FINAL REPORT

Intermodal Transportation Infrastructure Interactions: Utilizing Acoustic Emission and other Non-Destructive Evaluation Technologies

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ABSTRACT

This project studied application of acoustic emission (AE) technology to perform structural health monitoring of highway bridges. 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.

A candidate structure – a steel girder bridge crossing of the Interstate I-64 over the Route 165 Kempsville Road in Norfolk, VA, was selected for this study. This bridge has a known, visually identified defect on girder 9 – crack in the stiffener-to-girder connection weld. Therefore this work concentrated on the AE analysis of girder 9 of this bridge and girder 8 of this structure was taken up for comparison. AE activity was found to be occurring in both girders 8 and 9 of the steel girder bridge selected for this study. There was weak AE activity reported in girder 8 and this activity exhibited no increase during the period of this research. On the other hand, girder 9 of this bridge was found to be experiencing significantly stronger levels of AE activity which noticeably increased during the same period. The majority of the girder 9 AE activity sources were determined to be located in the vicinity of sensors 3, 4, and 5, which is where the visually identified crack exists on the girder. It was confirmed that the AE technique is capable of revealing material defects in steel girder bridges and is suitable for conducting long-term monitoring of structural safety to reduce and prioritize maintenance efforts.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

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.

The use of acoustic emission (AE) non-destructive testing (NDT) technology to monitor the structural condition of highway bridges can reduce maintenance expenses by reducing frequency of inspections and can provide other benefits such as quantifying structural damage and predicting bridge service life. The AE technology is based on the fact that failures in the structure redistribute internal mechanical stress which results in the formation of elastic waves which can be detected in real time. This makes AE advantageous over other NDT methods. Rapid release of energy from localized sources such as stress cracking, shear cracking, bond failure and corrosion within a concrete or metal structure generates transient stress waves resulting in AE. If the source location is inside the body of the structure, the generated elastic stress waves travel through the body of the structure to the surface and become surface waves. These surface waves are detected by the piezoelectric devices, called AE sensors (transducers), attached to the surface. By measuring signal parameters such as counts, amplitude, duration, rise time, and energy count, a great deal of quantitative information on the magnitude of defects, their location, time of origination, and rate of the propagation, can be obtained.

For the purpose of this study, a highway bridge that carries west-bound lanes of the Interstate I-64 over the Route 165 Kempsville Road in Norfolk, VA, has been suggested by the Virginia Department of Transportation (VDOT). This study used the AE approach to evaluate the condition of steel girders of this bridge with respect to the defects already present in the structure of this bridge, aiming to confirm the benefits of the AE technique.

OBJECTIVE

The main goal of this work was to conduct research on enhancing the highway bridge safety by predicting and thus preventing bridge failures by utilizing the acoustic emission (AE) technology of non-destructive testing (NDT). The selected bridge crossing (west-bound lanes of the Interstate I-64 over the Route 165 Kempsville Road in Norfolk, VA) has VA Structure No. 2832, Federal Structure ID 0020864. This bridge uses steel girders with stiffeners and cross-frames as superstructure and the supporting piers are constructed of rectangular reinforced concrete columns as seen in Fig. 1 below. The objective of this study was to evaluate the application of the AE approach on steel girder bridges, to conduct short-term monitoring of such structures, and to assess the AE footprint of the structural defects that exist in this particular structure.

Figure 1: General view of the bridge site.

SCOPE

The scope of the study was limited to identifying AE attributed to girders 8 and 9 (presented as beams 8 and 9 in the diagram below) in the middle span (span 2) of the selected bridge and locating the sources of such AE. Two AE systems were used in the study – the 16-channel Sensor Highway II system and the 4-channel 1284 Wireless AE system, both manufactured by the Mistras Group, Inc. Monitoring was performed during both high and low traffic conditions.

