

# **Final Report**

## **Non-Destructive Bridge Testing With Advanced Micro-II Digital AE system**

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## SUMMARY

The proposed research at the Coast Guard Blvd. in the City of Portsmouth was completed according to the plan of action prepared in consultation with the VDOT and the Virginia Council of Transportation Innovation and Research (VCTIR). 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/VCTIR
- Site visits with VDOT for test site selection on the bridge
- Acquisition of the battery operated digital DAQ for experimentation
- Planning of the newly designed and acquired Micro-II Digital DAQ system Acoustic Emission (AE) sensors for installations on the test site
- AE testing, data acquisition and analysis
- Analysis of the AE data in a linear and 2D framework to locate the damages
- Establish AE bridge inspection procedure and methodology based on the studies during quiet/low and peak traffic periods
- Investigate the AE generation from freight trains on the bridge structure component
- AE data acquisition, recording and analysis on a near real time basis.

### BRIDGE ON COAST GUARD BOULEVARD

The test bridge (Virginia Structure # 1809, Federal Structure ID # 21212), located on Route 164, falls on the stretch between the Cedar Lane and the Norfolk Road. The bridge was built in 1991. It was originally planned to cross over the Coast Guard Boulevard. Due to change in plans it currently crosses over the W. Norfolk Road and N&W R/R.



Figure 1: Bridge on Coast Guard Boulevard in Portsmouth, Virginia

Figure 1 shows the East and the West Bound Lanes (Route 164 EBL and Route 164 WBL) of Route 164 on the bridge. The bridge crosses the rail tracks of the Commonwealth Rail through which the cargo to and from the terminal is transported for subsequent loading and unloading to their destinations. The Route 164 is a primary road system that ferries cargo trucks. The bridge has an average daily traffic of 22,276 with 4% truck traffic according to the latest (2009) available data in comparison to an average daily traffic of 11,337 with 4% truck traffic in 2004. It is 432.1 Feet in length and 54.5 Feet in width.

The WBL on the bridge is supported by 2 central steel girders and 2 deck supporting steel girders, as shown in Figure 2. The west ends of the steel girders are anchored to the concrete back wall (Figure 2). Because of the high truck volume on the bridge and a heavy freight transport by trains that run under the bridge, the concrete back wall is expected to be under high stress not only because of the traffic volumes on the bridge but also due to traffic that runs on the rail tracks (Figure 3). It was, therefore, decided to investigate the back wall using the NDE technique of Acoustic Emission (AE) in consultation with VDOT/VCTIR.

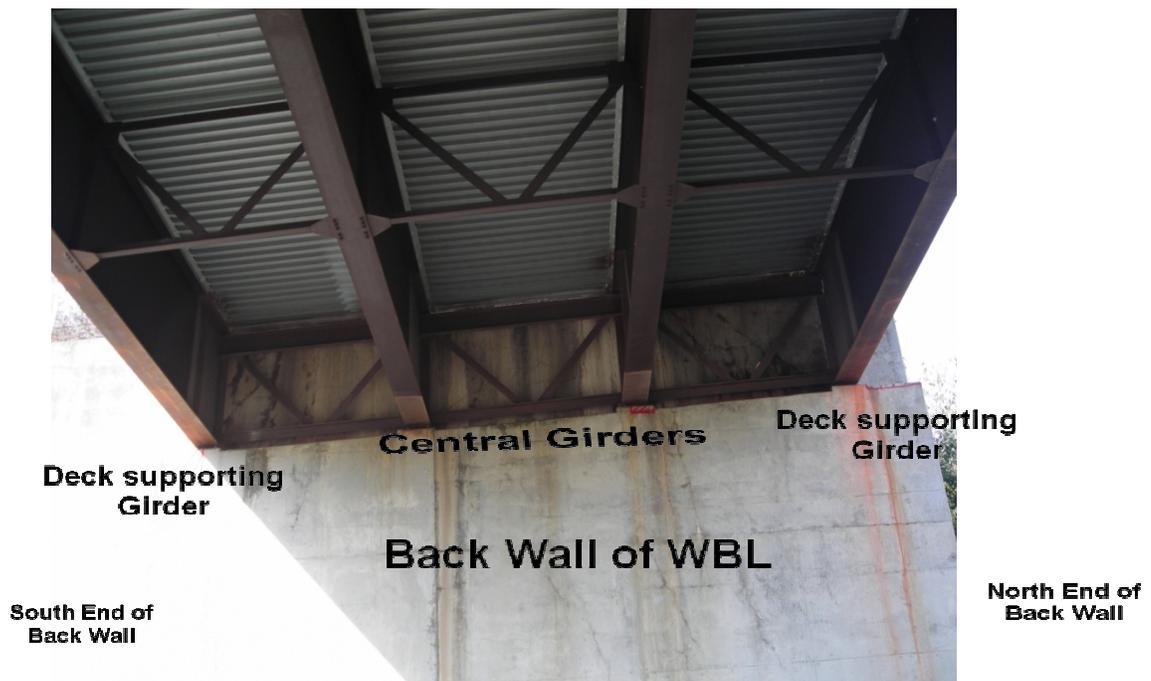


Figure 2. The West Bound Lane (WBL) supported by 4 steel girders

## OBJECTIVES

The technique of AE was used with following objectives:

- If the cracks exist in the concrete wall, (friction) will cause AE to be generated under load.
- If cracks grow in the area close to sensor, AE will hear it.
- If micro cracking is taking place in the test area.



