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Demonstration of Acoustic Emission Monitoring of Fatigue Cracks in a Revenue Service Bridge

by Dio Yoshino and Duane Otter

Summary

Fatigue cracks occur in many welded steel bridges, usually near welded joints. In an effort to study the growth behavior of these cracks, acoustic emission (AE) technology has been tested at the Transportation Technology Center (TTC) in a joint venture with DECI, Inc.[1] Based on the initial findings of the test, a long-term AE field demonstration was commissioned on a Canadian National revenue service bridge. This study was conducted as part of the Association of American Railroads' Strategic Research Initiative Program to extend the life of bridges.

Observations:

- The AE system was able to record crack growth related signals while simultaneously rejecting mechanical noise generated by passing trains.
- A remote monitoring system was established to transfer collected data over the Internet and monitor the state of various fatigue cracks over the long term.
- Web cameras were mounted on the bridge and used to remotely monitor various crack locations for any major changes in crack length.
- A stand-alone solar powered unit was developed to power the AE collection system and cameras. The solar system provided the AE system with adequate long-term power during the summer at TTC, but only enough power for a few days of operation in the northern climate of the test bridge. A landline power source was later installed at the bridge site to provide long-term power to the system.
- Application of acoustic emission technology can help decision making to prioritize span replacements based on crack growth activity. Use of remote monitoring technology might help with the application of AE technology for durations of a month or more in order to obtain long-term crack growth trends.
- An airborne noise source was present in the bridge testing area at frequencies near that of the resonant frequency of the AE sensors. The airborne noise introduced false readings into the AE data collection system.

While this demonstration was marginally successful, many improvements and increased reliability are needed before AE technology is ready for long-term revenue service field installations.

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INTRODUCTION AND CONCLUSIONS

Beginning in 2002 and continuing through 2005, Transportation Technology Center, Inc. monitored several fatigue cracks in a Canadian National (CN) steel bridge using AE technology. AE sensors can be used to determine whether or not fatigue cracks are growing in steel bridges by collecting data on acoustic waves emanating from growing cracks.

The bridge tested was built in 1966 with 16 spans and a total length of 432 feet. About 20 to 25 trains pass over the bridge every day with a maximum speed of 60 mph. Spans 1 through 4 of the bridge have significant fatigue cracks under nearly every web stiffener toe. The growth of fatigue cracks in spans 1 through 4 has been arrested by drilling holes through the crack tips and installing high strength bolts in the holes using the turn-of-nut method.

Several stiffener toes on spans 5 through 16 also contain fatigue cracks, but most are relatively small. There are two locations on spans 5 and 12 where fatigue cracks are larger than 1 inch long. These two cracks were monitored with AE sensors.

Due to the step like nature of crack growth in which there are short periods of rapid growth followed by longer periods of dormancy, long-term monitoring of fatigue cracks is necessary to determine the relative activity of a crack.[2] Therefore, the AE setup for the revenue service bridge was designed to run for long periods without supervision.

Acoustic Emission Technology

When a fatigue crack grows, it emits high frequency waves throughout the surface of the bridge steel. AE sensors record these high frequency stress waves. Most stress waves generated by mechanical noise are low frequency and are therefore rejected by the AE sensors. During crack propagation, three types of waves are emitted. These include a high frequency extensional wave, high frequency shear waves, and a low frequency flexure wave. Figure 1 shows the waveforms.

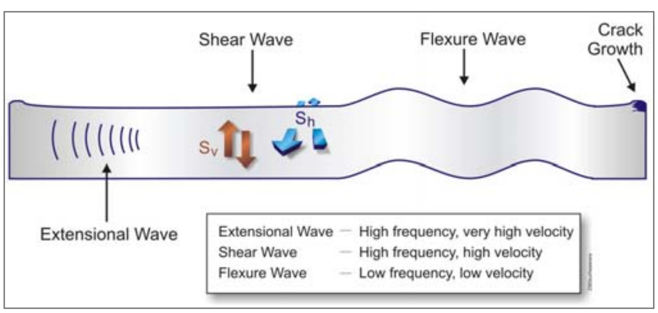

Figure 1. Acoustic Waves Propagating through Steel

The AE sensors primarily focus on the high frequency shear and extensional waves for crack growth detection. The low frequency flexure waves are also collected by the sensors for noise rejection purposes. In most cases, two sensors are placed at each crack location. One sensor is located near the crack tip while the other is located about 10 inches away, as Figure 2 shows.