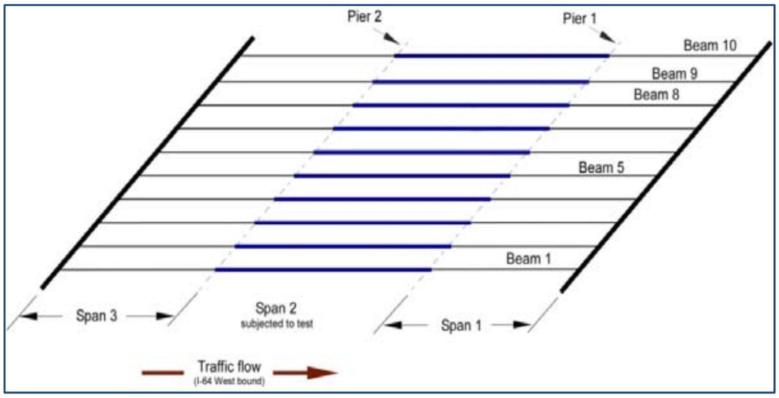


Figure 2: General layout and view of the bridge steel girder structure.

METHODOLOGY

Prior to selection of the bridge, HU research team in collaboration with the Virginia Department of Transportation (VDOT) and the Virginia Center for Transportation Innovation and Research (VCTIR) personnel identified several sites as possible candidates for this research. Field inspections were conducted to assess potential of installation of the AE sensing equipment. Due to the interest exhibited by the VDOT/VCTIR personnel and due to the relative ease of access, installation, and maintenance of the AE equipment, it was decided to proceed with the work at the Interstate I-64 Route 165 Kempsville Road bridge site in Norfolk, VA.

Girder 9 of this bridge had a visually identified defect (crack) at the stiffener-to-girder weld (Fig. 3). Girder 8 did not have any visually identified deficiencies.

Figure 3: Existing crack in the stiffener-to-girder connection weld on girder 9.

Testing and calibration of the 16-channel Sensor Highway II AE data acquisition (DAQ) system used in this study were conducted at the HU Dept. of Engineering NDT laboratory. Updated version of the AEwin DAQ software purchased from Mistras Group, Inc. was installed and the remote access link purchased from Verizon was also tested. Sensor Highway II equipment was operated on site using the battery due to the lack of suitable power source at the bridge. This system allowed short-term (time frame - several hours) monitoring capability (Fig. 4). A second DAQ system – 4-channel 1284 Wireless AE system was used to perform long-term (time frame - several days) measurements.

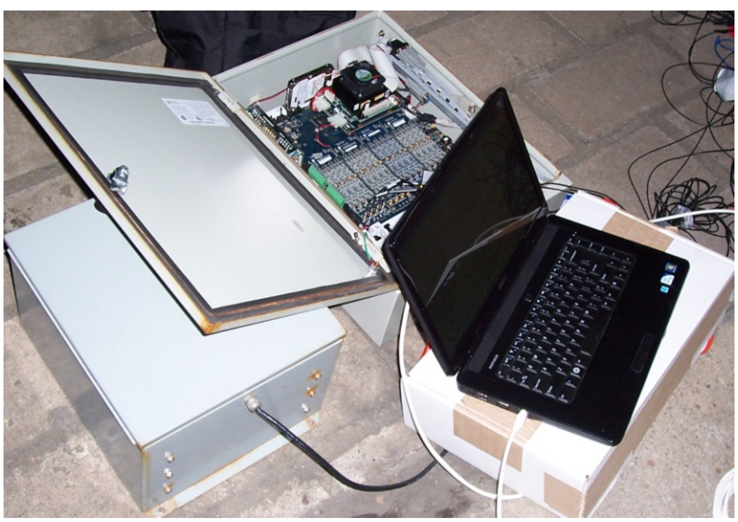


Figure 4: Sensor Highway II unit on site with the battery power source.

VDOT provided assistance with access and traffic control and also provided platform truck with required crew to perform installation of the AE sensors on girders 8 and 9. R15I-LP-AST 150 kHz sensors with built-in preamplifiers were used in this study. Initially, 1 sensor was installed in the middle part of girder 8 and 2 sensors were installed on girder 9 to the left and to the right of the crack at different distances. Acrylic adhesive was used to attach sensors and a dedicated cable connected each sensor with the main unit. Cables were routed along the girders and down the concrete pier to the area of limited access (fenced area) where the main unit was located. After conducting preliminary AE measurements and data analysis, additional sensors were mounted on girder 9. There were 2 new sensors mounted at approximately the same height as the original 2 sensors, but at greater distances from the crack. Later yet, 3 more sensors were attached at various heights along the same girder. Overall, there were 7 transducers mounted on girder 9. Fig. 5 below shows their locations. The overall height of the girder is 45 in.