Figure 3: Heavy Cargo component on the WBL of Route 164: (a) on the test brige; and (b) under the bridge in proximity to the test site of the wall

### 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 load on the steel girders and the component plates. The girders being anchored to and their ends resting on the concrete back wall, high stress effects are expected on the wall structure. The AE sensors, installed at strategic locations, are expected to provide information on local and global stress levels on the concrete wall.

### SENSOR INSTALLATION

8 AE sensors with the following characteristics were installed along the width of the wall:

- R0.45I-LP-SC-5 4.5 kHz (PAC/Mistra’s Group)
- low power sensors
- designed for outdoor use
- detection frequency chosen to minimize responses from ambient noise and vibrations
- Sensors were affixed with epoxy at predetermined locations on the wall
- The sensors were installed on the face of the test wall at the following strategic locations (Table 1).

In Table 1, the vertical locations from the ground are 7.00 feet. The installed sensors are shown in Figure 4 (a). The data was recorded using the Micro-II Digital DAQ system of Figure 4(b).

Table 1. Locations of AE sensors on the WBL Back Wall

Sensor #	1	2	3	4	5	6	7	8
Location (feet)	1	6	11	15	21	26	31	36

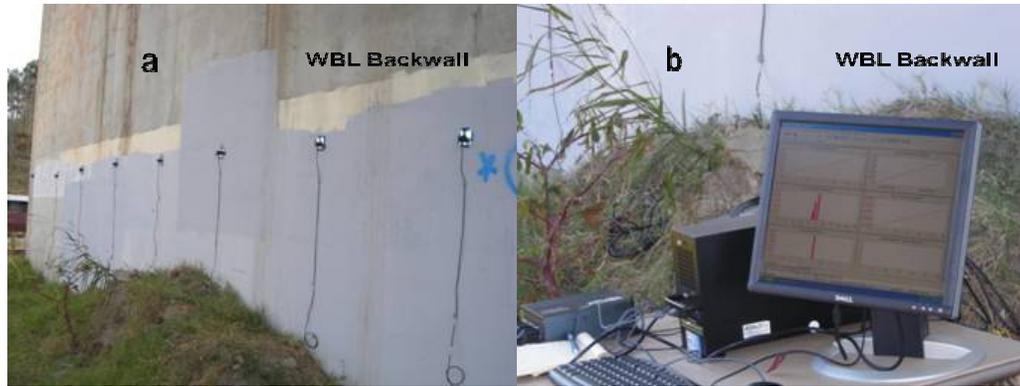


Figure 4. (a) 8 AE sensors installed on the WBL back wall at locations given in Table 1; and (b) The micro-II Digital AE DAQ system acquiring data

AE responses from the test location using 8-channel Micro-II Digital DAQ system were recorded during the research period of 2010 - 2011. This period included both low traffic volumes (acoustically quiet) and high traffic volumes (acoustically noisy), as well as periods with (i) No cargo (either truck and/or train cargo traffic), (ii) both train and truck cargo traffic; and (iii) only truck but no train cargo traffic.

## RESEARCH RESULTS AND DISCUSSIONS

AE sensors respond only when there is an AE activity at locations in the vicinity of sensors. The Micro-II Digital 8 channel DAQ system records several parameters related with Acoustic Emission; namely, the number of AE hits, number of AE events, AE energy, AE duration, AE amplitude, AE rise time, AE absolute energy etc. The DAQ system also time stamps the AE event. A typical AE plot of the events of December 7, 2010 is shown in Figure 5. During this period of recording there was no train cargo traffic under the bridge but there was a regular traffic on the bridge. The sensors 1-4, were located outside of the south deck of the bridge and sensors 5 – 8 were located under the bridge (Table 1). It may be noted from Figure 5 that sensor 1-4, being located outside of the deck area on the bridge, show no AE response. This is an area unaffected by the load on the bridge.

Studies were conducted for periods of:

1. Regular traffic (Cars + Trucks) on the bridge but no freight train movement under the bridge
2. Regular traffic (Cars + Trucks) on the bridge and also freight train movement under the bridge
3. No truck traffic on the bridge and no freight train movement under the bridge

Figure 6 shows responses from sensors 5 – 8 for locations given in Table 1 for the traffic situation in item 1 above where AE events have been plotted against the sensor locations on the back wall. The cluster of events in the wall stretch between sensors 5 - 6 and between 6 -7 are from locations falling under the central steel girders in Figure 2. These AE events are resulted from the existing cracks in these regions.

Figure 7 shows responses from sensors 5 – 8 for locations given in Table 1 for the traffic situation in item 2 above where AE events have been plotted against the sensor locations. The cluster of events in the wall stretch between sensors 5 - 6 and between 6 -7 are from locations falling under the central steel girders in Figure 2. These AE events are resulted from the existing cracks in these regions. Comparison of Figures 6 and 7 clearly demonstrates the effect of freight train movement on the AE activity in the wall. The effect is significant indicated by a large number of recorded hits, specifically in the sensor 6 - 7 stretch and in the vicinity of sensor 7 towards sensor 8.

These AE activity characteristics determine the source of the recorded signals. 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 in metal (rebar) are supposed to be dramatic. These will have high energy, high amplitude and very short duration. The AE amplitudes from sensors 5 - 8 installed on the test location in Table 1 are relatively feeble indicating their origin to be initiation and/or expansion of cracks in the concrete
2. The concrete wall is AE active and requires further investigation covering the entire width of the wall.

