FINAL REPORT

Acoustic Emission Safety Monitoring of Intermodal Transportation Infrastructure

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ABSTRACT

Safety and integrity of the national transportation infrastructure are of paramount importance and highway bridges are critical components of the highway system network. This network provides an immense contribution to the industry productivity and economic competitiveness. The infrastructure maintenance efforts must ensure a safe, timely, and reliable means of determining possible structural failures without undue disruptions to the traffic flow. As part of the National Center for Intermodal Transportation and Economic Competitiveness, with the assistance of the Virginia Department of Transportation, the application of the acoustic emission non-destructive testing methods is investigated for detecting and assessing structural conditions of the steel girder highway bridges. Acoustic emission can be used to identify suspected areas of the structure and helps to evaluate whether any further testing and analysis is warranted. A candidate bridge site, the interstate I-664 bridge crossing in Newport News, VA, was selected for this research.

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INTRODUCTION

The theme of the National Center for Intermodal Transportation and Economic Competitiveness (NCITEC) project is to promote the development of an integrated, economically competitive, efficient, safe, secure, and sustainable national intermodal transportation network by integrating all transportation modes for both freight and passenger mobility. Safety is a critical component in the development, implementation, operation and maintenance of the transportation system, and therefore it is imperative to conduct research on utilization of technologies that will allow enhancement of the highway structures safety by monitoring and predicting failures.

Highway bridges are a vital part of transportation infrastructure and there is need for reliable non-destructive methods to monitor their structural condition to ensure safety and efficiency. Many factors lead to the deterioration of highway bridges, including aging, extreme events such as natural disasters, other hazards including negligence, improper maintenance, and collisions, and, most importantly, operational loads from the increased freight transportation truck weights. Bridge structures, being vital for safety and economics, need the best protection, and the evaluation of their integrity becomes paramount. The ability to obtain necessary information regarding the bridge technical condition is often expensive and time consuming; furthermore, the inspection methods and techniques used need to be non-destructive, devoid of introducing any new damage during the monitoring process. With these goals in mind, this research addresses the application of the acoustic emission (AE) non-destructive testing (NDT) technology to evaluate and monitor the highway bridge integrity.

The current project is a natural continuation of the previous and ongoing efforts by Hampton University (HU) researchers in the area of acoustic emission monitoring and analysis and for the purpose of this study the interstate I-664 bridge crossing over Terminal Ave. in Newport News, VA (southbound lanes) was selected as a candidate site. This bridge forms part of the Hampton Roads Beltway in the vicinity of the Monitor-Merrimac Memorial Bridge-Tunnel crossing, handles significant heavy truck traffic, and is located in the immediate proximity to the railroad serving the CSX Railroad Coal Loading Dock in Newport News, VA.

OBJECTIVE

The overarching goal of this work is to advance the state of art in the steel girder bridge structural monitoring via the use of AE technology to reduce the conventional time and effort required to inspect such bridges for their integrity and safety. The impact will include the advancement of the NDT technology application expertise by utilizing the AE technology for data acquisition and real-time analysis for prediction of factors that lead to deterioration and wear in the highway structural components under the stresses of traffic environment. The objective is to determine methodology to identify defects within the bridge structure utilizing their AE footprint.

This project's goal is twofold. Firstly, it addresses the problems of evaluation of highway bridges and structures within the intermodal environment by using the AE technology to conduct assessment of their condition to assure that they are in the "state of good repair" and provide early indications of structures with deficiencies. Secondly, this work enhances HU capabilities and minority students' participation in the transportation-related projects by actively engaging them in the research, thus forming the next generation of transportation workforce. This research directly affects the *Safety* and the *State of Good Repair* strategic goals of the U.S. DOT, therefore also impacting the *Economic Competitiveness* goal.

SCOPE

The scope of this work was limited to the AE study of the selected bridge crossing - the interstate I-664 bridge crossing over Terminal Ave. in Newport News, VA (southbound lanes). This highway bridge has VA Structure No. 2235, Federal Structure ID 0020750. As was mentioned previously, this bridge forms part of the Hampton Roads Beltway in the vicinity of the Monitor-Merrimac Memorial Bridge-Tunnel crossing, handles significant heavy truck traffic, and is located in the immediate proximity to the railroad serving the CSX Railroad Coal Loading Dock in Newport News, VA. Due to this as well as due to the interest exhibited by the VDOT/VCTIR personnel and the relative ease of access, installation, and maintenance of the AE equipment, this bridge was identified as an appropriate intermodal structure for this research. The bridge section under investigation utilizes the I-shaped steel girders with stiffeners and cross-frames as superstructure and supporting piers are constructed using the box-type steel cross girders with reinforced concrete columns as shown in Fig. 1 and 2.

Figure 1: General view of the I-664 bridge crossing over Terminal Ave. in Newport News, VA.

The AE monitoring can be generally classified into two types – a global monitoring and local monitoring. A global monitoring assesses the entire structure’s integrity, while local monitoring assesses a specific area of suspected or existing damage. With respect to this, the scope was also limited to the local monitoring of an existing damage – a crack – present in the steel girder structure (girder #8). The AE monitoring area included steel cross girder #6A/32SB as well as longitudinal girders #7 and #8 of the bridge superstructure.

Figure 2: Close-up view of the girder to cross girder connection.

METHODOLOGY

The phenomenon of AE represents transient elastic waves produced by the rapid release of energy in a stressed material. The classic sources of AE in engineering structures such as bridges are the defect-related deformation processes such as crack initialization and growth as well as plastic deformation. Sudden movement at the source produces a stress wave, which then radiates out into the structure.

The diagram below (Fig. 3) represents a general schematic of an AE monitoring system. Such system would include a transducer which detects the bursts of energy emitted by the source within the structure and a data acquisition hardware and software that receives, stores, and analyzes the AE data.

