TECHNOLOGY DIGEST

Using Acoustic Emission to Monitor Fatigue Cracks on the Bridge at FAST

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Summary

Fatigue cracks monitored during 1999 and 2000 on the bridge at the Facility for Accelerated Service Testing using the acoustic emission (AE) technique will provide information to assist bridge engineers in prioritizing repairs and, in many cases, extending the life of steel railroad bridges. Results from using this technique to date demonstrate that:

- The AE technique can be used to identify active fatigue cracks and to monitor their growth under heavy axle loads in steel bridges.
- On the bridge at FAST, a vertical crack at the flange (Exhibit 1) became dormant, whereas a crack at one of the welds (Exhibit 1) remained active in both directions. The growth at the right-hand side of the crack was much greater than at the left-hand side.
- Crack growth over car cycles (time) was not constant, exhibiting a step-wise behavior with faster growth followed by periods of slow growth.
- Monitoring of the cracks over longer periods of time is necessary in order to determine the overall rate of crack growth and to possibly relate this growth to the urgency of needed maintenance on a bridge structure.
- It is feasible to create a system for remote monitoring whereby crack growth data may be collected in real time from a location anywhere in the U.S.

Transportation Technology Center, Inc. (TTCI) and Dunegan Engineering Consultants Inc. (DECI) collaborated their efforts to monitor the fatigue cracks. The objective of this work was to develop a method of determining the presence of fatigue cracks and their growth behavior in steel bridge components.

*Dunegan Engineering Consultants Inc.

Suggested Distribution:
☐ Maintenance of Way
☐ Bridge & Structure
☐ Track Maintenance
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INTRODUCTION

For the past few years, TTCI has been investigating the effectiveness of different, nondestructive techniques for use in the inspection of railroad bridges. Acoustic emission (AE) is one such technique that measures the stress waves generated at the tip of a fatigue crack as the crack propagates. Monitoring of these waves under the passage of trains can indicate the degree of activity of a crack present in a bridge component.

During 1998, TTCI conducted laboratory tests on specimens made from removed railroad bridge spans. The tests showed a strong positive correlation between the growth rate of the cracks and the degree of acoustic activity.[1] This also showed that AE could be an effective method for detecting the presence of fatigue cracks in critical bridge members and for determining the relative activity of these cracks. However, one important issue with the AE technique is the separation of crack signals from the noise generated by train operation.

Demonstrations conducted by TTCI and Dunegan Engineering Consultants Inc.(DECI) on the bridge at FAST in November 1999 and June 2000 demonstrated that this problem could be successfully overcome with the use of new 10-channel AESMART 2000™ equipment. This equipment utilizes modal analysis of the acoustic emission signals to separate crack-growth related signals from extraneous noise by setting adequate high to low frequency ratios.

The equipment and software used have been undergoing continuous enhancements, and the system can now monitor a number of cracks and automatically record data while a train is over the bridge.

Data collected from May 2001 and June 2001 is primarily free from extraneous noise and represents a valid interpretation of crack growth in the monitored area.

BACKGROUND

For large complex structures such as bridges, AE detection and analysis of crack growth is continuously monitored during normal service. The loading cycle depends on the characteristics of the train and the bridge. The AE count is affected by the geometry of the member being investigated. The extraneous noise from train operation is significant and needs to be separated from the AE signals for proper analysis of crack-growth rate and its severity.

FAST BRIDGE

The bridge at FAST consists of two open-deck, all-welded steel deck plate girder spans. A few weeks after the installation of these spans in November 1997, the first fatigue crack was found.[3] Now at over 490 MGT of traffic, there are several cracks in both spans of the bridge. The bridge at FAST is well protected against any mishap by cribs built beneath it and by an alarm system that would trigger should the deflection of the long span exceed a set amount.

The crack under intermediate stiffener 1 of girder 1 of span 2 (55 ft.6 in. long) and the crack near intermediate stiffener 6 of girder 1 of span 1 (65 ft. long), Exhibit 1, were selected for AE monitoring because they were the most active during the preliminary tests. Other NDE techniques have indicated that the first crack has run into the flange of the girder. The second crack is in both the weld and web and is growing at both ends. These cracks are referred to here as the "flange crack" and the "weld crack," respectively.