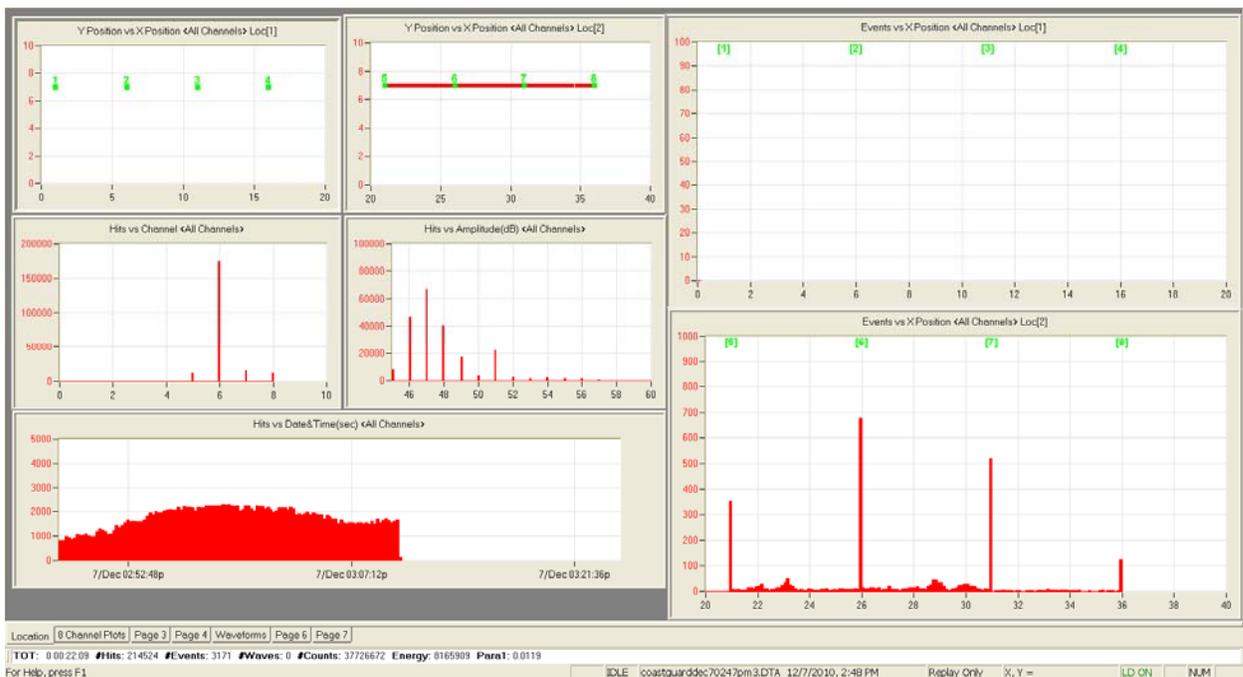


Figure 5. Typical response from AE sensors December 7, 2010 for the sensor locations in Table 1. Sensors 1-4 do not show any response being located on the wall area outside of the bridge.

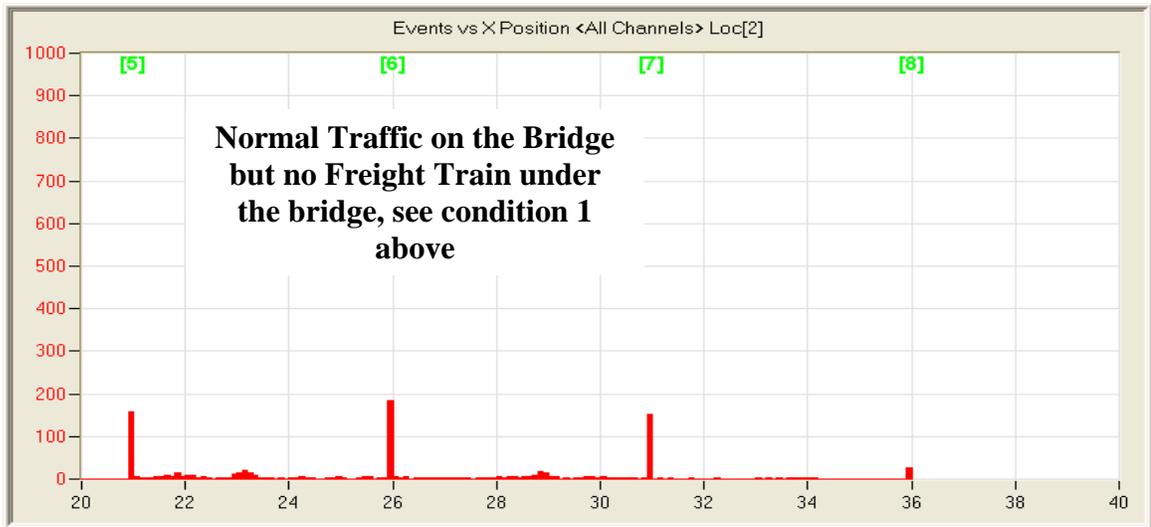


Figure 6. AE responses from AE sensors 5 – 8 recorded on December 7, 2010 for the sensor locations in Table 1 for a regular traffic on the bridge and no freight train movement under the bridge.