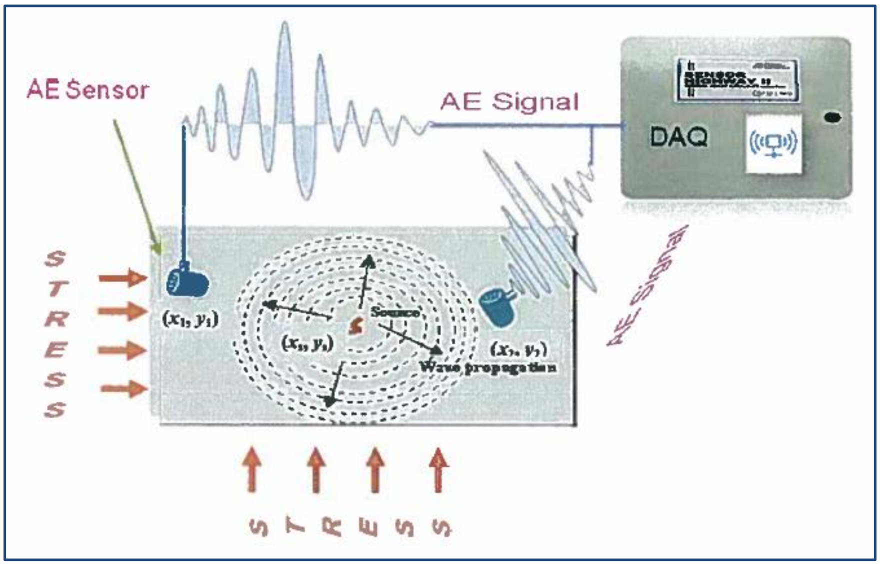


Figure 3: Schematic of the AE technology application.

The advantages of the AE technology include possible early detection of the flaws such as cracks in the structure, the advantage of real time monitoring, minimization of traffic flow disturbances, and significant cost reductions. Among the disadvantages, however, are issues with the background noise elimination, lack of standard methodology as it applies to AE monitoring of bridges, and the difficulties with assessing the damage quantitatively as opposed to qualitatively.

The PK15I piezoelectric transducers produced by the Mistras Group, Inc. were used in this study (Fig. 4). The purpose of a transducer is to detect mechanical stress waves and convert them into electrical signals. The PK15I sensor is a 150 kHz, low power, medium frequency, resonant AE sensor with a built-in 26 dB pre-amplifier.

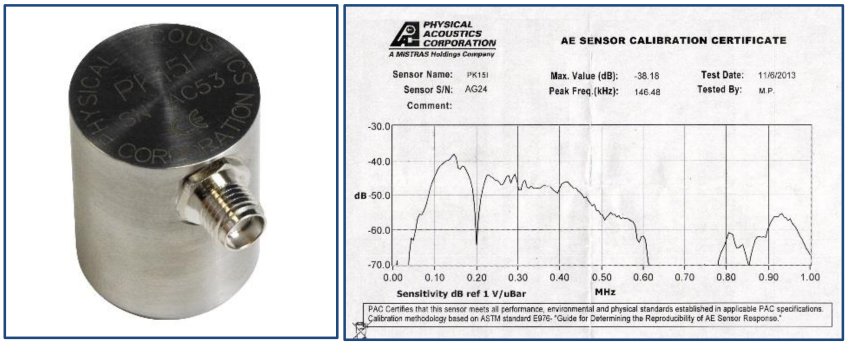


Figure 4: General view of the PK15I AE sensor (left) and a sample calibration chart of the sensor (right).

Sensor Highway II (SHII) data acquisition (DAQ) equipment manufactured by Mistras Group, Inc. was available for this project. SHII is a 16-channel system designed for unattended monitoring of structural health with particular application for highway bridges. This system was fitted with the internet link through the cellular phone provider to allow for remote control of the unit as well as remote download of the AE data (Fig. 5).

Figure 5: General view of the Sensor Highway II equipment.

The Virginia Department of Transportation (VDOT) provided assistance with this research project, including supplying the lifting equipment and support personnel to perform the installation of AE sensors on the bridge structure and to mount the related wiring. The existing defect – a crack – is located at the top end of the girder #8 at the side where this girder is attached to the cross girder #6A/32SB. Overall, 9 PK15I AE transducers were mounted within the area on 2 steel girders (#7 and #8), and on the steel cross girder (#6A/32SB) (Fig. 6 and 7). Locations of the sensors were chosen to monitor the AE activity from the cracked steel member of the bridge. Sensors were mounted using the magnetic attachment as illustrated in Fig. 8.

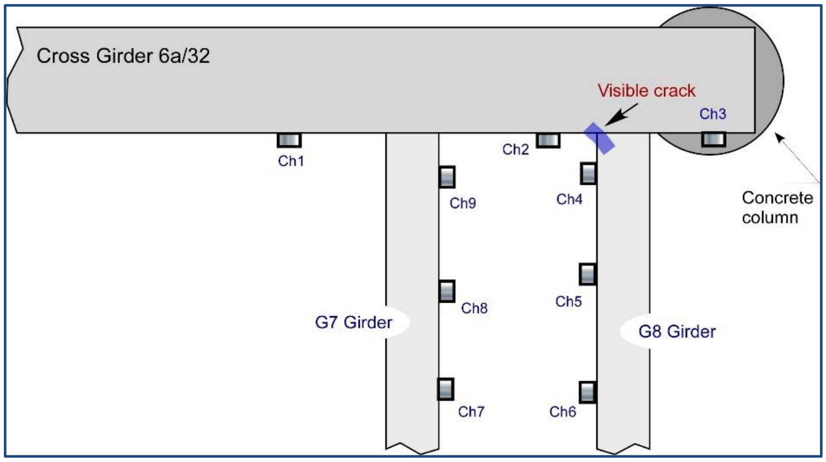


Figure 6: General layout of the AE sensors positions in relation to the crack location.