Sensor	AE Channel	Direction (from crack)	Distance, in (from crack)	Height, in (from bottom of girder)
1	5	left	105	31
2	1	left	71	approx. 5
3	6	left	42	36
4	2	left	8	approx. 5
5	3	right	12	approx. 5
6	7	right	126	30
7	4	right	495	approx. 5

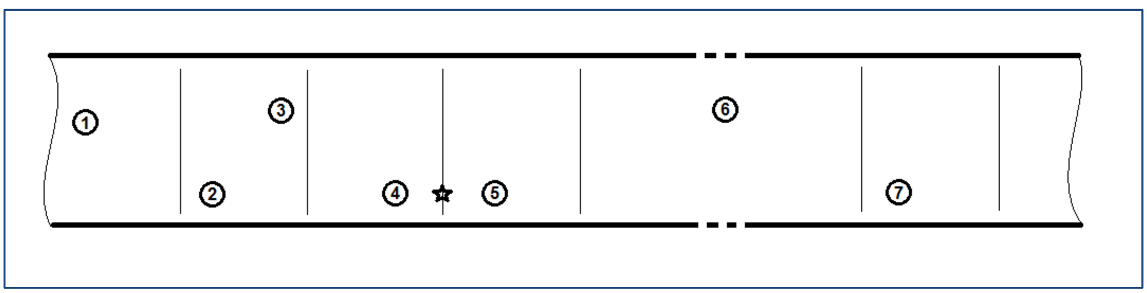


Figure 5: Diagram of sensors locations on girder 9 (not to scale). The crack location is marked with star.

Figure 6: Installation of AE transducers on the bridge structure.

Figure 7: Typical views of AE sensors attached to the girder.

DISCUSSION OF RESULTS

AE data for this study was obtained at certain intervals for a period of approximately 1 year. This included different periods of traffic activity (high traffic and low traffic conditions) as well as short-term and long-term measurements. AE DAQ units (both Sensor Highway II and the 1284 Wireless AE unit) were placed in a safe and secure area and measurements were performed. Our initial effort was to identify whether a girder had any active defects. This would be deduced from the AE activity measurements carried out over a period of several months. Girder 9 exhibited considerable increasing rates of AE activity on the signals measured over a period of three months, while girder 8 did not. The three-dimensional diagram below (Fig. 8) shows the time vs. amplitude in the X-Y plane and the number of AE hits/second on the Z-axis for girder 8. Fig. 9 shows the same measurements at the same times for girder 9.

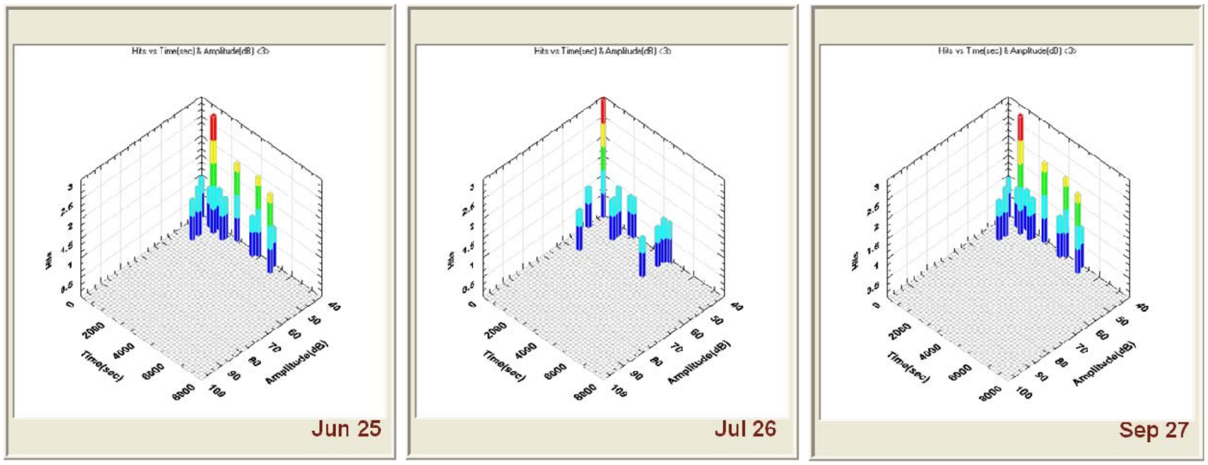


Figure 8: AE activity in girder 8 (single AE sensor).