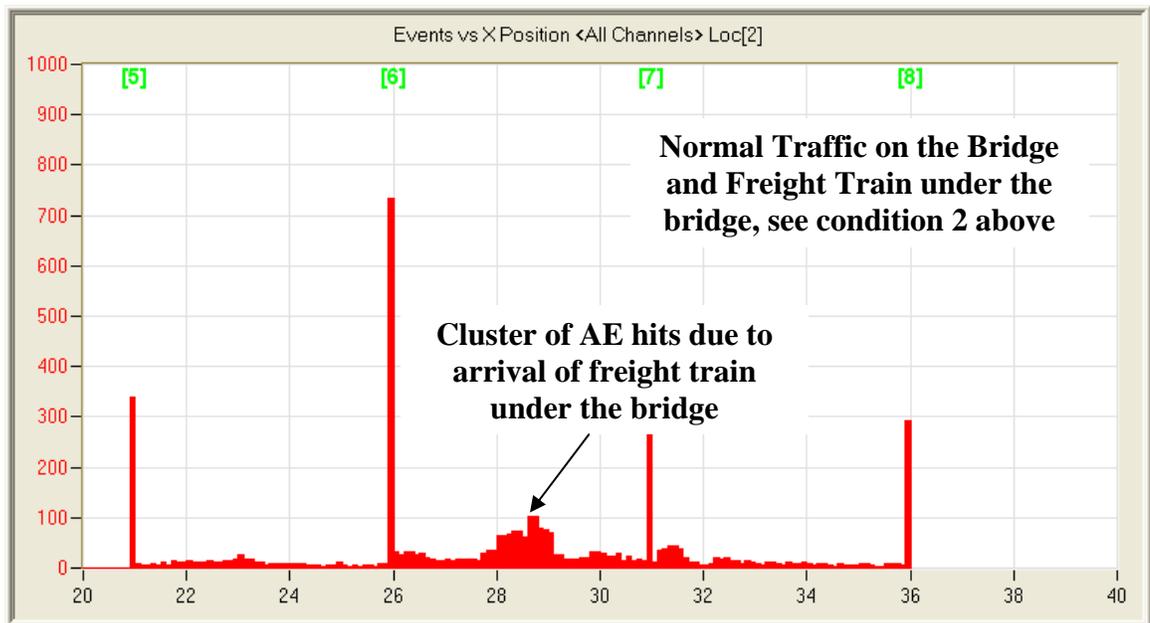


Figure 7. AE responses from AE sensors 5 – 8 recorded on December 14, 2010 for the sensor locations in Table 1 for a regular traffic on the bridge and also freight train movement under the bridge.

The recorded AE signals characterize the events that take place around the test area. In order to cover the remaining width of the bridge, the sensors were relocated according to the scheme given in Table 2. The installed sensor locations are shown in Figure 8. The data was acquired using the Micro-II Digital AE DAQ system for the conditions of: Studies were conducted for periods of:

1. Regular traffic (Cars + Trucks) on the bridge but no freight train movement under the bridge
2. Regular traffic (Cars + Trucks) on the bridge and also freight train movement under the bridge
3. No truck traffic on the bridge and no freight train movement under the bridge

Table 2. Locations of AE sensors on the WBL Back Wall

Sensor #	1	2	3	4	5	6	7	8
Location (feet)	16	21	26	31	36	41	46	51



Figure 8: The AE sensors relocated to cover: (a) the entire width of the back wall; and (b) the most active areas

Figure 8 (a) shows installations of the relocated sensors (see Table 2 for locations) to cover the wall area between 16 feet – 51 feet. Considering the width of the back wall of the bridge as 54.5 feet, this relocation covers the entire width of the wall at 7.75 feet from the ground. The responses from sensors 5-8 in this configuration acquired on December 22, 2010 are demonstrated in Figure 9 in the absence of any freight movement under the bridge. However, when the freight train arrived on the same day, the data showed a significant change in AE activity shown in Figure 10. Figure 9 shows responses from sensors 5 – 8 for locations given in Table 2 for the traffic situation in item 1 above where AE events have been plotted against the sensor locations. Figure 10 shows the cluster of events in the wall stretch between sensors 5 - 6 and between 6 -7 are from locations falling around the central steel girders in Figure 2. The situation in Figure 10 corresponds to the condition of item 2 above where there is also the presence of train freight apart from the normal traffic on the bridge. These AE events are resulted from the existing cracks in these regions as well as generation/expansion of new cracks. Comparison of Figures 9 and 10 clearly demonstrates the effect of freight train movement on the AE activity in the wall. The effect is significant as indicated by a large number of recorded hits, specifically in the sensor 6 - 7 stretch and in the vicinity of sensor 7 towards sensor 8.