Figure 7: Crack location on girder #8 of the bridge.

Figure 8: Magnetic attachment of AE sensors.

DISCUSSION OF RESULTS

The AE transducers were mounted at 9 locations within the steel structure and were located such as to effectively collect AE signals from the visible crack at the girder #8 in the vicinity of the cross girder #6A/32SB. Fig. 9 presents details of the sensors location on each of the steel members. Each sensor location is marked with a small red circle, and each sensor number corresponds to the channel number, that is sensor 1 is Ch. 1, sensor 2 is Ch. 2, etc.

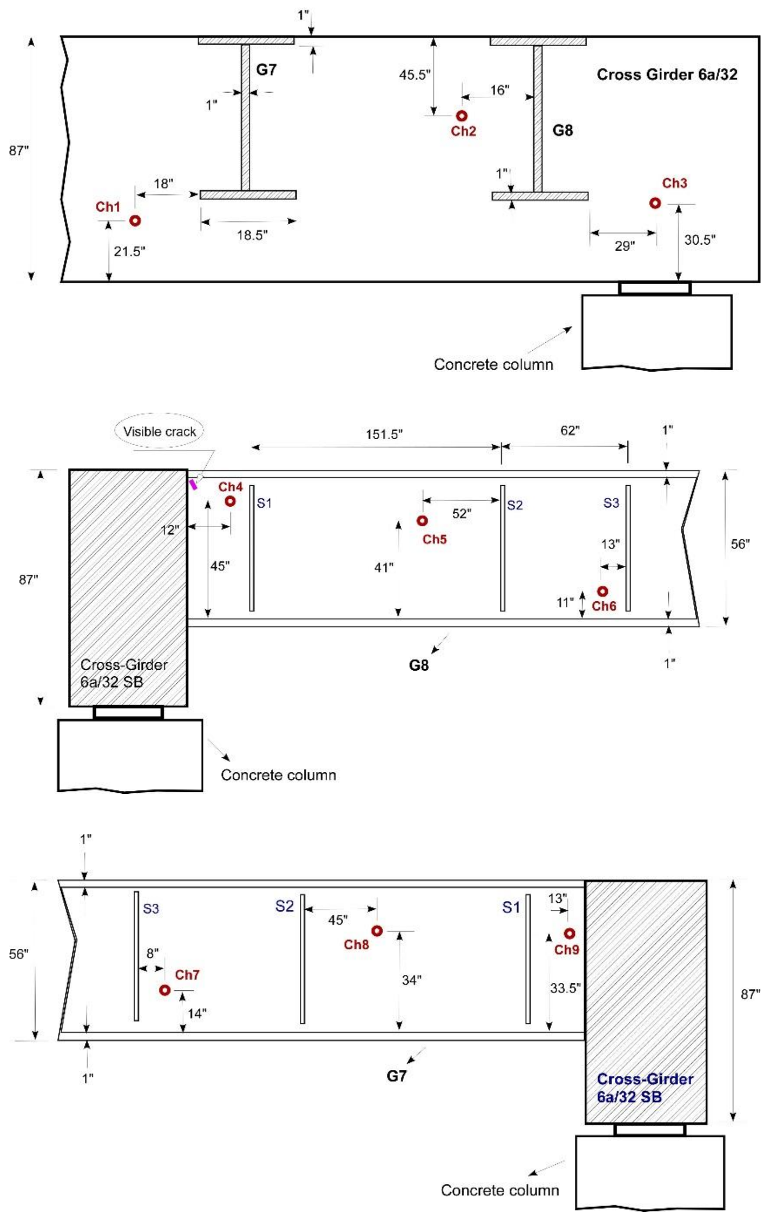


Figure 9: Diagram of sensor positions on cross girder #6A/32SB (top), girder #8 (middle), and girder #7 (bottom).

Overall, the data for this study was collected periodically over a period of about 1 year. On connecting the sensors to the AE instrumentation, it was noticed that the sensor 6 installed on girder #8 (corresponding to the channel 6 of the equipment) was not giving any signal probably due to the defective cable or connection. However, since there were eight other sensors at useful locations in the vicinity of the suspected region to provide sufficient information regarding AE activity at the crack site, it was decided to proceed with the data acquisition.

Fig. 10-17 show the comparison of the AE activity levels captured by each of the 8 sensors. Data acquisition was conducted during the time period from summer 2014 to summer 2015. Graphs presented below show the change (or lack of change) in the AE strength from fall 2014 to summer 2015. All measurements were carried out during similar traffic conditions on average, however, other factors such as ambient temperature and weather conditions differ during the each AE data collection event. The AE hit threshold was set to 60 dB. The strength of AE signal is expected to rise significantly with time when the crack is propagating - that is when the crack is active. However, these test results indicate that over a year period there was no significant rise in the AE activity levels. At times there were some noticeable increases in the AE strength due to the short time traffic impact.

