

**COMBINED APPLICATION OF ULTRASONIC INSPECTION AND ACOUSTIC
EMISSION MONITORING FOR EVALUATION OF FRACTURE CRITICAL
MEMBERS IN RAILWAY BRIDGES**

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Abstract

A combined, cost-effective inspection procedure, using ultrasonic (UT) scanning, or related NDT, to detect fatigue crack initiation and acoustic emission (AE) monitoring to assess crack activity, is presented. Application of this procedure to detecting and assessing fatigue cracks under rivet heads in hanger angles, in link pins and eye bars and in other fracture critical members is discussed. Specialized AE and UT procedures for bridge inspection are reviewed and a method of classifying fatigue crack severity is discussed. The incorporation of this type of inspection into a bridge maintenance program is discussed from a bridge owner's perspective.

Key Words: acoustic emission monitoring, ultrasonic scanning, fracture critical, fatigue cracks, maintenance of way

Introduction

Many of the steel railway bridges currently in use in North America are well beyond their original design life, while railway equipment loads have been increasing substantially above original bridge design values. Some much newer bridges of welded design, are experiencing premature structural problems from component fatigue. Safely extending the life of such steel railway bridges, safely maximizing their load ratings and maintaining ongoing, uninterrupted train operations, is of great economic benefit to the bridge owner. Achieving such goals depends to a large extent on developing and maintaining an effective bridge inspection schedule.

This paper discusses inspection methods, developed jointly by TISEC Inc. and Canadian National Railways, based on tests of over 175 steel railway bridges, for interpreting and extending the findings of the trained visual inspector. It presents advanced inspection methods that provide the bridge engineer with additional information required to make the decision at a specific fracture critical location that no further action is required, that the location should be monitored during more frequently scheduled inspections or that a retrofitting procedure be immediately implemented.

The bridge engineer usually has access to life expectancy data, load data, structural analysis data, strain measurement data and field inspection reports. These combined data still may not provide sufficient information to make a decision to repair a bridge member, to replace a span, or to leave things as they are. Although fatigue cracks develop in most bridges, in many cases they propagate only a certain distance and then become dormant due to stress relaxation. However, when propagation continues, it becomes a judgement call for the bridge engineer as to whether, or how soon, funds be allocated for repair or replacement. This paper presents a method for providing the bridge engineer with this additional information. This jointly developed method

relies on a logical combination of visual inspection results, strain measurements, acoustic emission (AE) monitoring, ultrasonic scanning (UT), or related types of nondestructive testing (NDT) to assess and classify the severity of fatigue cracks in fracture critical members. It also includes a technique for classifying fatigue crack activity.

Inspection Requirements

The bridge engineer has a mandate to maintain the safety and capacity of the existing bridge plant to ensure uninterrupted train operations while controlling or reducing repair and refurbishment costs. In maintaining this balancing act, within an infrastructure of bridges which may have exceeded their expected life and which may currently be carrying loads greater than originally designed for, the bridge engineer relies on other engineering data from structural analysis, load history, strain measurement and inspection, to determine effective repair and replacement schedules.

Visual inspection by a trained bridge inspector, combined with advanced inspection techniques, using AE monitoring and UT scanning can play an important role in determining whether repairs may be delayed, may not be required, or whether immediate corrective action may be needed on certain fracture critical members. The combined inspection usually concentrates on fracture critical members with known defects; on fracture critical members on similar span designs, with a history of defects; and on structures where the loading frequency and magnitude has significantly increased, or on which the expected fatigue life has been exceeded. The combined inspection is used for detecting new fatigue cracks, for assessing the activity level of existing cracks and for assessing the effectiveness of retrofit repairs.

Bridge Inspection Using NDT Techniques

A number of NDT techniques have been used in bridge inspection for detecting and assessing cracks and discontinuities. These include dye penetrant tests (PT), magnetic particle (MT) tests, ultrasonic (UT) scanning and acoustic emission (AE) monitoring. Each method has its advantages and its shortcomings. However, when the results of several NDT techniques are logically combined and used together with other engineering data, this approach becomes a powerful and cost-effective bridge inspection tool. The following provides a brief description of AE and UT inspection techniques, the advantages and shortcomings of each technique, as well as a review of jointly developed inspection procedures that combine AE monitoring with UT scanning, or related NDT to characterize and classify the activity level and severity of fatigue cracks in fracture critical members.

Acoustic Emission Monitoring

Acoustic emissions are transient elastic waves generated by the rapid release of energy from a localized source within a structure (1). In fatigue-fracture occurrences, a portion of the strain energy released by a growing crack is transmitted through a structure as an acoustic signal (an acoustic event) that may be detected by appropriate acoustic transducers and related monitoring equipment. AE monitoring of railway bridges is a passive acoustic technique; transducers are appropriately placed on members of interest and monitoring takes place while the bridge is dynamically loaded under train traffic. A variety of acoustic signals occurs during the monitoring process, such as noise from loose fasteners and working members, mechanical noise transferred from the track and random electrical signals, which in many cases may mask the

acoustic signals from a growing crack. Since an acoustic event from a growing crack has a typical, characteristic waveform, signal characteristics are used to identify and filter crack-related acoustic events from noise.