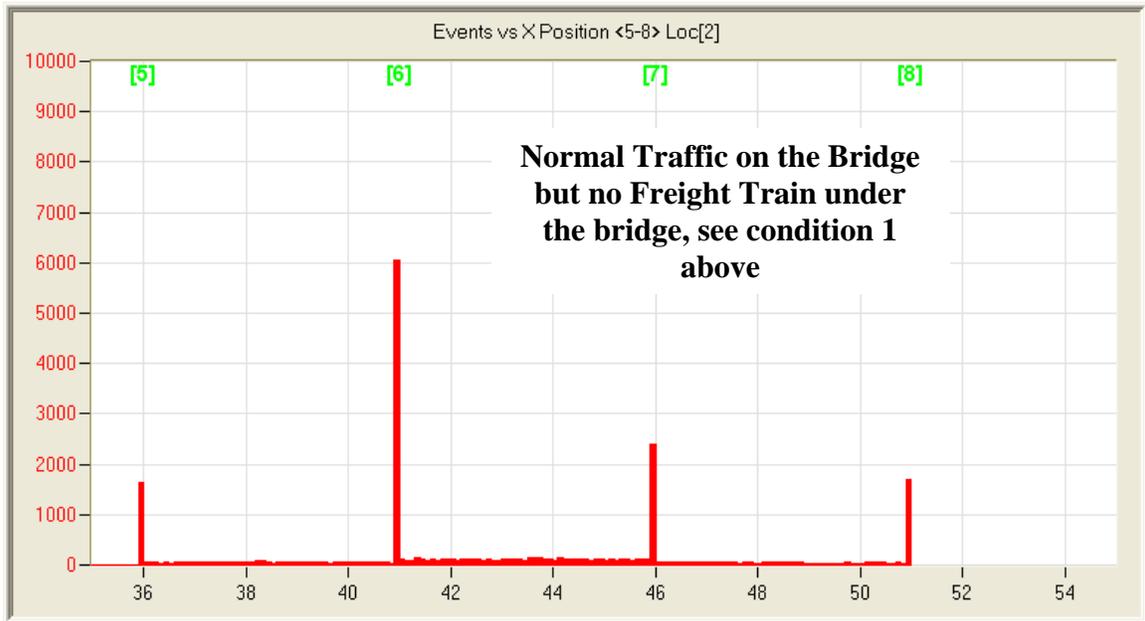


Figure 9. AE responses from AE sensors 5 – 8 recorded on December 22, 2010 for the sensor locations in Table 2 for a regular traffic on the bridge and no freight train movement under the bridge.

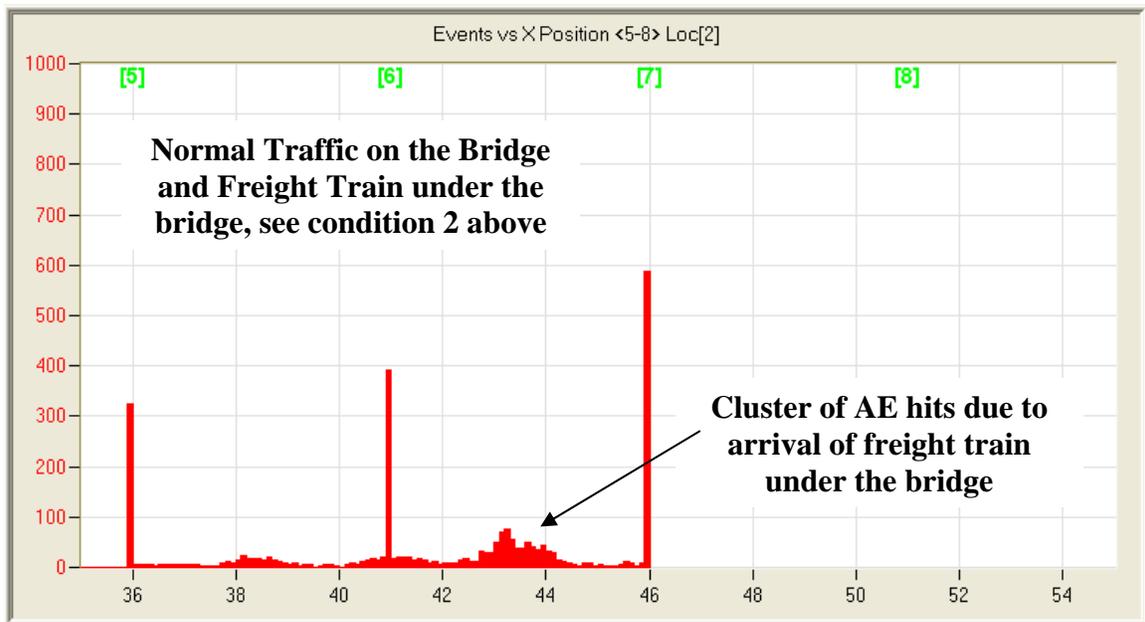


Figure 10. AE responses from AE sensors 5 – 8 recorded on December 22, 2010 for the sensor locations in Table 2 for a regular traffic on the bridge and also freight train movement under the bridge.

### 3D PERSPECTIVE

The data of Figures 9 and 10 for the absence and presence of the freight train component has further been analyzed to give a 3 D perspective in Figures 11 and 12, respectively. In 3D diagrams, the AE hits and their amplitudes have been plotted against the time of the hits being recorded at a given sensor. A “hump” of hits related to AE activity due to arrival of freight train in Figure 12 is absent in Figure 11.