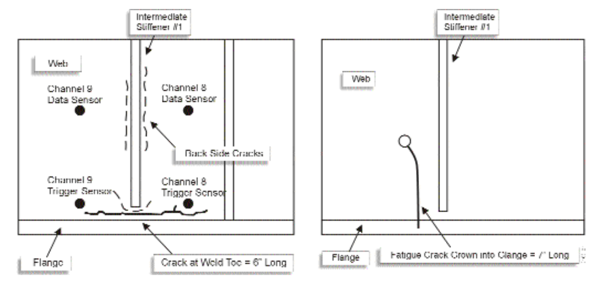

Exhibit 1. Location of Fatigue Cracks Monitored

TEST PROCEDURE

Monitoring beginning in October 2000 involved a 68-car FAST train operating at 40 mph. Each car weighed approximately 315,000 pounds. The AE response at 40 mph was dramatically different than that observed at slower speeds. The higher speed resulted in a significant increase in the signal density in both the high and low frequency ranges used for recording the AE data.

Data transducers and strain gages were installed at the weld crack and flange crack locations. In addition, a string potentiometer was installed under the flange crack location. This string potentiometer provided the number of cycles of displacement data that was correlated with the AE data from the flange crack. It also provided an indication of train presence over the bridge for the start and pause of data collection.

Each crack location had a "trigger" sensor located near the crack tip, and a "data" sensor located 10 inches from the trigger sensor. Each sensor collects both high and low frequency signals by using piezo-electric crystals. The purpose of using a trigger sensor in conjunction with a data sensor is to isolate a small area around the crack tip from which to collect AE signals. Transducers, strain gages, and a string potentiometer were connected to AE equipment as necessary to provide the parametric inputs for recording data during different test runs. The system was on continuously, but the instrumentation was set up such that data was recorded only when the train was present on the bridge. Exhibit 2 shows the instrumentation at both crack locations, and Exhibit 3 shows the AE equipment in use.

CRACK GROWTH BEHAVIOR

When a crack propagates in a plate-like material, it emits two primary waves: (1) an extensional wave with particle motion parallel to the plate dimensions, and (2) a shear wave having both Sv and Sh polarization. A third type of wave is created by the interaction of the Sv shear wave and the plate boundaries. This wave is a dispersive flexure wave and has much lower frequency components than the extensional and shear waves. The magnitude of this wave is dependent on the depth in the plate where crack growth occurs.

For conditions where the crack growth occurs at exactly mid point in depth in the plate, no flexure wave component is created. The flexure wave component due to crack growth is much smaller in magnitude than that produced by out-of-plane sources such as impact and friction.

For situations where the wavelength of the AE signal is small compared to the thickness of the plate, another type of wave called a surface wave is created. Each of these waves travels at different velocities throughout the steel plate. One of the primary characteristics of a crack-growth signal is the ratio of the high frequency components (extensional and shear waves) divided by the low frequency flexure wave component and designated by HF/LF ratio. Actual crack-growth signals will exhibit a high value for this ratio while noise signals will generally have lower values.

TEST RESULTS

During 2001 monitoring, no AE activity was measured at the flange crack indicating that after propagating into the thick flange, this crack had become dormant. On the other hand, the weld crack showed a lot of AE activity and grew in both directions.

Exhibits 4 and 5 show the summation of counts as a function of cycles from the transducers placed on the left- and the right-hand side of the weld crack, respectively. The crack appears to be much more active on the right-hand side than the left-hand side as evidenced by a higher density of signals and a higher number of counts per cycle. This correlates with growth measured by visual inspection. It should be noted that the growth of the crack tips as determined by visual inspection were not linear as indicated in the exhibits but grew in a stepwise manner. The AE data collected does not always correlate with an increase in crack length because a crack may be growing in depth instead of length. The stepwise nature of the AE data from the bridge is believed to be due to formation of a plastic zone between the crack growth occurrences that act as temporary barriers. The slope of the plots represents the rate of crack growth. An accelerated increase in slope is an indicator of increase in the stress intensity factor K, and therefore the crack growth rate increasing. On the other hand, a decrease in the slope is an indicator that crack arrest may occur. The location of the fatigue crack in conjunction with its growth and the geometry of the structure could be used to determine the urgency of maintenance of a bridge.