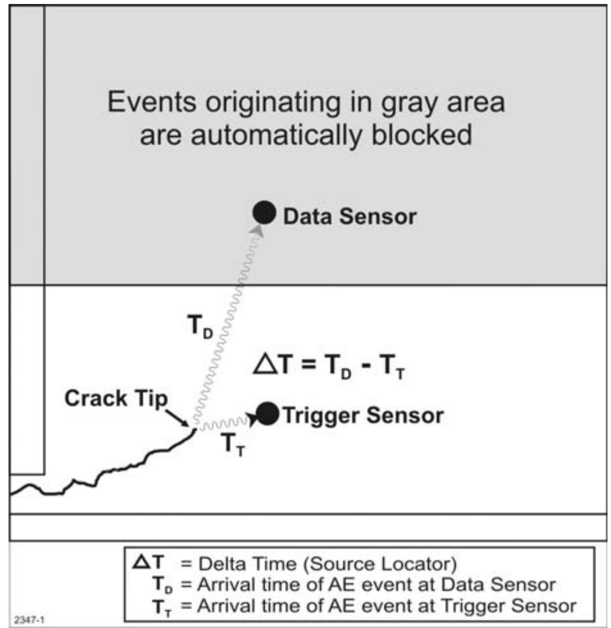

Figure 2: Use of Trigger and Data Sensors for Noise Rejection (side view of bridge)

The sensor near the crack tip or the "trigger sensor" is the first to detect a crack growth signal and informs the "data sensor" that a signal is coming. The data sensor then analyzes the signal based on several waveform characteristics and determines whether the signal is noise or a legitimate crack growth event. Noise is rejected by the system while legitimate AE events are recorded to a spreadsheet. Signals with a frequency in the range of 350 kHz and 700 kHz are likely high frequency shear or extensional waves and are potentially crack related.

Cameras

Two cameras were set up to monitor the fatigue cracks on the bridge. One camera was located near the trailer and connected with USB cable. The other camera was located on the far end of the bridge. A cable was connected between the trailer and camera to power the camera. Both cameras produced acceptable still photographs in the daytime but only darker images at night. Real-time video of the crack locations was somewhat blurry, but the photographs were sharp and provided a clear image. The camera proved to be an effective low-cost addition to the system.

Solar Power

A fully solar powered AE system was developed and set up to remotely collect data. However, the fully charged batteries combined with solar power only provided enough energy for an estimated 3 days of data collection. This was largely due to snow and the lack of sunlight in the north woods winter. Previous tests at TTC during the summer have shown that a solar powered system can operate for at least a few weeks. The power consumption of the system is estimated at about 100 watts.

The breakdown of power consumption is:

Laptop computer:	50 watts
AE system:	20 watts
Router:	10 watts
2 cameras:	20 watts

After a few days of testing, it became apparent that a standalone solar powered unit was not feasible for long-term monitoring in northern climates. A landline power source was later installed near the AE trailer to power the system.

Internet Remote Monitoring

In order to monitor the AE activity of the bridge cracks remotely, an Internet-based monitoring system was developed. The system makes use of a cable modem Internet connection at a nearby building. Wireless antennas and a radio repeater were used to bridge the gap from the cable modem Internet connection to the AE trailer. The distance between the cable modem and trailer is approximately 1 mile.

Inexpensive remote desktop software was used to control the laptop computer in the AE trailer. The wireless connection uses the 802.11b wireless standard for Internet communications that allows for high speed data transfer and seamless monitoring.[3] The computer was controllable from any computer connected to the Internet with the proper software and login password.

Data Collection

Fatigue cracks can only grow when there is a train passing, applying stress to the bridge. For this reason, the AE system was configured to collect data only when there was a passing train, and then pause data collection when the bridge was at rest. The AE system was triggered to begin data collection when a wheel detector on the rail detected a passing wheelset. The collection would then continue until there was 10 seconds or more with no activity, after which it would return to a waiting state.

For purposes of checking the installation, a pulsar, used to simulate crack propagation, was temporarily set up on one of the bridge members to test the noise rejection ability of the AE system. The pulsar emits crack growth simulation signals at a rate of one signal per second. When a train passed over the bridge, the AE system was able to detect the simulated growth signals from the pulsar while simultaneously rejecting mechanical noise generated by the passing train. The pulsar was subsequently removed from the bridge.

