AE Observations During Cyclic Testing of A572 Steel Laboratory Specimens

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Abstract
Unusually large (300mm x 300mm x 12.7mm) compact tension specimens of A572 steel were tested in cyclic loading, as part of a program to apply AE to structural health monitoring of highway bridges. AE from the fatigue crack was observed, both during initiation (very low amplitudes) and during the late stages of fatigue life (much higher amplitudes). There were interesting visual observations of the plastic zone, and interesting patterns in the grating (fretting) signals from crack face interference late in the test (late Stage II fatigue and on). Next, cruciform specimens were tested in order to approach more closely the geometry of highway bridge details. In these specimens the crack was not so readily visible. These tests were stopped when the crack was judged to have reached Stage III fatigue on the basis of AE warnings. The specimens were examined with ultrasonic testing and penetrant testing, to assist the development of lifetime prognostic techniques based on AE.

Keywords: Acoustic emission, A572 steel, fatigue, cruciform, grating signals, plastic zone, crack sizing, NDT

1. Introduction

Materials testing studies have been conducted as part of a program to develop a self-powered, wireless AE system for monitoring cracks in highway bridges [1]. These studies have been conducted in order to provide data for the development of prognostication methods [2]. For the first set of studies, compact tension specimens of A572 steel were used. Background considerations and key AE results from this work have been described elsewhere [2-6]. In a second set of studies, cruciform specimens were used in order to approach more closely the geometries used on actual bridge structures. The present paper will describe some supplementary observations on the compact tension (CT) specimens as well as some preliminary results obtained on cruciform specimens. Photography, electron microscopy, ultrasonics, penetrant testing and active acoustic sensor methods are used as well as AE. The later part of the fatigue life, when the crack is growing rapidly, is of particular interest.

2. Crack Growth in Compact Tension Specimens

Reference [2] describes tests on compact tension specimens, 12” x 12” x 3/4”, made of A572G50 steel using the geometry of ASTM E 647. These were fatigue tested at 2 cycles/sec with an R-ratio of 0.1, and monitored with R15I and WDI AE sensors. The tests were conducted at the University of South Carolina (USC) and typically lasted several days. Specimen failure occurred at stress intensity factors of around 130 MPa√m. A major part of the work was filtering the acquired AE data, in order to eliminate noise and focus on the most structurally significant signals for purposes of failure prognosis. The thrust of the analysis was to develop methods for prognosis using sparse data sets, so that in eventual application using self-powered systems on bridges, the power required for data transmission would be minimized.

In the analysis described in the present paper these constraints are relaxed in order to reveal some other points of general interest. Especially, whereas in [2] all signals occurring at loads less than 80% of peak were discounted, here they are accepted. Mechanisms such as crack face interference (here called “grating”) are thus included in the results shown below.
Presented here are some detailed results from one particular CT specimen, numbered CT-5. This specimen was unique in that its surface was specially polished to make the plastic zone visible. The polished surface was examined by eye from time to time. In the early part of the test, the only thing to be seen was that the surface was flat (plane strain) and the crack opening scarcely visible. Later however, when the crack tip was about 30 mm from the notch root and 110 mm from the load line, small curving marks were visible on the surface and were attributed to plasticity. At this point the crack was growing at about 0.0005 mm/cycle. The surface was still flat to the eye, except for a tiny dimple at the crack tip, about 0.2 mm in size. Figure 1 shows the curving marks, photographed much later after the end of the test. This photograph includes the first 65 mm of crack propagation from the notch root.

A day later the test was nearing its end. The crack was about 145 mm long and was growing at about 0.001 mm/cycle (transition from Stage II to Stage III fatigue). The crack opening at the notch root had become significant, about 0.5 mm, suggesting that the specimen was in general yield. As the crack grew to a length of 150 mm measured from the load line, the curving marks of plasticity on the specimen surface became much larger, extending to a radius of about 8 mm on either side of the crack. One had the impression that these marks were forming first on one side and then on the other, and that this was how the plastic zone was developing in response to the advance of the actual crack tip.

At this point in the test the AE hit rate was on the rise, and 19 events had been located right at the position of the crack tip. As the crack grew faster and the stress intensity factor approached criticality, AE activity rose dramatically. Figure 2 shows 4-sensor source location plots taken from the last three data files prior to test termination. A key technique used to obtain these plots was to reconstitute the hit times from the recorded waveforms, using a threshold of 31 dB\text{AE} instead up to the data acquisition threshold of 40 dB\text{AE}. This improved the source location accuracy, tightening the clusters and reducing the number of outliers.

