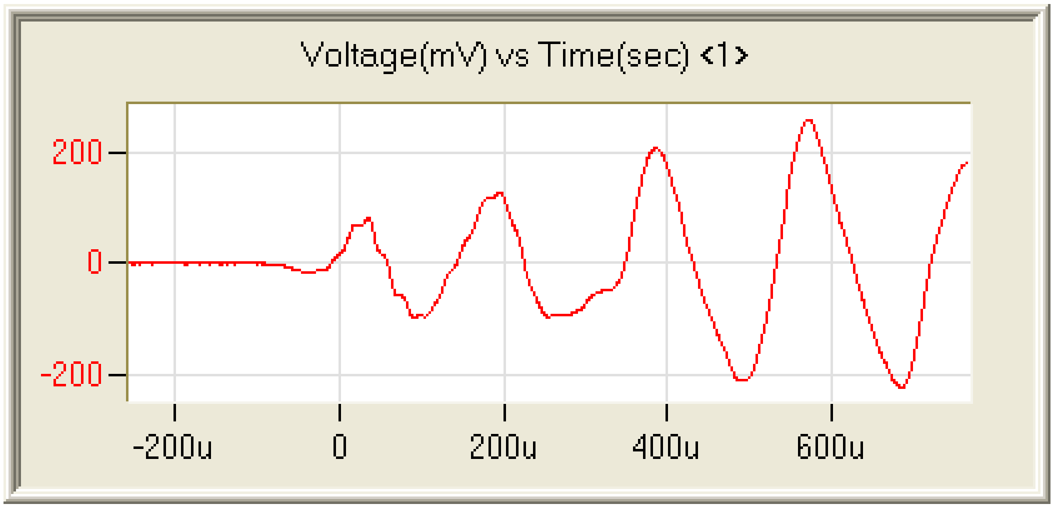

Figure 5. An AE event representing pre-existing concrete crack rubbing recorded by sensor 1

The walls of a pre-existing crack in concrete near sensor 1 rub against each other producing long duration (~ 750 microseconds) but low energy counts (up to ~ ±250 mV)

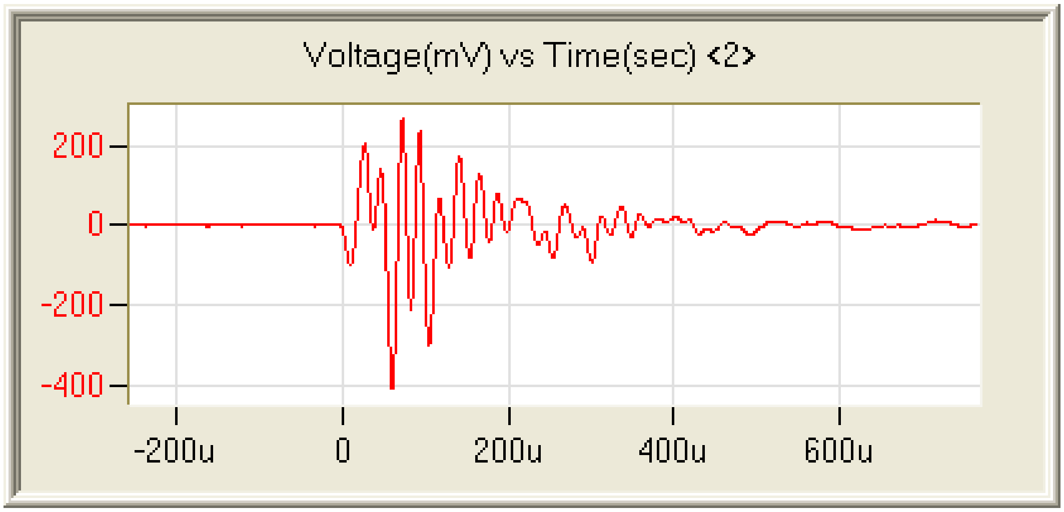

Figure 6. An AE event representing pre-existing concrete crack rubbing followed by high energy counts of short duration representing crack formation/crack expansion recorded by sensor 2