All acoustic emission data is stored in a Microsoft Excel spreadsheet. When a crack growth signal is detected, the AE system immediately evaluates the signal and records relevant parameters to the spreadsheet. No post processing of the data is necessary. Figure 3 shows one week of AE data. There existed an intermittent airborne noise source in the area that caused the system to record faulty AE events. This issue could not be resolved and therefore much of the collected data became unreliable. A frequency analyzer was later used to confirm the existence of an airborne noise source.

Ignoring possible noise contamination, Figure 3 shows a growth rate of about 25 AE counts per load cycle. This is approximately 3 times the rate observed on a bridge at the High Tonnage Loop at TTC over about a 1-month period in which there was approximately 0.25 inch of crack growth.[1] Due to the remote monitoring nature of the test, crack extension measurements were not available for the revenue service bridge during the period illustrated in Figure 3.

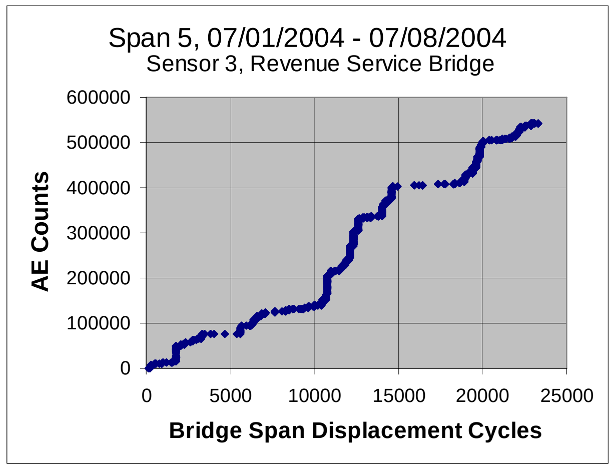

Figure 3: Crack Propagation Based on AE Counts

Lightning

At one point during the AE test, lightning struck the AE trailer and damaged several system components including the AE system, laptop computer, and other peripheral devices. Although the AE trailer was equipped with a grounding rod and lightning arrestor circuits were in place for many of the line connections, these safeguards were not sufficient in preventing a large amount of damage to the AE equipment.

Results

The demonstration of AE technology on CN has shown that it is possible to separate crack growth acoustic signals from mechanical noise generated by a passing train. In the case of the revenue service bridge, the collected crack growth data was corrupted by airborne noise from an external source that resulted in signals similar to those generated by crack growth. This noise occurred intermittently and was prevalent even when all sensors and cables were removed from the bridge.

A stand-alone solar powered system was developed for the AE project and was functional for several days. However, the amount of sunlight in the northern climate was not enough to power the system for long-term monitoring. A landline power source was needed for long-term AE monitoring.

The Internet based remote monitoring system was shown to be an effective tool to remotely collect data and monitor the health of the system. Web cameras provided a continuous view of two of the bridge fatigue cracks from a remote location.

Knowledge of the growth activity of fatigue cracks may be used to help postpone the replacement of a welded steel bridge for several years. AE technology may also help decision makers in prioritizing span replacements for multiple span bridges.

Further Work

Further development work is needed in several areas in order to make this technology viable for long-term use on steel railroad bridges. Items specific to the AE system include:

- Better isolation from lightning strikes
- Better rejection of ambient electro-magnetic interference
- Development of interpretive software with a user-friendly interface

Other items, related to wayside detection systems in general include:

- Reliable power and communications
- Protection from vandalism
- Ruggedness and reliability

For a fraction of the cost, web cameras alone can be installed as a cost-effective monitoring system. They cannot provide all the benefits of a full AE system, but they are an off-the-shelf technology that is much easier to implement and interpret. Web cameras would only detect major changes in crack length, but they would not provide information concerning crack growth rate.

In considering the cost of any bridge monitoring system, it should be compared to the cost of making repairs, the risks of delaying repairs, and any benefits achieved by delaying repair or replacement of the particular components.

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REFERENCES

1. Yoshino, D., A. S. Uppal, and H. Dunegan. May 2005. “Acoustic Emission Monitoring of Fatigue Cracks on the FAST Steel Railroad Bridge,” Research Report R-972, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colo.
2. Yoshino, D., A. S. Uppal, and H. Dunegan. April 2002. “Using Acoustic Emission to Monitor Fatigue Cracks on the Bridge at FAST,” *Technology Digest* TD-02-005, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
3. Yoshino, D. and A. S. Uppal. February 2005. “Hardware Requirements for Remote Monitoring of Fatigue Cracks in Steel Bridges Using Acoustic Emission Technology,” *Technology Digest* TD-05-003, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.