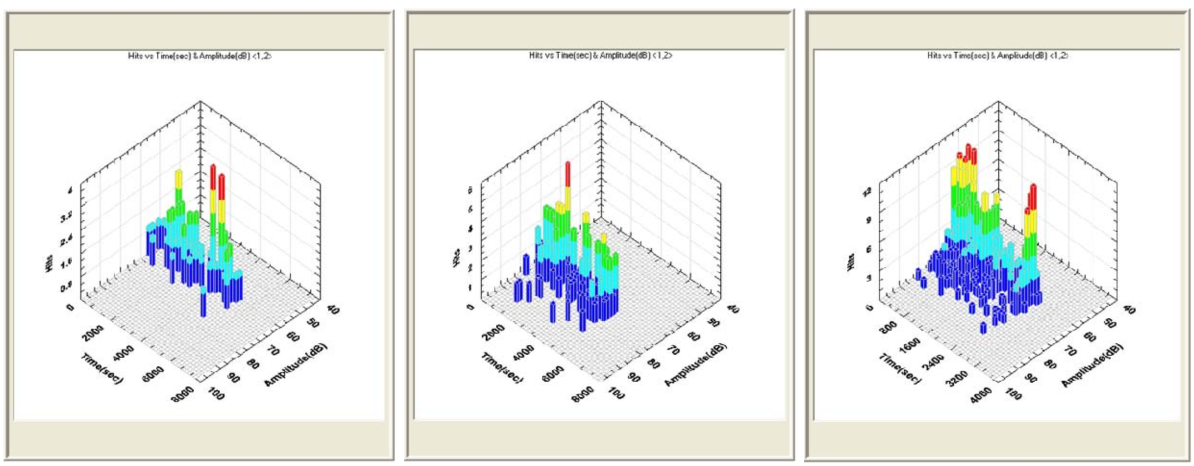


Figure 9: AE activity in girder 9 (two AE sensors).

The amplitude and AE activity in girder 8 appear to be low, which indicates there are probably no active cracks exist in this beam. On the other hand, the AE activity found in girder 9 were much stronger and the amplitude and scale of the AE activity appear to be increasing during the successive periods of measurements. Therefore, there is a strong evidence to suspect that an active crack or other defect exists in this beam and results in such strong AE. These measurements were taken during the high traffic conditions on work days around 11:00 am for periods of about 1 hour 30 min. Beam 9 had 2 AE sensors installed at this point (sensors 4 and 5 in Fig. 5 above).