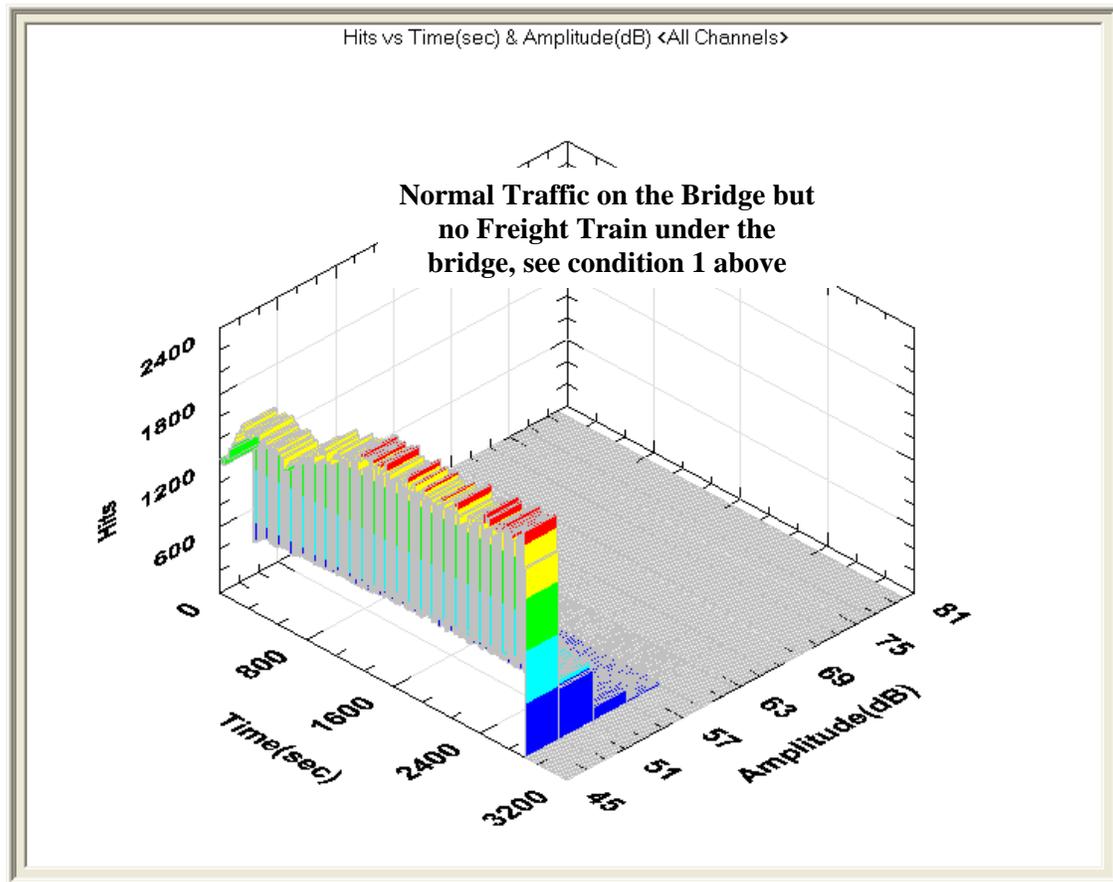


Figure 11. 3D representation of responses from AE sensors 5 – 8 recorded on December 22, 2010 for the sensor locations in Table 2 for a regular traffic on the bridge and no freight train movement under the bridge.

### FOCUS AREAS OF SIGNIFICANT AE ACTIVITY

As shown in Figure 10, areas of significant AE activity have been found around locations of sensors 5-7. In order to focus on this area, AE sensors were redistributed to include vertical distance variations according to the location scheme of Table 3. In this scheme, sensors 3, 5 and 7 were relocated 32” higher than shown in Figure 8(a). The new scheme of sensor locations is shown in Figure 8(b). This redistribution allowed closer look around sensors 2, 4 and 6. The AE sensor locations and AE response from sensors in scheme of Table 3 is shown in Figure 13. Areas of high and low AE activity are clearly

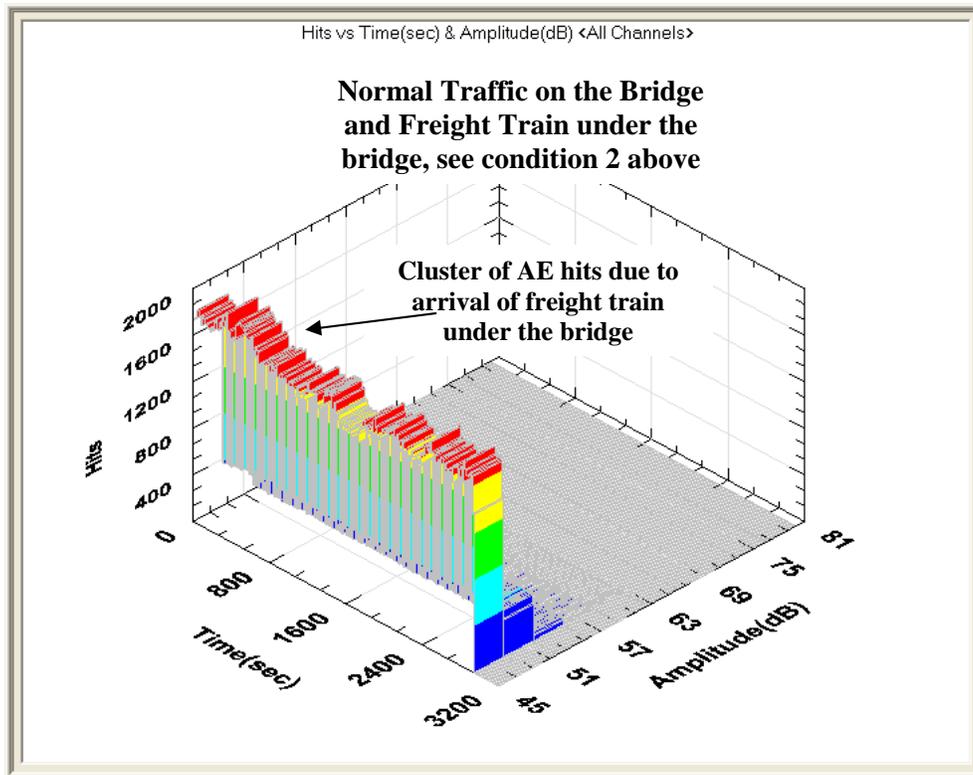


Figure 12. 3D representation of responses from AE sensors 5 – 8 recorded on December 22, 2010 for the sensor locations in Table 2 for a regular traffic on the bridge and also freight train movement under the bridge.