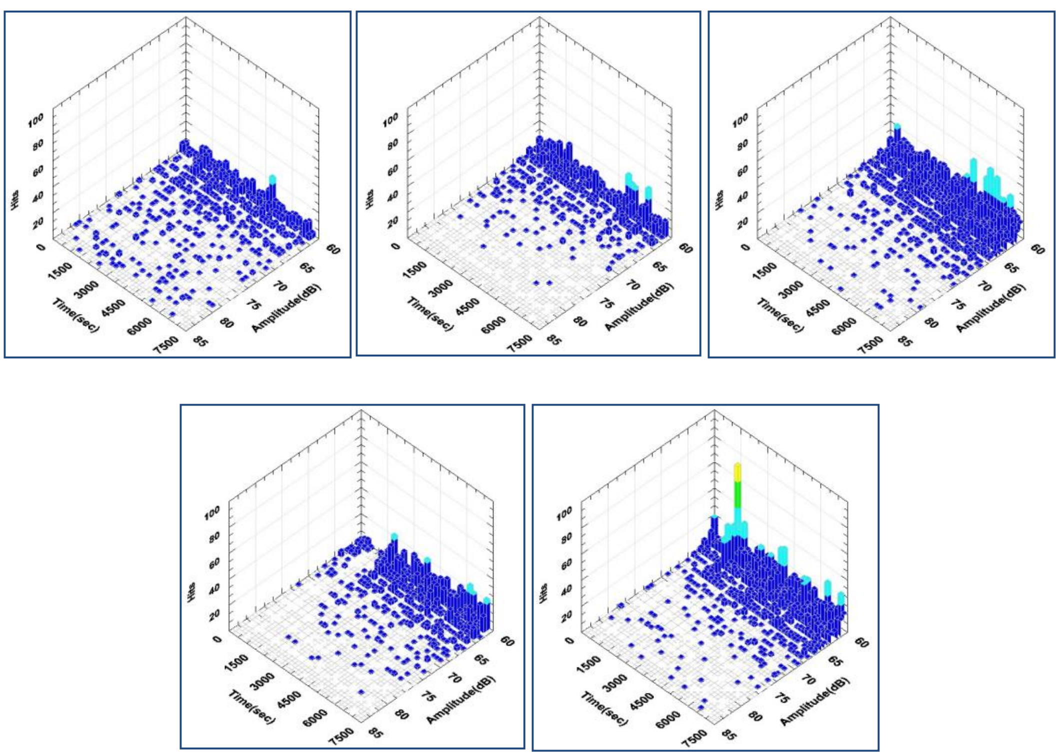


Fig. 10: AE activity observed at sensor 1 location.

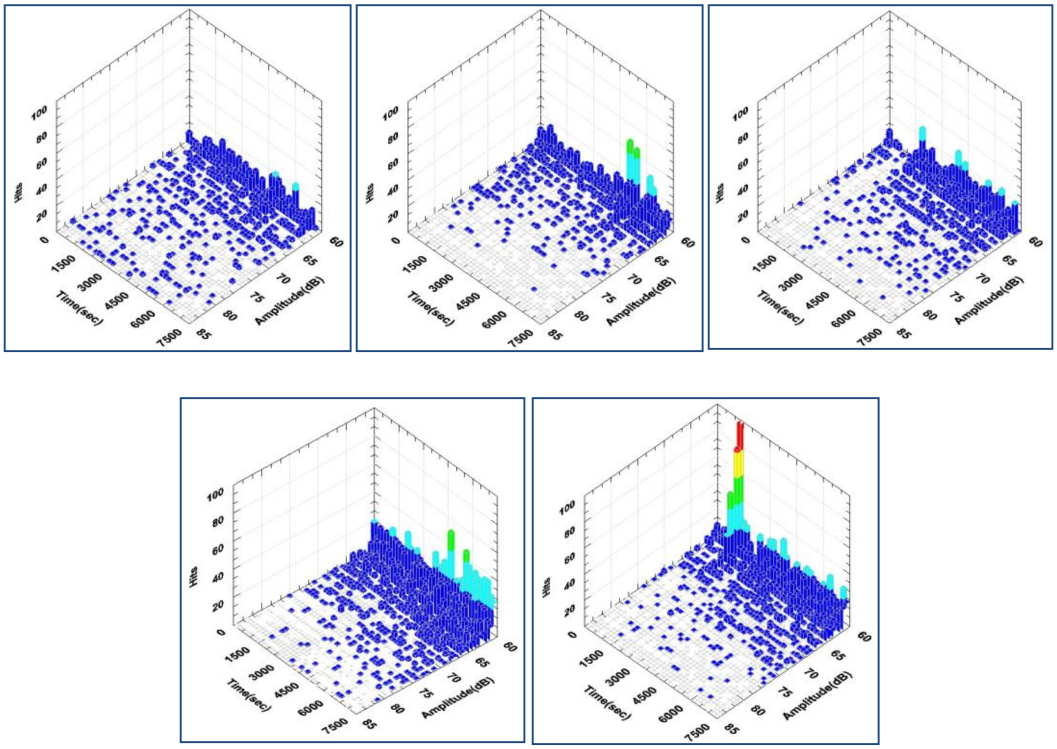


Fig. 11: AE activity observed at sensor 2 location.