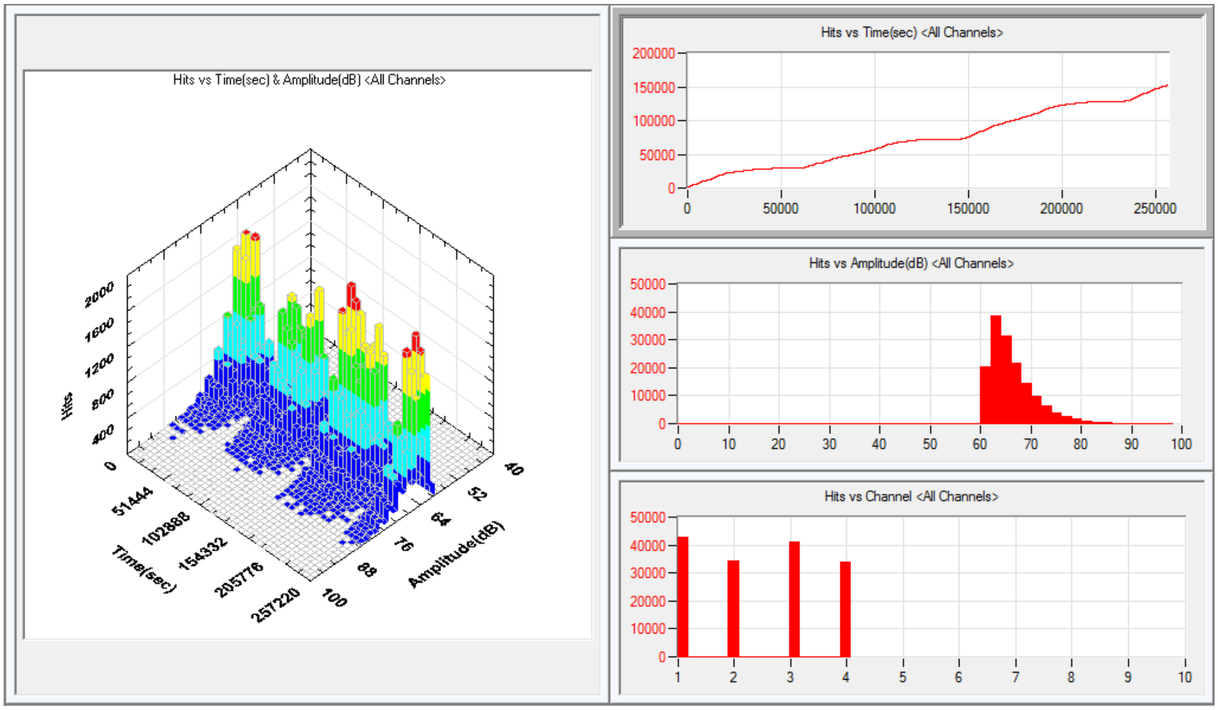
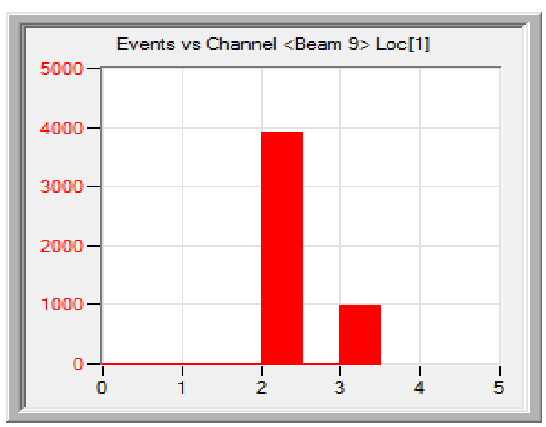


Figure 10: Long-term measurement of AE activity on girder 9 (4 AE sensors).

Two additional transducers of the same type (R15I-LP-AST 150 kHz) were then installed on girder 9. Fig. 10 shows the result of the long-term measurement conducted over a period of almost 3 full days (2 days 23 hours 27 min) covering high and low traffic conditions and it clearly indicates the presence of strong AE activity in this beam.

The analysis to estimate the location of the source of the AE activity was also conducted using the AE signals time stamps. Using the speed of sound in a given material, an estimate can be made as to the AE source location. Linear as well as two-dimensional location analyses were performed.



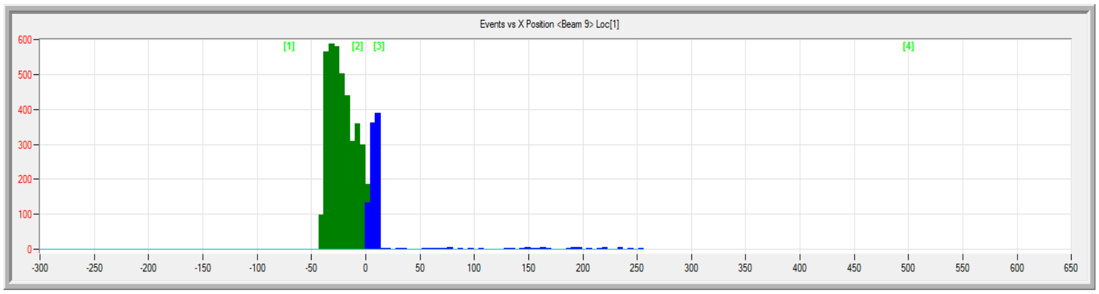


Figure 11: Linear location analysis of the AE activity on girder 9 using data from 4 transducers – Events vs. Channels (top) and Events vs. X-Position (bottom). Events were determined to be attributed to sensors 4 and 5.