during an event shown in Figure 5. Figure 6 shows another event representing crack formation demonstrated by short duration (~ 75 microseconds) but high energy (up to ~ ±400 mV) bursts recorded by sensor 2. An AE event representing initiation of a higher energy (up to ~ ±200 mV) but a shorter duration (~ 100 microseconds) micro crack followed by a longer duration (~ 400 microseconds) rubbing is shown in Figure 7. In all such cases, crack rubbing has been prominent and has been a common feature in crack expansion and crack initiation. New crack formation is invariably has been found to be followed by crack rubbing.

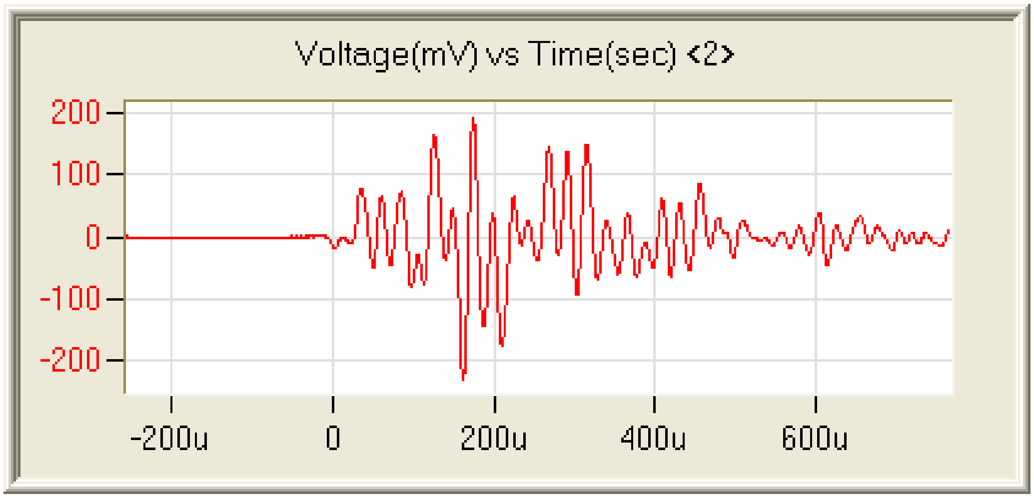

Figure 7. An AE event representing crack formation followed by rubbing recorded by sensor 2

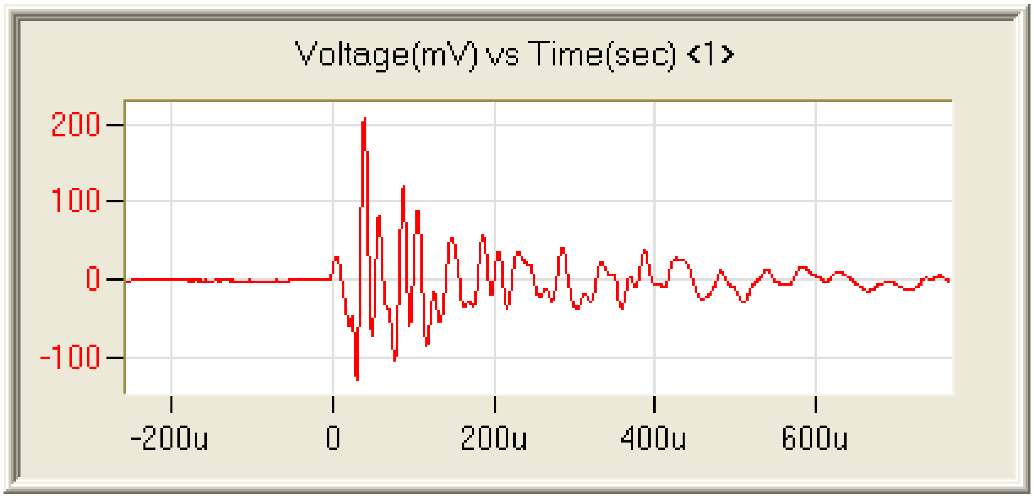

Figure 8. An AE event representing initiation of a lower energy longer duration rubbing recorded by sensor 1