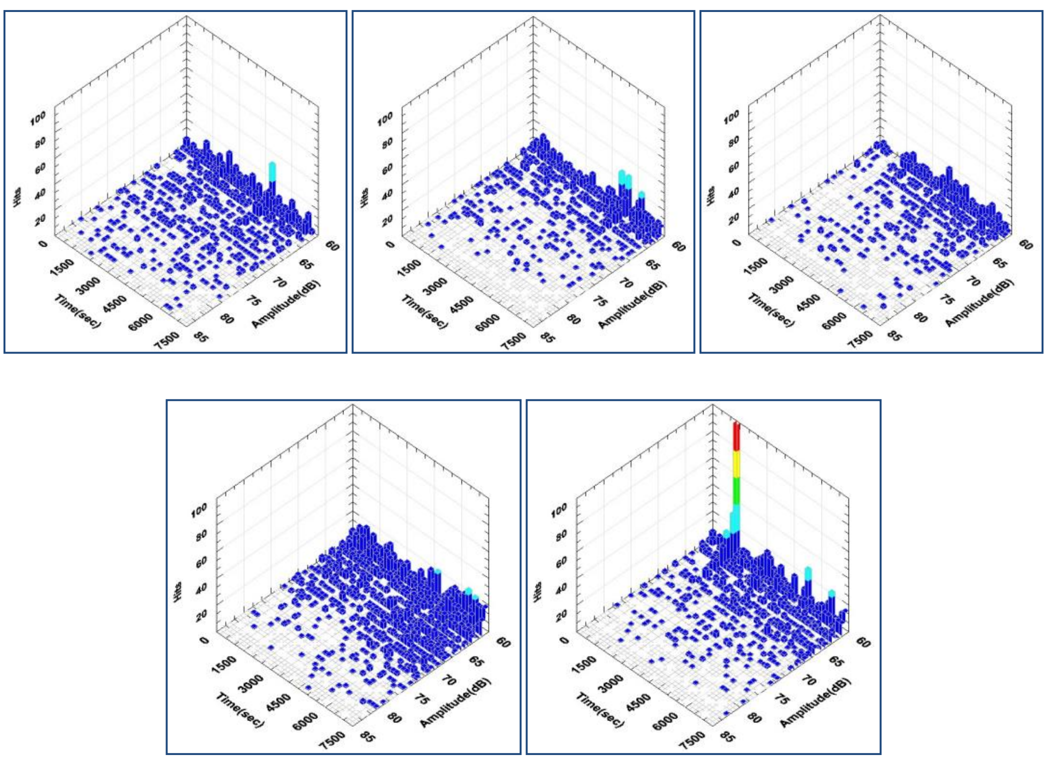


Fig. 12: AE activity observed at sensor 3 location.

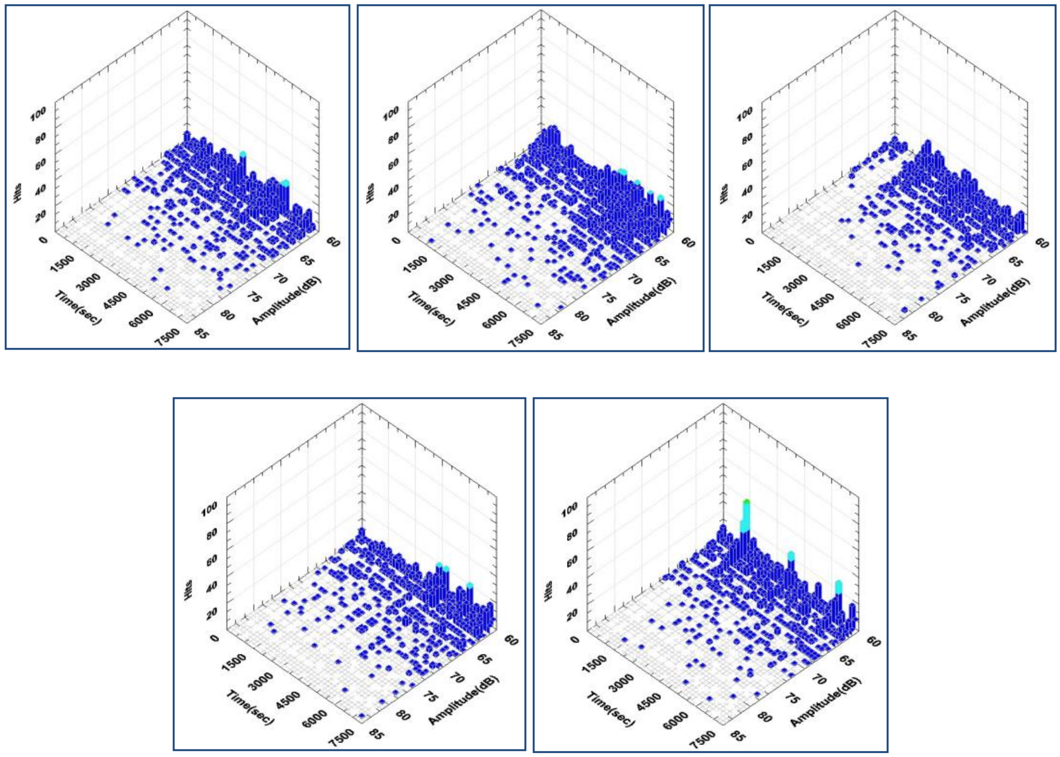


Fig. 13: AE activity observed at sensor 4 location.