The linear location analysis presented in Fig. 11 shows that the majority of the AE activity originated in the regions between sensors 2 and 4 and sensors 4 and 5. The existing defect on this girder (visually identified crack) is located between sensors 4 and 5. Subsequent two-dimensional location analysis of the data (Fig. 12 below) also confirmed intensive AE activity source at this location.

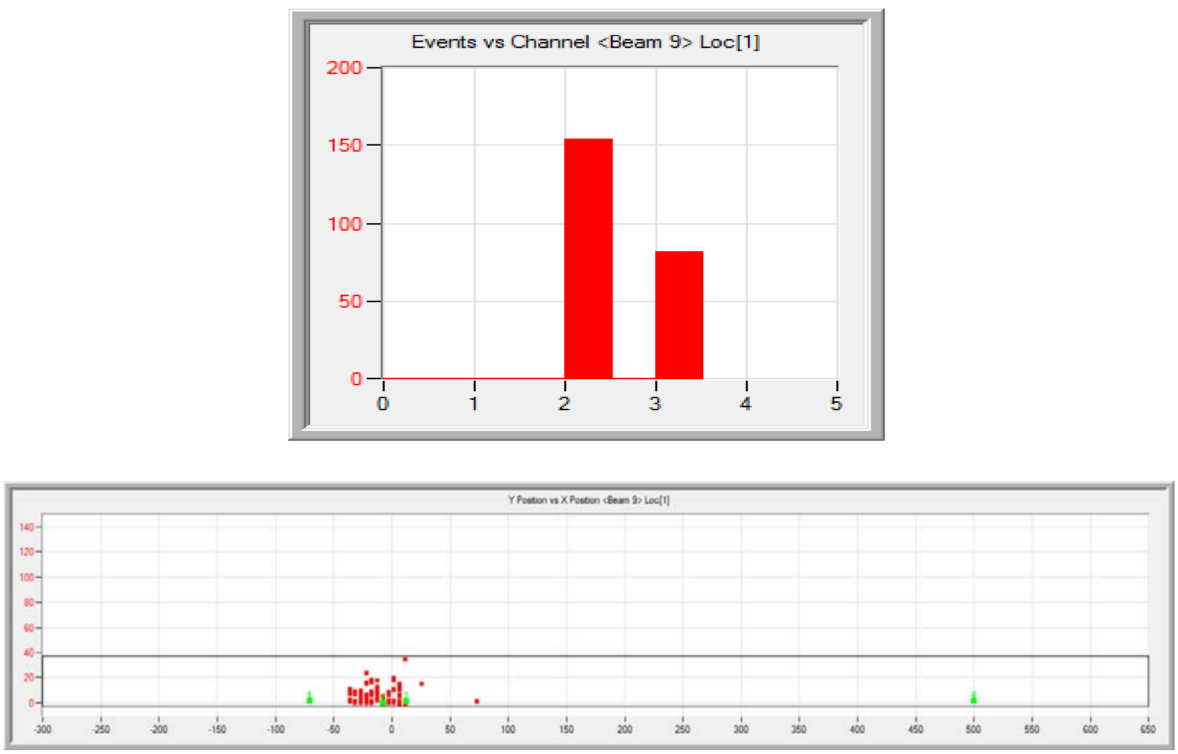
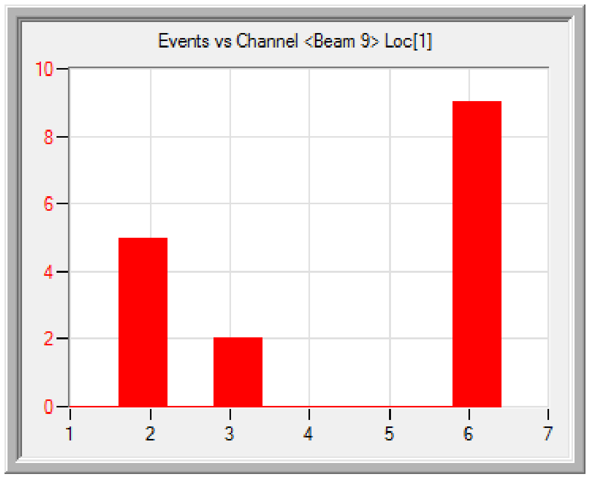