Typical example of an AE hits as function of date and time of an experiment conducted in October 2009 is shown in Figures 9 and 10. Figure 9 shows the response of sensor 1 and Figure 10, the response of sensor 2 during the same period. A higher AE activity is recorded by sensor 2 during the same event.

AE signals were also evaluated in terms of their durations, amplitudes and energy. Figure 11 shows a typical plot of the AE signal durations as function of amplitudes at different energies. This was done to estimate the location of the AE activity as the AE system timestamps each received signal. Thus, an estimate can be made using the speed of sound in a given material.

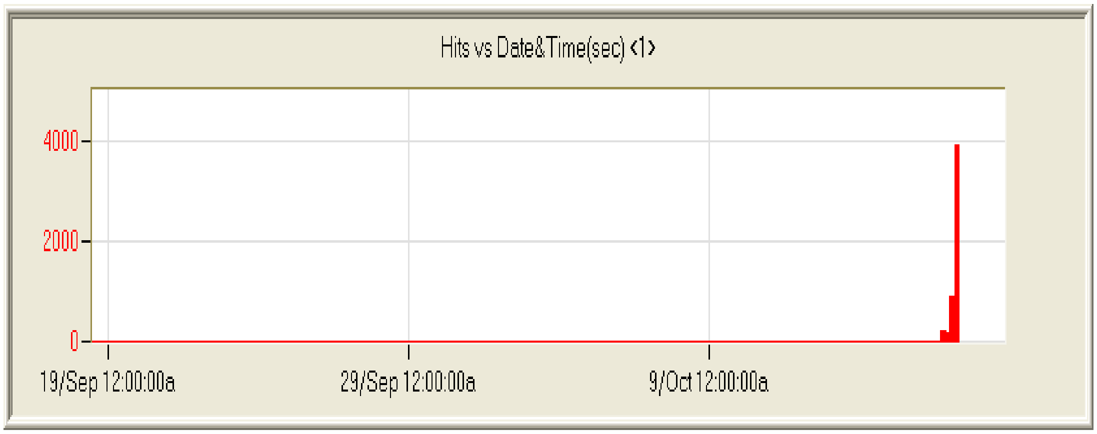

Figure 9. AE hits recorded by sensor 1 during an experiment in October, 2009

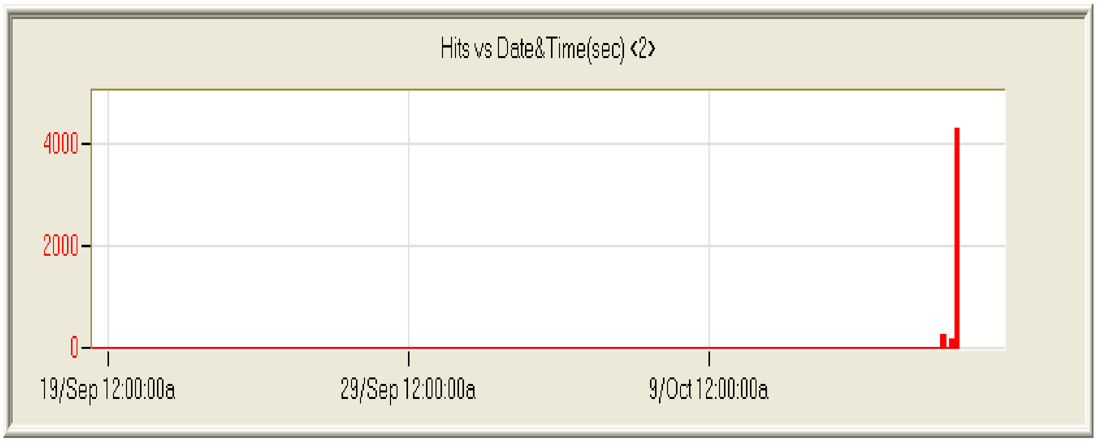

Figure 10. AE hits recorded by sensor 2 during an experiment in October, 2009

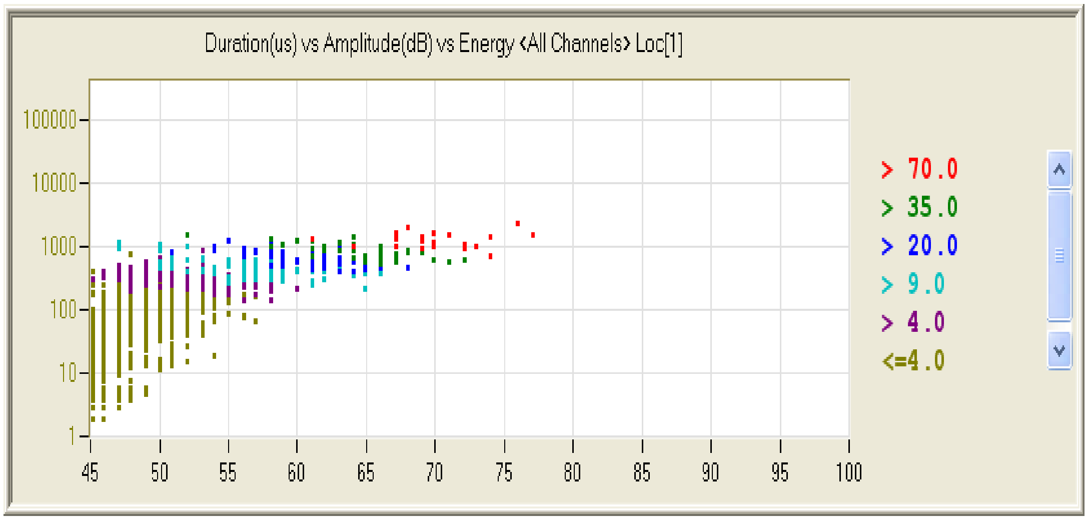

Figure 11. Duration, amplitudes and energies of AE hits recorded by sensor 1 during an experiment in October, 2009

The following has already been achieved during this period:

- Potential sites for monitoring and for analyzing AE were identified (Figure 4).
- An 8 sensor system for monitoring the test sites has been designed.
- The newly designed AE monitoring system is based on 12V rechargeable batteries and inverters.
- The DAQ, computerization and power systems are designed for their operational capability in situations where regular power is not available for instrument operation.
- The designed equipment is under fabrication and is being acquired by ESITAC with RITA approval.
- Studies on Virginia bridges using the newly designed AE system will continue.
- AE monitoring during the investigation involves metal and non-metal (e.g. concrete) bridge structural components.
- An inspection procedure and methodology is to be established based on the studies during quiet/low and peak traffic periods.
- The role of thermal factors needs to be investigated and incorporated in the inspection procedure.
- The AE data need to be monitored, recorded and analyzed on a real time basis from a remote location such as from the office of the bridge engineer/inspector.

FUTURE PLANS

The following is being proposed for the period of 2010:

- To continue studies on Virginia bridges (i.e. Figure 1) using the newly acquired 8 channel AE sensor and DAQ system.
- AE monitor both the metal and non-metal (e.g. concrete) bridge structural components.
- Analyze the AE data in a linear and 2D framework to locate the damages including in areas where accessibility is a challenge for the inspection team.
- Establish an bridge inspection procedure and methodology based on the studies during quiet/low and peak traffic periods.
- Investigate the role of thermal factors and incorporate in the inspection procedure.
- Monitoring, recording and analysis the AE data on a near real time basis.