Table 3. Locations of AE sensors on the WBL Back Wall as in Figure 8(b)

Sensor #	1	2	3	4	5	6	7	8
Horizontal Location (feet)	16	21	26	31	36	41	46	51
Vertical Location (feet)	7	7	9.75	7	9.75	7	9.75	7

seen on Figure 13. Whereas, no AE activity was recorded between sensors 4 and 5, 4 and 6; and 7 and 8, there was AE activity between sensors 3 and 4. Further, strong AE activity was recorded between sensors 1 – 3, 5, 6 and 7. These observations clearly show AE activity originating from vertical locations. Further, the amount of AE activity shown in between sensors 3 and 4; and between sensors 5 and 6 is lower in comparison to that between 5 and 7. This demonstrates that the AE activity is not uniform in the entire wall but there are strong AE activity areas along the wall closer to the foot of the wall.

Figure 14 shows spur in AE activity due to arrival of freight train under the bridge in comparison to that in Figure 13 when the freight traffic is absent.

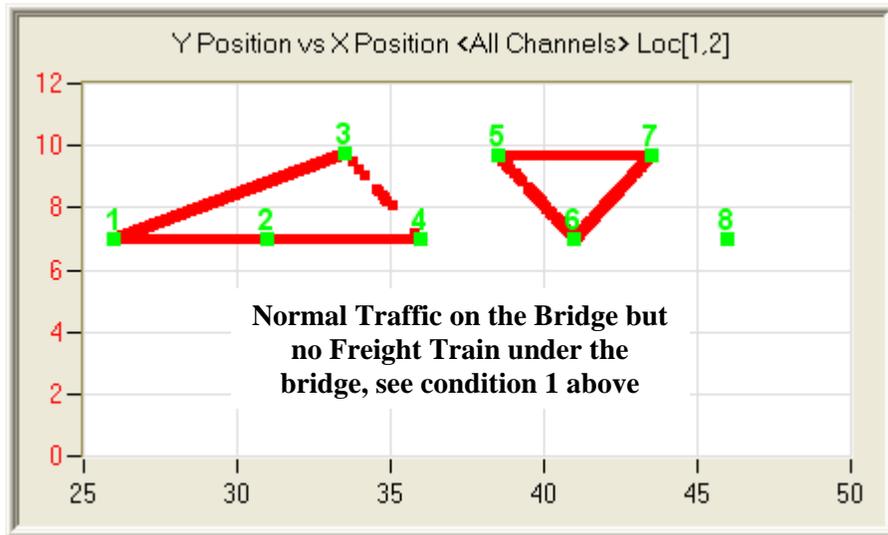


Figure 13. AE responses from AE sensors 1 – 8 recorded on February 02, 2011 for the sensor locations in Table 3 for a regular traffic on the bridge but no freight train movement under the bridge.

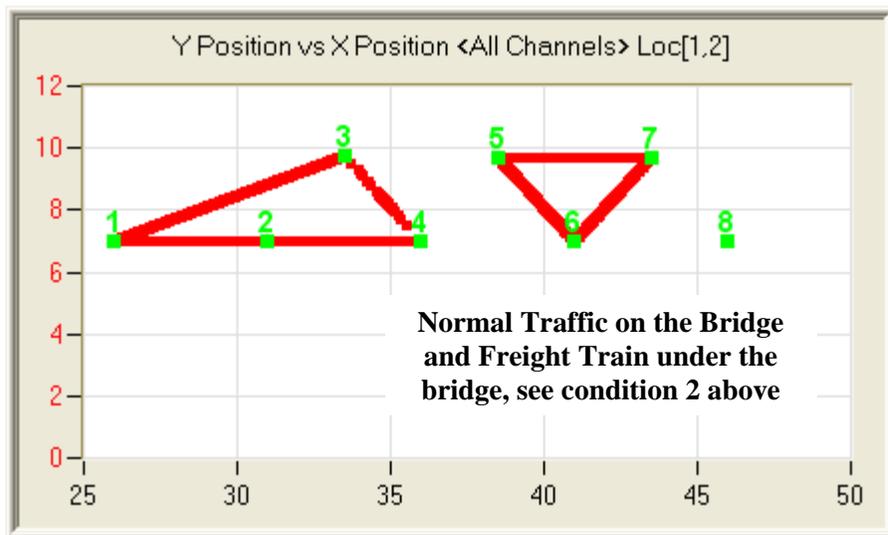


Figure 14. AE responses from AE sensors 1 – 8 recorded on February 07, 2011 for the sensor locations in Table 3 for a regular traffic on the bridge and also freight train movement under the bridge.