Original analogue AE monitoring systems (2) used time-based signal characteristics to filter AE events from noise signals. In some cases this was successful and in other cases, because of noise characteristics, it achieved only limited success. Current digital AE monitoring systems (3) enable the use of much more sophisticated and effective frequency-based techniques for identifying signals from growing cracks. Indeed, with such systems and advanced signal analysis techniques, it is possible to detect the differences among signals from growth at the tip of an active fatigue crack and fretting or rubbing of the crack walls. The current, jointly developed procedure for AE bridge monitoring of identified fatigue cracks includes the following techniques:

Geometric Clustering. This is a planar source location technique, utilizing four transducers surrounding an area of interest and effectively excluding all acoustic signals from outside the monitoring area.

Load Cycle Correlation. This technique correlates parametric input from a strain or load transducer with the AE signal, identifying whether a signal occurs on a rising or falling load. Signals occurring at no-load conditions are filtered out.

Waveform Classification. Waveform characteristics are compared, classified and filtered both with respect to signal type, position on the load cycle and location within the monitoring region. This enables differentiation among activities such as growth at the crack tip and crack wall fretting.

Pattern Recognition. Statistics are gathered by a variety of means from the acoustic waveform data and special classification software is used to find similarities, or patterns among these individual waveforms. When compared to the statistics gathered from waveforms of known origins, a higher degree of certainty can be placed upon signals of unknown origin.

Ultrasonic Scanning

Ultrasonic scanning, in contrast to AE monitoring, is an active acoustic inspection technique. A sound wave is directed at an area of interest; if it intersects a crack or other discontinuity, a reflected wave is returned. UT is performed on an unloaded structure and employing a geometrically similar calibration block, can be used to locate cracks or discontinuities at specific areas of interest. UT can also be used to size the length, depth or location of a discontinuity. Since UT scanning depends on inserting a known acoustic signal into a member at a specific angle and direction, to reach a specific location, it requires a relatively smooth member surface. As a result, it is difficult to use on badly corroded members.

The differences between AE monitoring and UT scanning are quite apparent. AE monitoring can detect the source of an emission from a crack, as well as the relative activity of the crack. UT scanning, on the other hand, can determine the size and location of a discontinuity or the length of a hidden crack. It cannot, however, determine if the detected crack is active or inactive. It is easy to see how AE and UT can be complementary in many inspection situations.

Complementary Test Procedures

Three complementary test procedures have been jointly developed to address the identification and classification of fatigue cracks in specific fracture critical members on steel

railway bridges. When used in combination with related engineering data, they provide the bridge engineer with additional powerful tools to assess repair and refurbishment requirements.

The following corporate standards identify these procedures:

Acoustic Emission Testing to Assess the Activity of Fatigue Cracks in Bridge Members.

This corporate standard presents procedures for AE inspection of steel railway and highway bridges to assess the activity of existing and developing fatigue cracks in fracture critical members. When used on a long-term, continuous basis, this procedure may also be used to monitor changing rates of crack activity

Ultrasonic Testing to Detect Fatigue Cracks in Bridge Hangers. This corporate standard presents detailed procedures for the ultrasonic inspection of bridge hanger angles and bridge hanger channels to detect developing fatigue cracks at points of high stress around fasteners, with the particular capability of inspecting under rivet heads. When used on a scheduled ongoing basis, this procedure may be used to monitor the growth of suspected cracks. This procedure may also be used, as the initial inspection step, to determine which bridge hanger test locations should be considered for AE monitoring.

Ultrasonic Testing to Detect Fatigue Cracks in Bridge Pins and Eye Bars This corporate standard presents detailed procedures for the ultrasonic inspection of steel eye bars and pins on bridges for detection of developing fatigue cracks in regions of high stress such as at thread shoulders and eye bar contact areas. When used on a scheduled ongoing basis, this procedure may be used to monitor the growth of cracks. This procedure may also be used, as the initial inspection step, to determine which pin and eye bar test locations should be considered for AE monitoring.

Classifying and Characterizing Fatigue Crack Activity. The AE monitoring standard states that a method for characterizing and reporting relative crack activity shall be developed in consultation with the bridge engineer, to provide the most meaningful interpretation. One such method is using the fatigue crack index, as detailed in Table 1. As may be noted, the fatigue crack index, which ranges from 1 for a minor defect with no activity to 5 for a major defect with critical crack growth activity, is determined based both on AE monitoring results and related observations and measurements, which include use of all of the above standards:

Table 1. Rating Relative Crack Activity

Fatigue Crack Index	Crack Description
1	No AE activity. Minor defect indicated by AT or MT. Normal strain
2	Minor AE. Small crack indicated by VT, UT or MT. Normal strain.
3	Moderate AE. Moderate crack size. Higher than normal strain.
4	High AE activity. Significant crack size. High measured strain.
5	Very high AE activity. Large crack size. Very high measured strain.