Exhibit 2. Instrumentation at Crack Locations

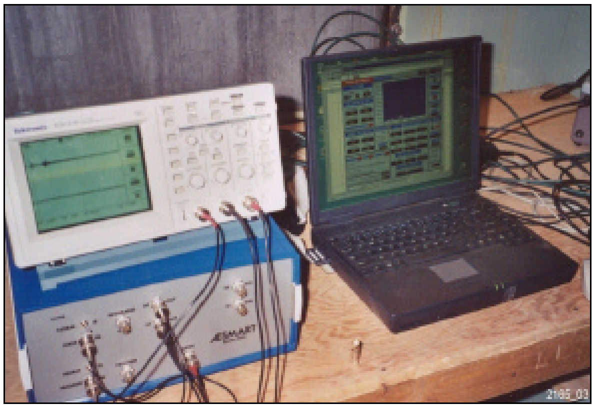

Exhibit 3. AE Equipment Used

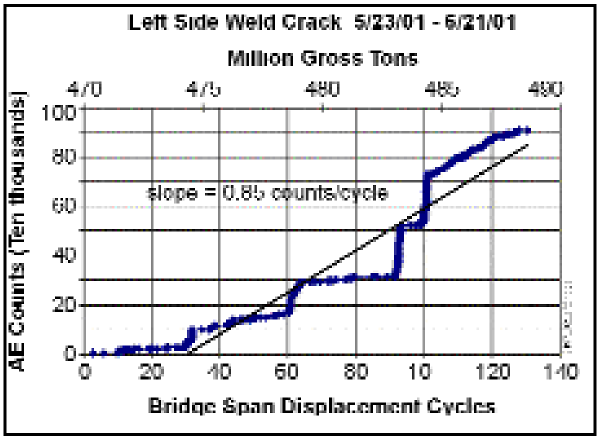

Exhibit 4. Summation of AE Counts vs. Loading Cycles, Weld Crack Left

RECOMMENDATIONS FOR FURTHER WORK

For continuing the monitoring of the cracks described herein, the following measures are recommended.

- Crack growth gages or micro-potentiometers should be placed at crack tips to measure incremental crack growth. This will allow for better correlation of AE data with observed growth data. Even using techniques such as dye-penetrant and magnetic particle inspection, it is difficult to accurately monitor the growth of the crack over time.
- Improvement in fixtures to attach sensors to vertical bridge members is necessary. Several methods of sensor attachment have been tested, and each method has its strengths and weaknesses. However, no single method allows for all desirable characteristics, including ease of attachment and removal, maintaining a good coupling surface over long periods of time, and achieving uniform sensitivity among all sensors.
- Create a system for remote monitoring whereby crack-growth data may be collected in real time from a location anywhere in the U.S.

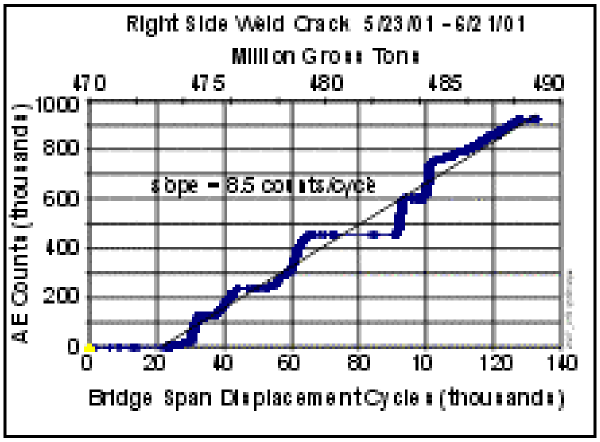

Exhibit 5. Summation of AE Counts vs. Loading Cycles, Weld Crack Right

REFERENCES

1. Uppal, A.S., et al, "Acoustic Emission Monitoring of Fatigue Cracks in Bridge Components," *Technology Digest* 99-008, Transportation Technology Center, Inc., Association of American Railroads, February 1999.

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3. Otter, D.E., et al, "Cracks in Welded Girders of the FAST Bridge," *Technology Digest* 98-030, Transportation Technology Center, Inc., Association of American Railroads, December 1998.

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