Figure 12: Two-dimensional location analysis of the AE activity on girder 9 using data from 4 transducers – Events vs. Channels (top) and Y-Position vs. X-Position (bottom). Events were confirmed to be attributed to sensors 4 and 5.

The results of the two-dimensional location analysis using all 7 AE sensors are presented in Fig. 13. This data was obtained during the work day high traffic condition around 11:00 am for the duration of 1 hour 20 min. This short-term data did not produce as many AE source locations as previously, but nevertheless it confirmed strong AE hits in the area between sensors 2 and 5.



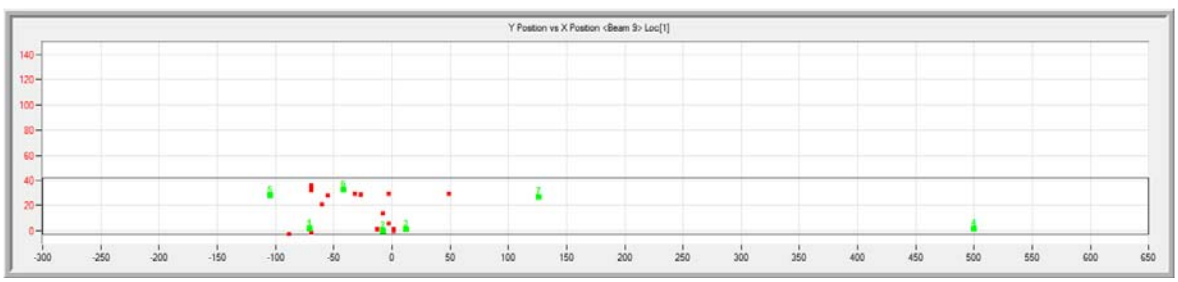


Figure 13: Two-dimensional location analysis of the AE activity on girder 9 using data from 7 transducers – Events vs. Channels (top) and Y-Position vs. X-Position (bottom). This analysis attributed events to sensors 3, 4, and 5.

CONCLUSIONS

AE activity was found to be occurring in both girders 8 and 9 of the steel girder bridge selected for this study. However, girder 8 of this bridge did not show any indication of the presence of an active crack, as the AE activity did not show any progressive and significant increase during the period the signals were monitored. A visual examination also did not show any signs of deterioration in the steel structure. On the other hand, girder 9 of this bridge was found to be experiencing significantly stronger levels of AE activity which also exhibited consistent increase in intensity during the same period. The majority of the girder 9 AE activity sources were determined to be located in the vicinity of sensors 3, 4, and 5 where the visually identified crack exists on this girder. It is very difficult to ascertain whether the crack actually propagates or stays arrested only by visual examination and the AE measurements help to determine whether such cracks are active or not. It was confirmed that the AE technique is capable of revealing material defects in steel girder bridges and is suitable for conducting continuous long-term monitoring of structure safety in order to reduce and prioritize maintenance efforts.

RECOMMENDATIONS

VDOT is currently paying more attention to this suspected location. Dye penetrant tests were carried out to check for the presence of hairline cracks. It is recommended to carry out long-term AE monitoring using the entire length of the girder 9 to determine further levels of AE activity related to growth of the existing known defects as well as to determine other possible defects in this girder that might have contributed to the higher level of AE activity in this structure. AE monitoring should be considered as a regular measure for evaluation of highway bridge health and safety and should be conducted on a larger number of bridges, with the structures that exhibit more AE activity being afforded inspection priority as compared to other structures.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AE	Acoustic Emission
DAQ	Data Acquisition
HU	Hampton University
NDT	Non-Destructive Testing
VCTIR	Virginia Center for Transportation Innovation and Research
VDOT	Virginia Department of Transportation

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