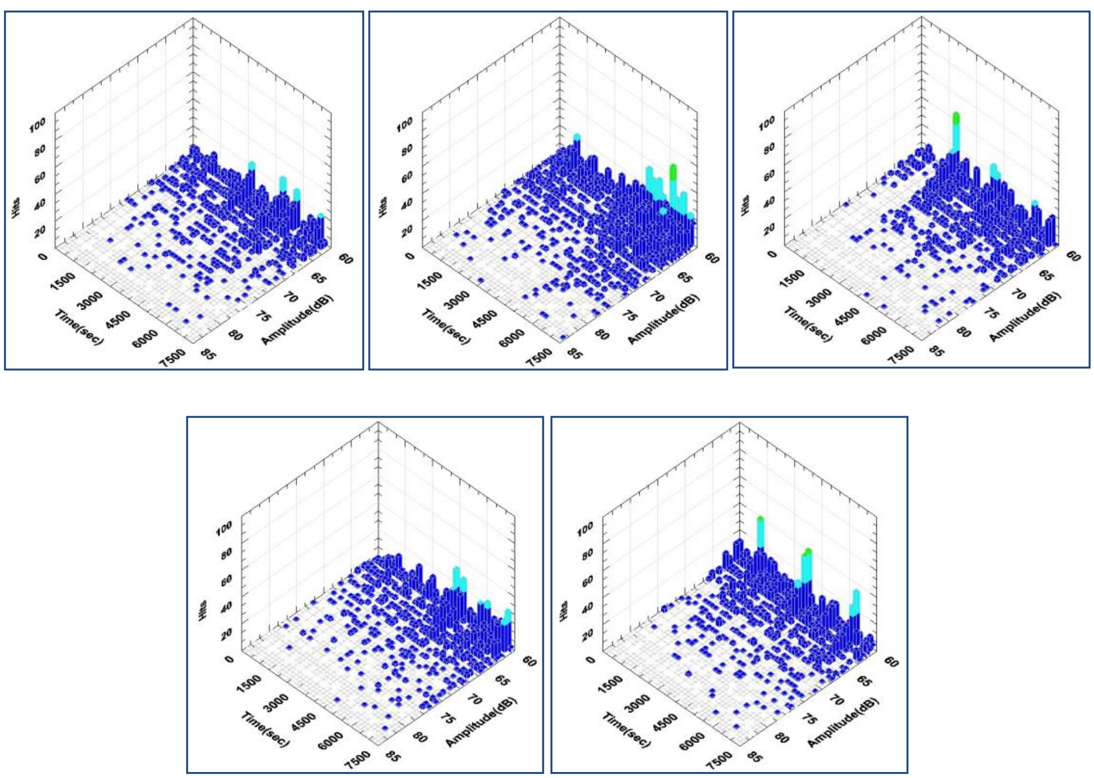


Fig. 14: AE activity observed at sensor 5 location.

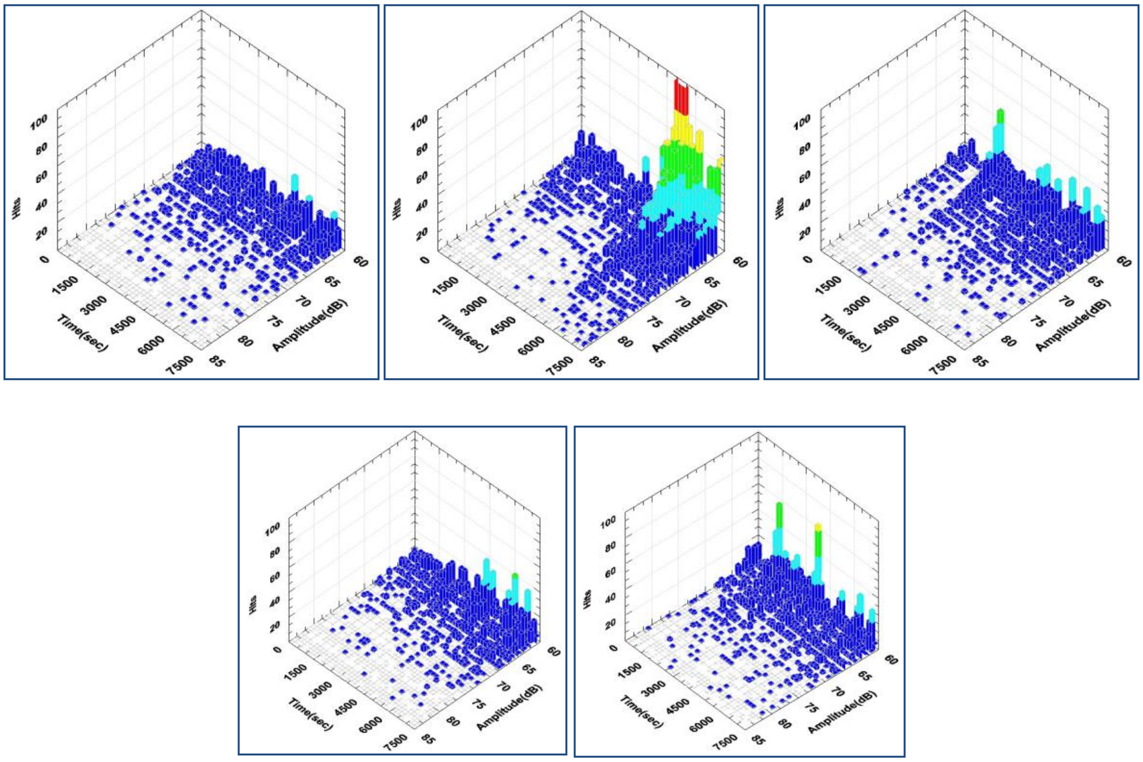


Fig. 15: AE activity observed at sensor 7 location.