A Review of Some Typical Field Inspection Results

The following presents several examples of using the above complementary test procedures to inspect known cracks in fracture critical members. The first example is the inspection of an existing crack in a floor beam web at its connection to a girder in a 100 year old through plate girder span. The crack originated in a corrosion-reduced groove at the bottom of the floor beam web, running 4 in (100 mm) upward, disappearing under the connection angle. Figure 1 presents the results of AE monitoring of this location. As can be seen a very active source was detected between the fourth and fifth rivets from the bottom of the web. Each yellow dot in this cluster represents a recorded AE event with the waveform characteristics of crack growth. Ultrasonic scanning was then used to confirm the presence of a crack under the connection angle. Although corrosion prevented continuous scanning, portions of the web could be scanned, confirming at total crack length of 15 in (380 mm), with the crack tip coinciding with the AE event cluster. Figure 2 shows the results of UT scanning, with detected crack indications drawn in white. Based on AE monitoring results, UT scanning results, corresponding strain measurements and related visual inspection, it was concluded (Table 1) that this location had a fatigue crack index, $D = 5$, with a recommendation for immediate retrofit.

Figure 3 presents another example of combined monitoring results on one of the link pin and eye bar hanger assemblies connecting the stringers of a 93 year old deck truss span to a through truss span. Ultrasonic scanning, using specially fabricated calibration blocks and pins, was first conducted on the upper and lower pin and eye bar assemblies to check for the presence of cracks or indications at critical cross sections. Any locations showing UT indications were then subject to AE monitoring to assess crack activity. Figure 3 shows the results of AE

monitoring on one of the top outer eye bars. UT scanning had detected a 0.04 in (1 mm) deep crack, through the left inside of the eye bar, under the pin-retaining nut at its critical region. The AE data presented in this figure are coarsely filtered and include several types of signals, however a number of the events in the left cluster, which coincides directly with the crack location, had unique characteristics related to crack growth. It was concluded that this location had a fatigue crack index, $D = 3$ and it was recommended that this location be inspected on a scheduled basis.

Finally, Figure 4 shows AE monitoring results at a crack originating at the cope of the connection angle between a floor beam and girder on a through plate girder span. Although only the root of the crack was visible, dye penetrant testing indicated that the crack was over 1 in (25 mm) long, ending at the center of the cluster of AE events. The individual AE events all had waveform characteristics related to crack growth. Based on AE monitoring results, PT testing, strain monitoring and related visual inspection, it was concluded that this location had a fatigue crack index, $D = 3$. Scheduled inspection of this location was recommended.

Summary and Conclusions

- 1) AE monitoring can play a very effective role in enhancing safety, ensuring availability and reducing repair/refurbishment costs of steel railway bridges.
- (2) A most important part of an AE monitoring program is developing a comprehensive test procedure in cooperation with the bridge owner so that test program addresses the owner's needs.

(3) Experiences with tests on over 175 bridges stress the importance of combining AE monitoring with visual inspection, complementary forms of NDT (UT, MT, PT) and strain monitoring.

(4) Geometric clustering, load cycle correlation, waveform classification and pattern recognition are important parts AE data analysis and interpretation. This interpretation in itself is however usually not sufficient for rating fatigue crack activity. Substantiation from additional complementary NDT is important in classifying crack activity.

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Figure 1. A cluster of source located AE events, with crack growth characteristics, between the fourth and fifth connection angle rivets.



Figure 2. Ultrasonic scanning results of the same location as shown in Figure 1. Note the location of the crack beneath the connection angle, ending between the fourth and fifth rivets.

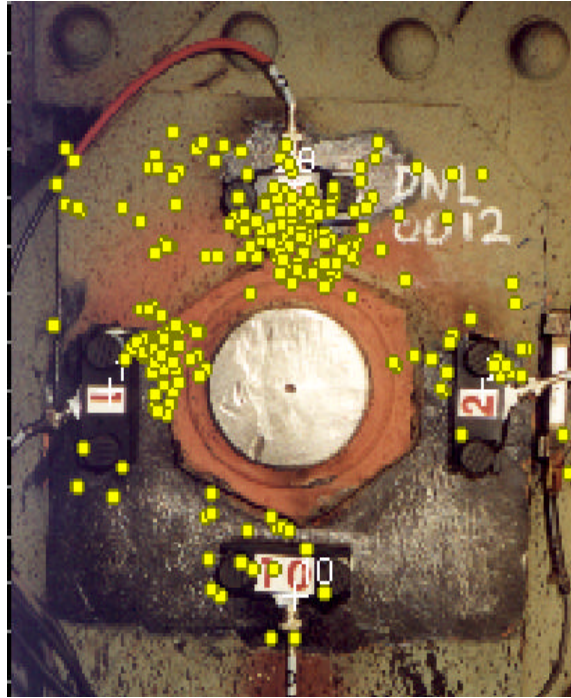


Figure 3. Results of AE monitoring of an eye bar. A 0.04 in (1 mm) deep crack had been detected with UT at the left critical eye bar section under the pin-retaining nut.



Figure 4. AE monitoring results from a crack originating in the cope of a floor beam connection angle. PT inspection confirmed that the tip of the crack was at the center of the cluster of located AE events.