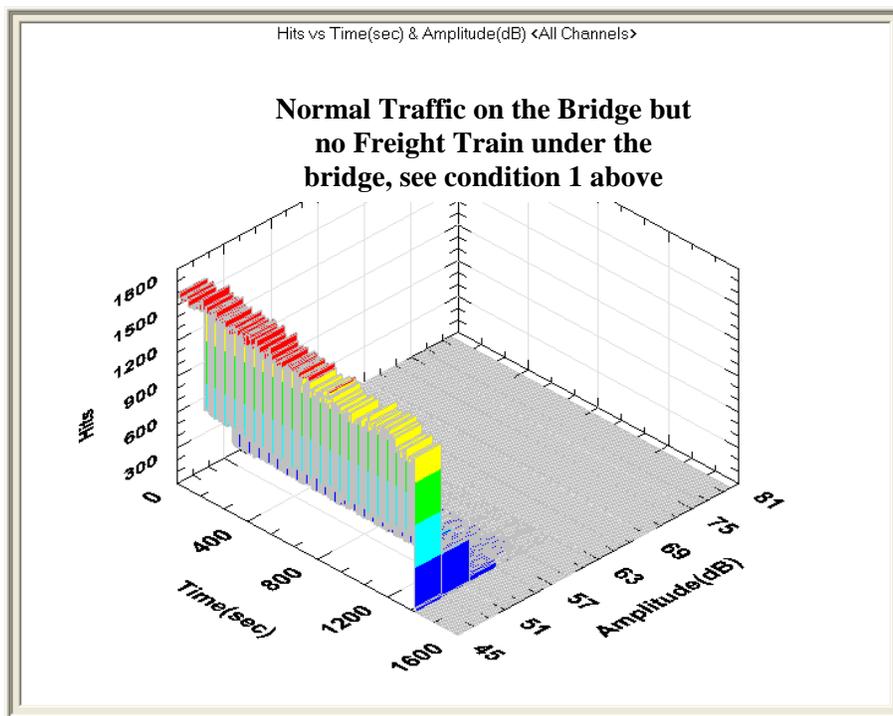


Figure 15. 3D representation of responses from AE sensors 1 – 8 recorded on February 02, 2011 for the sensor locations in Table 3 for a regular traffic on the bridge and no freight train movement under the bridge.

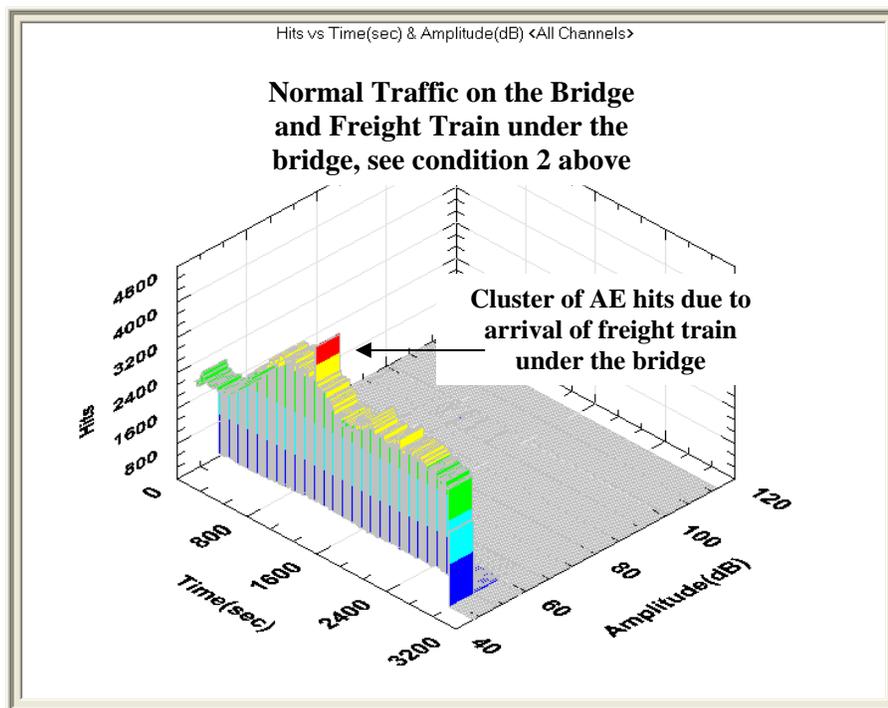


Figure 16. AE responses from AE sensors 1 – 8 recorded on February 07, 2011 for the sensor locations in Table 3 for a regular traffic on the bridge and also freight train movement under the bridge.

## CONCLUSIONS

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

The following has been achieved during this period:

- The sites selected for monitoring and for analyzing AE were investigated.
- An 8 sensor system, Micro-II Digital DAQ system designed and acquired for monitoring the test sites has been used.
- AE activity has been detected in the back wall of the WBL of bridge on Coast Guard Boulevard on Route 164.
- AE activity is higher in the regions right under the supporting middle (two) girders.
- AE activity is stronger in the presence of cargo traffic (trucks).
- AE activity further increases with train activity under the bridge.
- Unusually high AE activity in the back wall between 41 – 44 feet from the south edge of the wall has been observed although no prominent cracks could be seen in the area. This leads to the conclusion that there are AE active regions within the wall.
- AE activity for 3D locations of the active areas needs further investigations.

## RECOMMENDATIONS

- *Measurement and mapping of the cracks (both active and existing) in all the (4) back walls of this bridge should be undertaken. AE is relatively better suited technique for the purpose.*
- *Evaluation of the entire height of the wall, especially the areas falling under the central girders and the anchorage regions of the girders with the walls should be conducted.*
- *VDOT should consider using AE periodically to evaluate the health of this structure and determine which regions are exhibiting the greatest AE activity. Regions with elevated AE activity should take precedence over non-active regions during inspection.*
- *More number of bridges that cross R/R should be evaluated using AE in conjunction with other inspection techniques if necessary. VCTIR and HU/ESITAC should provide guidance for this recommendation on request from VDOT.*

## **FUTURE PLANS**

The following is being proposed for the period of 2011:

- To investigate **Denbigh Boulevard Bridge** using the newly acquired 8 channel AE sensor and DAQ system.
- AE monitor both the concrete beams and pillars of the bridge.
- AE investigate the role of train traffic on the bridge structural components.
- Analyze the AE data in a linear, 2D and 3D framework to locate the damages including in areas where accessibility is a challenge for the inspection team.
- Establish a 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.

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