ACOUSTIC EMISSION TESTING OF A DIFFICULT-TO-REACH STEEL BRIDGE DETAIL

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Abstract

Discovery of a 130 mm (5 in) long full-depth crack in a fracture-critical member of a large steel through truss bridge led to the deployment of acoustic emission (AE) testing in concert with other, more traditional, non-destructive evaluation methods. While AE continues to gain acceptance as a method for evaluating civil structures, the application of AE testing to steel bridge details that are fully exposed to the elements and difficult to reach presents some special challenges; as such, AE work typically has been contingent on favorable field conditions. In this study, a custom weatherproof enclosure and robust communication and control methods were deployed to obtain useful AE data in this environment. First-hit channel analysis, planar location, and spatial/temporal clustering analysis were used to determine if the crack was actively growing. The AE results were validated by corroborating results from ultrasonic testing and radiography.

Introduction

The John F. Kennedy Memorial Bridge, a large cantilever through truss bridge opened in 1963, carries Interstate 65 across the Ohio River between Louisville, Kentucky and Jeffersonville, Indiana. According to a count by the Kentucky Transportation Cabinet (2003), the bridge carries over 120,000 vehicles per day. Inspections revealed a 130 mm (5 in) long full-depth transverse crack in the horizontal web in a tension region of the top chord on the east truss, the site indicated in Fig. 1a. A partial-depth saw cut and an irregularly shaped hole of unclear origin are present along the web-flange weld, and a 25 mm (1 in) diameter stop hole is present at the end of the crack, as shown in Fig. 1b. The crack is in a fracture-critical member, meaning that fracture of the member would likely cause partial or complete failure of the bridge. Acoustic emission (AE) monitoring was employed in conjunction with other non-destructive evaluation techniques, including ultrasonic testing and radiography, to help detect and characterize any indications that the crack might jump the stop hole or propagate into the vertical flange of the member.

Previous AE Work on Steel Bridge Details

Acoustic emission testing is well established as a technique for locating and characterizing cracks and other defects in a variety of engineering materials. Though the application of AE testing of details on in-service steel bridges dates as least as far back as the 1970s (Holford and Lark, 2005), it continues to present some special challenges. From a data acquisition perspective, the most vexing problems stem from the very noisy environment on highway bridges, where “noise” takes the form of both spurious electrical signals and real physical phenomena that may obscure events of interest. The former may stem from radio-frequency interference due to capacitive coupling between the AE transducers and the bridge itself, which serves as a large antenna, or from signals picked up in the cables between the AE transducers and data acquisition system. The most common examples of real phenomena causing spurious AE events on a steel bridge are fretting at bolted or riveted connections and other noises associated with live traffic.
Fig. 1. I-65 Kennedy Bridge. (a) Overall view of Kennedy Bridge showing crack location. (b) 130 mm (5 in) long transverse crack, stop hole, partial-depth saw cut, and an irregularly-shaped hole in horizontal web of top chord.

As it is rarely practical to completely shut down a major highway bridge for testing, most AE applications will take place with uncontrolled traffic loads on the bridge.

Most steel bridge members do have a characteristic that simplifies AE testing, particularly source location: AE signal wavelengths in steel at frequencies of interest are on the order of 25 mm. Consequently, most steel bridge members may be analyzed as thin plates where Lamb wave conditions are predominant (Prine, 1985). This condition greatly simplifies testing, particularly in light of the complicated geometry of many steel bridge details.

In the 1980s, Hopwood and Prine (1987) deployed AE equipment originally developed for welding process monitoring on a number of steel highway bridges. They employed a flaw detection model described by Prine (1985), which discriminates between AE events from a growing flaw and background noise (e.g., fretting of bolted or riveted connections) based on the assumption that a growing flaw will produce AE events at a high rate and from a very specific location. That is, a group of events must occur within a certain time interval and be located within a given
radius of each other in order to pass the filter. A later study on a movable bridge (Prine, 1994) showed good corroboration between AE and ultrasonic testing for detection of cracks. Prine’s method forms the basis for analysis of data in this paper.

More recently, AE testing of steel elements in bridges and other large civil structures has been shown to be quite useful for failure analysis (Prine, 2001), noise localization (Prine, 2004), fatigue crack monitoring (McKeefry and Shield, 1999), and retrofit evaluation (Kosnik and Marron, 2007).

A Note on “Crack Activity”

In AE literature, AE hits generated by internal material mechanisms (e.g., microstructural changes inherent in crack development) are often designated as primary AE, while hits from other sources, particularly fretting along existing crack faces, are called secondary AE (Holford and Lark, 2005). Much work has been done to distinguish these two types of events so that analysis may focus exclusively on the primary AE associated with crack growth, and this is indeed helpful in a variety of situations. However, the experience of the author’s group has been that AE hits from both primary and secondary sources can be instructive, particularly in characterization of a known defect.

For example, if a crack is actively growing, primary AE will emanate from the crack tip, but it is likely that the local state of stress along the crack will result in fretting along the crack faces or crushing of debris inside the crack, and secondary AE will occur at the same time. By contrast, if a crack has extinguished itself, there will be no primary AE from the crack tip, and the amount of secondary AE likely will be reduced as well, since the local stresses have been relieved. Thus, provided that appropriate transducer geometry and guard channels are employed to restrict data to the detail in question, it is sufficient to consider both primary and secondary AE in aggregate as crack activity for the purpose of characterizing cracks and other defects in steel highway bridge details.