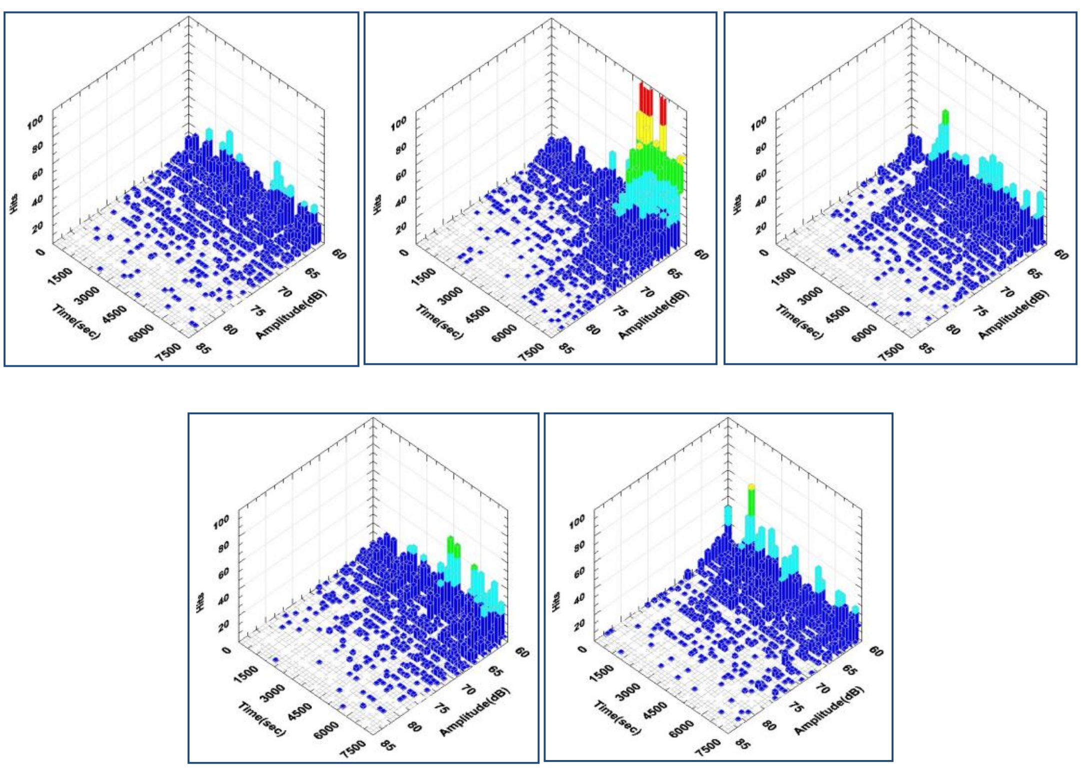


Fig. 16: AE activity observed at sensor 8 location.

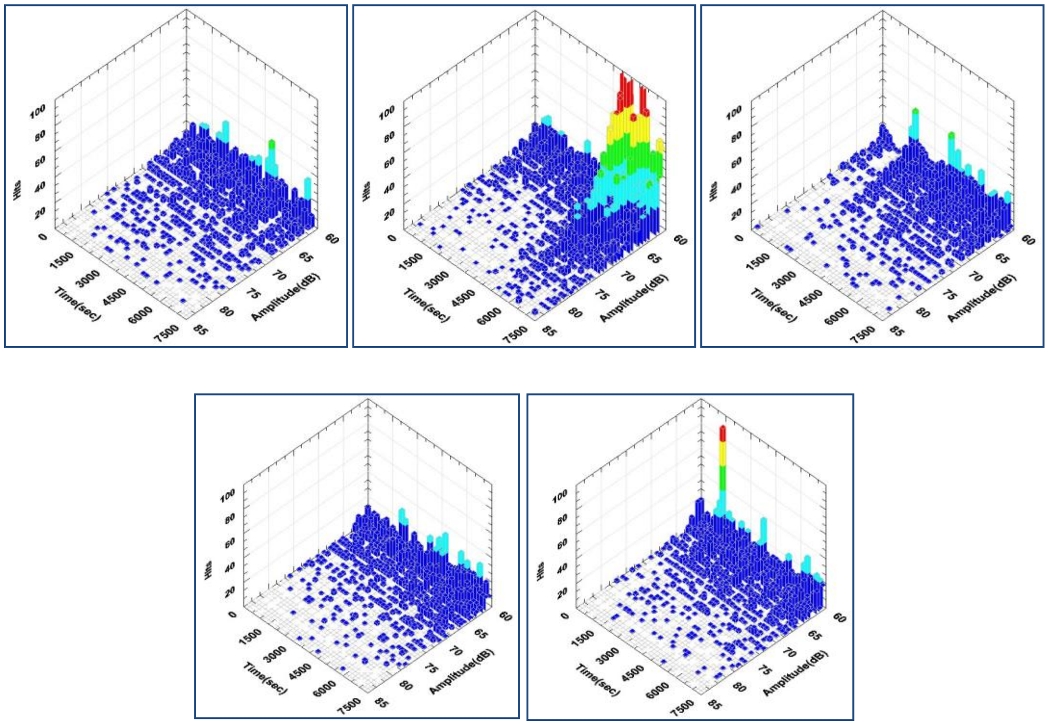


Fig. 17: AE activity observed at sensor 9 location.

Fig. 18 shows AE levels captured from 5 transducers mounted close to the region with the crack. Transducers close to the active crack will receive stronger AE signals compared to the other sensors; sensor 4 is mounted very close the crack, followed by sensors 2, 5, 3, and 1. What Fig. 18 reveals is that at times when strong acoustic emission is encountered due to the traffic condition, that strong acoustic emission is realized in sensors 1, 2, and 3, but not in sensors 4 and 5. Since the cross girder #6A/32SB with sensors 1, 2, and 3 mounted on it supports critical bridge structure, it happens to encounter severe load impacts and as a result strong AE signals, which are subsequently captured by sensors 1, 2, and 3. This in turn suggests that the monitored crack is not active at this time.

The AEwin software by Mistras Group, Inc. was utilized for all acquisition, graphing, and analysis studies. Two-dimensional source location analysis results for the cross girder #6A/32SB are shown in Fig. 19. These results were obtained for similar time intervals as those in Fig. 10-17. The AE hit threshold was set to 55 dB. These graphs show that the determined AE sources are scattered relatively uniformly throughout the region, with no particular location producing significant number of events. Therefore this also suggests that there are no active AE sources within the area of the crack location and one can deduce that the crack is not actively propagating - that is the crack tip is not active at all.

