A NEW APPROACH TO ACOUSTIC EMISSION TESTING OF DIFFICULT-TO-REACH STEEL BRIDGE DETAILS

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Introduction

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

(a) Overall view of Kennedy Bridge showing crack location   **(b)** Crack in horizontal web of top chord

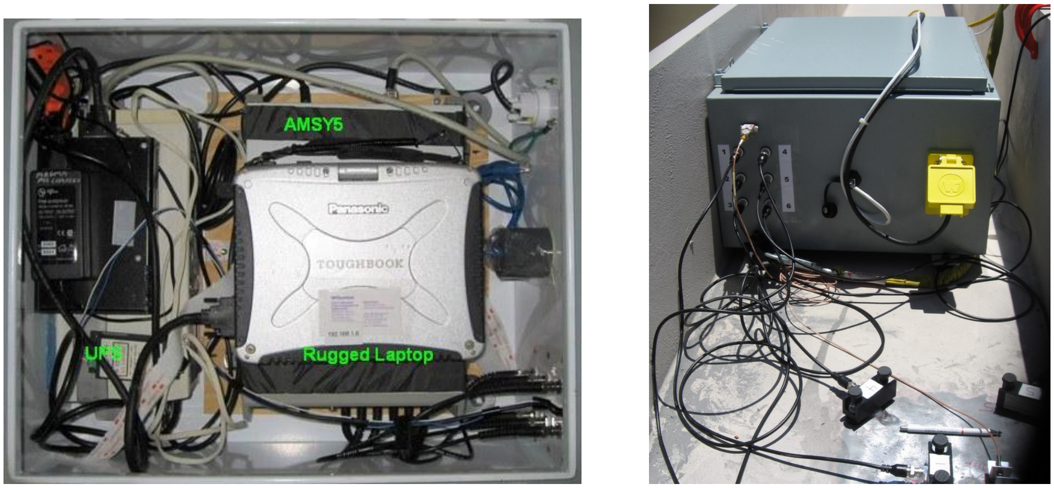
Figure 1: I-65 Kennedy Bridge

A New Approach for AE in a Challenging Environment

Acoustic emission (AE) testing is well-established as a technique for locating and characterizing cracks and other defects in a variety of engineering materials. AE testing of steel elements in bridges and other large civil structures has been shown to be quite useful for failure analysis [4], noise localization [6], and retrofit evaluation [2]. However, AE monitoring of bridges has generally 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. Since the upper chord of the Kennedy Bridge is unsheltered, provides no electrical connection, and requires a lift bucket for access, a new approach was needed to enable AE testing under these less-than-ideal conditions. To meet this challenge, the customized weatherproof enclosure shown in Figure 2a was developed to protect the AE hardware and connect it to a rugged laptop computer and a battery-backed power supply. This enclosure could be clamped to the bridge near an area of interest, as shown in Figure 2b, making long noise-prone 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 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 Procedure and Results

Two test configurations were employed. The first configuration was a planar array on the vertical flange of the cracked member, 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



(a) Interior of enclosure showing AE unit, rugged laptop, and battery-backed power supply

(b) AE enclosure deployed on the top chord of the Kennedy Bridge

Figure 2: Weatherproof enclosure for AE testing of difficult-to-reach details on steel bridges

Systeme AMSY5 acoustic emission system with Vallen VS150-RIC 150 kHz-resonant piezoelectric transducers with integrated preamplifiers. A 40 dB recording threshold was used. 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 tranducer 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) to intercept noise from that element. The transducer arrays for the vertical flange and horizontal web tests are shown in Figures 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.

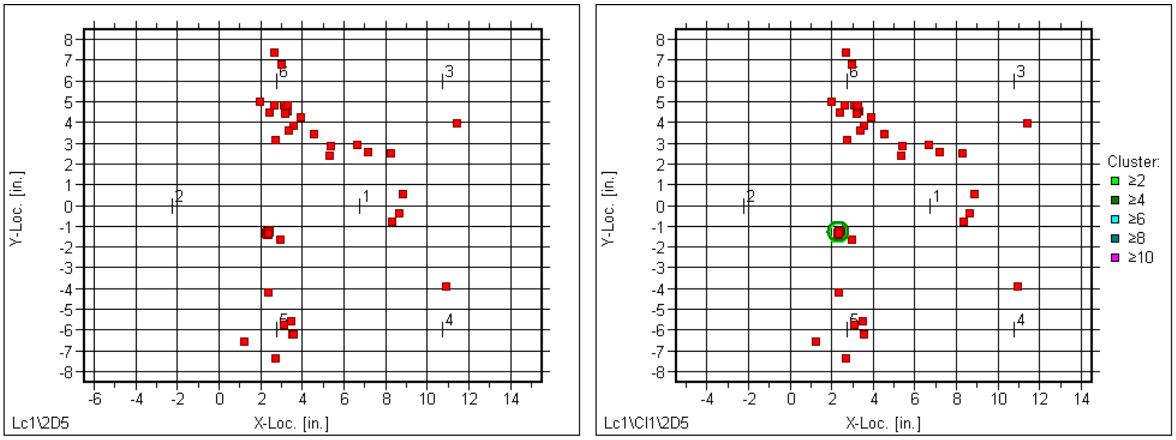
(a) Array on vertical flange

(b) Array on horizontal web

Figure 3: AE transducer arrays

The two test runs on the vertical flange yielded the low hit rates of 0 and 10 hits per minute, 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.

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 per minute, 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 member, not all hits yielded a location; those hits that could be located are shown in Figure 4a. Spatial/temporal cluster analysis provided particular insight into the behavior of the horizontal web. This filter, previously deployed in AE monitoring of a moveable bridge [5], requires a minimum of three AE events within a one-inch radius and one-second time interval. A number of clusters were identified in the analysis; however, a tight group of clusters was observed at the point highlighted with a green circle in Figure 4b, indicating a probable defect at that point. Subsequent radiography confirmed the presence of this defect, which is believed to be a slag inclusion [3].



(a) Planar location results on horizontal web

(b) Spatial/temporal clusters on horizontal web

Figure 4: AE hit location and cluster plots (after [3])

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 has 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 a new approach to AE testing and monitoring of large civil structures. A specialized enclosure, which could be installed at the area of interest from a bucket lift 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 promises to make AE testing of large civil structures, especially fracture-critical bridges, easier and more widely available.

References

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