AE Testing in a Challenging Environment

As illustrated in the preceding section, AE testing of steel bridge elements can be quite useful in a variety of engineering situation. This utility comes with an important caveat, however: AE monitoring of bridges generally has been limited to short-term tests contingent on either fair weather or availability of some shelter on site, e.g., a bridge tender’s shack or the inside of a box girder; furthermore, AE testing generally has been practical only on elements where access is relatively easy. Experience has shown that these favorable conditions are rarely encountered in the field. In the case of the Kennedy Bridge, the upper chord is completely exposed to the elements, requires a lift bucket — available only during limited lane closures — for access, and provides no electrical connection.

To meet this challenge, the customized weatherproof enclosure shown in Fig. 2a was developed to protect the AE hardware and connect it to a rugged laptop computer and a battery-backed uninterruptible power supply (UPS). This enclosure may be clamped to the bridge near an area of interest, as shown in Fig. 2b, making long, noise-prone instrument cable runs unnecessary. To reduce electrical noise and spurious AE hits from the enclosure itself, the enclosure was mounted on rubber feet and placed well outside the AE arrays so any events would be rejected by the AE processing filters. An umbilical consisting of extension cords and Category 5e Ethernet cable, available at home improvement stores, connected the enclosure to a gasoline-powered generator.
and the operator’s laptop computer on the bridge deck. The operator used remote access software to control the AE acquisition software running on the rugged laptop in the enclosure.

**Test Procedures and Results**

Two test configurations were employed. The first configuration, a planar array on the vertical flange of the cracked member, was used to detect indications that the crack might have propagated beyond the partial-depth saw cut into the vertical flange. The second configuration, a planar array on the horizontal web around the stop hole, was used to detect indications that the crack might have jumped the stop hole. Both test configurations used a Vallen Systeme AMSY-5 AE system with Vallen VS150-RIC 150 kHz-resonant piezoelectric transducers with integrated pre-amplifiers. A 40-dB recording threshold was used. Pencil-lead breaks were performed before each test. Auto-calibrations were performed before and after each test to show that the array had not been disturbed during the test.

For both the horizontal web and vertical flange tests, a transducer was installed directly on the area where crack activity was suspected, and four additional transducers operating in combination guard/normal mode were installed in a rectangular array with the “crack” transducer at the center. These combination-mode transducers were used for both planar location and filtering via first-hit channel (FHC) analysis; FHC filtering was particularly important to intercept noise from a bolted connection near the crack. Finally, a guard transducer was deployed on the member element not being tested at that time (i.e., on the vertical flange while the five-sensor array was on the horizontal web, and vice versa) to intercept noise from that element. The transducer arrays for the vertical flange and horizontal web tests are shown in Figs. 3a and 3b, respectively. Three distinct techniques were employed for analysis of the acquired AE data: first-hit channel analysis, planar location, and spatial/temporal clustering.
Vertical Flange Test
The two test runs on the vertical flange yielded low hit rates of 0 and 10 hits/min, respectively. Consequently, there was no indication that the web crack was propagating beyond the partial-depth saw cut into the vertical flange. Due to the low hit count and complicated geometry of the detail, location and clustering analyses were not practical.

Horizontal Web Test
For the horizontal web test, the “crack” transducer was placed near the stop hole opposite the crack. FHC analysis showed considerable AE activity around the stop hole; the two test runs yielded hit rates of 206 and 377 hits/min, respectively. However, the bulk of these events had an amplitude less than 45 dB, and are believed to be caused by fretting of the existing crack sides rather than crack propagation. Planar location analysis yielded locations for many AE hits for the horizontal web test. Due to the complicated geometry of the detail, not all hits yielded a location; those hits that could be located are shown superimposed on a photograph of the array in Fig. 4.
Spatial/temporal cluster analysis provided particular insight into the behavior of the horizontal web. This filter, originally developed for welding process monitoring (Prine, 1985), requires a minimum of three AE events within a 25 mm radius and one-second time interval. A tight group of clusters was observed at the point highlighted with a green circle in Fig. 5, indicating a probable defect at that point. Subsequent radiography confirmed the presence of this defect, which is believed to be a slag inclusion (Marron and Kosnik, 2008).

![Spatial/temporal clusters on horizontal web. Individual located events are shown as red boxes, while the one cluster that passed the spatial/temporal filter is circled in green.](image)

**Conclusions**

The AE data revealed no indication that the crack had propagated into the vertical flange in the area of interest. However, considerable AE activity was measured in the horizontal web. These events were generally of low amplitude, which suggests that they originate from fretting of the existing crack faces. There were no AE indications that the crack had jumped the stop hole. Spatial/temporal AE cluster analysis did show indications of a defect in the horizontal web. The presence of this defect, which is believed to be a slag inclusion, was later confirmed by radiography.

These measurements were made possible by special techniques for AE testing and monitoring of large civil structures. A weatherproof enclosure, which could be installed at the area of interest from a lift bucket during a brief lane closure and then powered and controlled via a simple umbilical, was developed to eliminate long lead cables and exposure of AE equipment to the elements. This approach also facilitates longer-duration tests, allowing AE events to be recorded under a wider variety of traffic and other environmental conditions. The flexibility and robustness of this method promise to make AE testing of large civil structures, especially fracture-critical bridges, easier and more widely available.
References