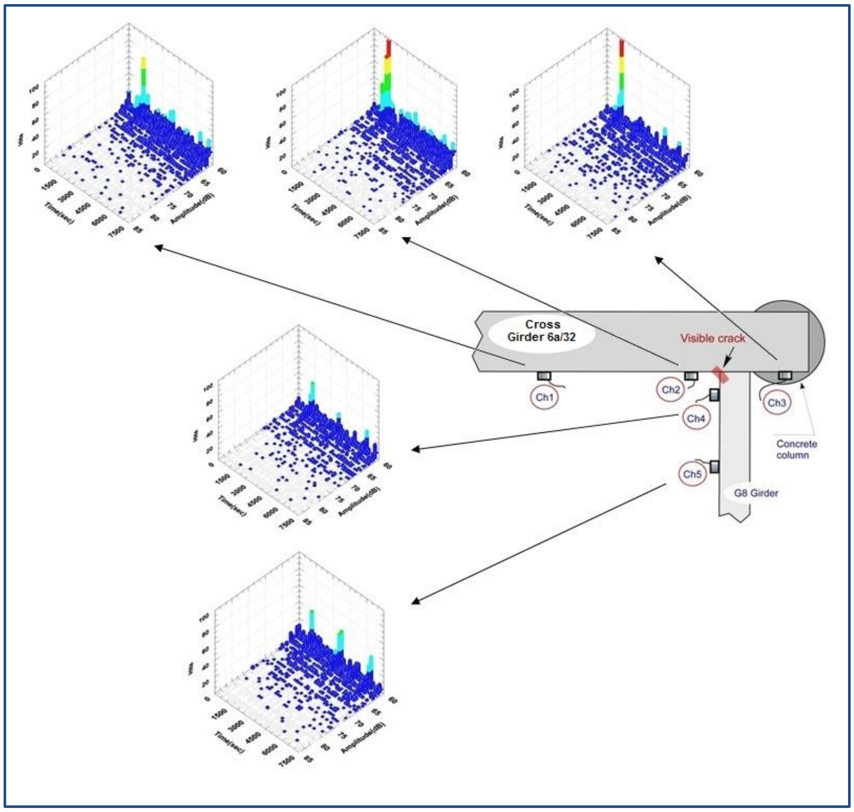
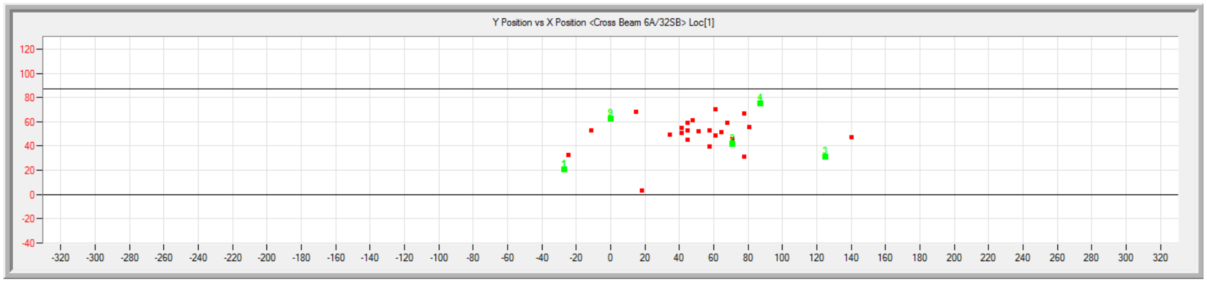


Fig. 18: AE monitoring results in the vicinity of the crack.



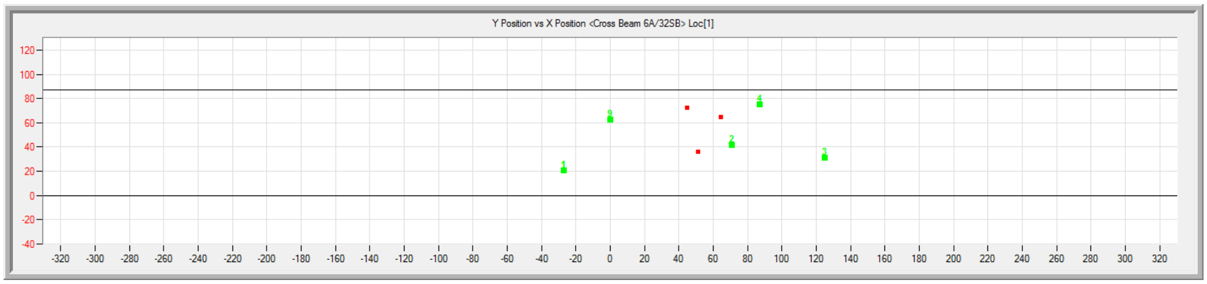


Fig. 19: 2D source location analysis results in cross girder #6A/32SB using the AEwin software.

CONCLUSIONS

The analysis of AE activity in the affected location of the bridge structure did not show any signs of an active crack propagation. The level of AE activity measured corresponds to the normal AE activity which can be present in critical bridge structures and this also coincides with the results of periodical visual inspections conducted by VDOT personnel which conclude that the crack appears to be inactive. It is sometimes difficult to determine whether the crack actively propagates or stays arrested only by visual inspections and the AE technique can help to determine whether such cracks are active or not. AE should be considered as a regular maintenance measure for economical early detection of possible structural failures. In this case, the AE technique confirmed the crack status as being inactive, while in the previous research by the authors the same technique was able to confirm an actively growing defect within the steel girder structure.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AE	Acoustic Emission
AEwin	Software for AE data acquisition and analysis
Ch	Channel
DAQ	Data Acquisition
dB	Decibel
HU	Hampton University
in	Inch
kHz	Kilohertz
NDT	Non-Destructive Testing
NCITEC	National Center for Intermodal Transportation for Economic Competitiveness
SHII	Sensor Highway II
VCTIR	Virginia Center for Transportation Innovation and Research
VDOT	Virginia Department of Transportation

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