The test was stopped as the crack was accelerating towards final fracture of the specimen, having attained a length of 179 mm. The moment to stop was chosen based on previous experience with other CT specimens. The crack was then growing at about 0.01 mm/cycle (1 mm/minute) and would likely have failed in another ten minutes (about 1000 cycles).
Photographs were made of the plastic zone during the test, but better ones could be taken after its end. One of these is shown as Figure 3. It shows very well the plasticity marks (lines or bands) on the surface that had really blossomed out by the time the test was stopped. These lines would start at the crack tip, loop out and then return towards the crack plane, so that older ones would be overlaid by newer ones as the crack advanced, giving a criss-cross appearance. The lines are spaced 1 mm to 2 mm apart. The last ones to be formed, toward the right side of the photograph, extend at least 40-50 mm ahead of the crack tip. The whole field of view in this photograph is 80 mm from left to right. The photograph also indicates that the crack tip opening displacement was on the order of 0.3 mm at the time the test was stopped. Fig. 1 indicates that the final crack opening displacement at the notch root was about 0.9 mm.

Table 1 provides background information on the late stages of crack growth, to help in appraising Figures 2 and 3. The lengths in the “Crack Growth” column, directly observed on the specimen surface during the test, can be compared with the advance of the AE source locations across the specimen shown in Figure 2. The agreement is very good. Crack lengths are measured from the loading line because that gives the “a” used in fracture mechanics calcula-
tions. The “Located Events” column shows a dramatic increase as criticality approaches, confirming the ability of AE to warn of impending failure. Stress intensity factors $K$ were calculated from standard formulae (ASTM E 647). The increase in $K_{\text{max}}$ can be compared with the critical value of 130 MPa$\sqrt{\text{m}}$ reported in [2]. The plastic zone size $r_p$ for plane stress, estimated from the standard formula $r_p = (K_I/\sigma_y)^2/\pi$, can be compared with the direct observations on the polished surface discussed above and below.

<table>
<thead>
<tr>
<th>File Name</th>
<th>File Length (min)</th>
<th>Crack Growth $a$ (mm)</th>
<th>Located Events</th>
<th>$K_{\text{max}}$ (MPa$\sqrt{\text{m}}$)</th>
<th>$\Delta K$ (MPa$\sqrt{\text{m}}$)</th>
<th>$r_p$ (mm) (plane stress)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT5 008</td>
<td>36</td>
<td>138 to 142</td>
<td>31</td>
<td>52.5 to 55.8</td>
<td>47.2 to 50.2</td>
<td>3.7 to 4.2</td>
</tr>
<tr>
<td>CT5 009</td>
<td>90</td>
<td>143 to 165</td>
<td>165</td>
<td>56.7 to 84.7</td>
<td>51.0 to 76.2</td>
<td>4.3 to 9.6</td>
</tr>
<tr>
<td>CT5 010</td>
<td>24</td>
<td>165 to 179</td>
<td>1629</td>
<td>84.7 to 117.1</td>
<td>76.2 to 105.4</td>
<td>9.6 to 18.3</td>
</tr>
</tbody>
</table>

Table 1 Crack growth data (observed and calculated) and AE events recorded in the last three files of the test.

Figure 3 gives a good impression of the “sucking in” of the material in the heavily deformed region close to the crack tip. The plastic strain close to the crack tip is compressional in the out-of-plane direction and extensional in the in-plane directions. Conversely, the plastic strain at the back edge of the specimen is extensional in the out-of-plane direction, and compressional along the line from specimen edge to crack tip. At the end of the test, the back edge of the specimen had deviated from straightness by about 1 mm (an angle of $\pm 0.4^\circ$ approximately). The crack opening displacement at the notch root was also about 1 mm. Thus the specimen was well into general yield by the time the test was stopped. One can speculate whether the plasticity marks shown in Figures 1 and 3 accounts for a significant part, or even for the whole of this general yield. It is unknown whether the plasticity marks were only a surface effect, or whether there was also some similar process, taking place in the mid-thickness of the specimen. Other mechanisms may have been at work. Shortly before the test was stopped, a slight haziness was observed on the surface in the region of most intense plasticity, but this could not be photographed and was not found again when the specimen was re-examined some months later.

Figure 4 Fractographs from a CT specimen, in early (left) and middle (right) Stage II fatigue.

Further information on the nature of the fracture process comes from the electron micrographs shown in Figure 4. These were taken on another specimen in the same series, number CT-12.
In early Stage II fatigue (crack length around 95 mm), the fracture surface was dominated by microvoid coalescence (left hand picture of Figure 4). In mid Stage II (crack length around 125mm) the fracture surface shows quasi-cleavage with some traces of fatigue striations (right hand picture of Figure 4). The striation spacing, on the order of 1µm, is compatible with the crack growth rate. The quasi-cleavage appearance persisted through to late Stage II (crack length around 175mm).

3. Some Characteristics of Grating AE

It is a well-known feature of fatigue crack growth that the crack surfaces, fully separated when the load is at its peak, can make contact when the load falls. Crack closure affects the propagation rate and is also a well-known source of AE. Various terms are in use including crack face interference, rubbing, friction and grating. From the standpoint of AE, the most noteworthy characteristic of this kind of signal is that it repeats, cycle after cycle. The AE is attributed to the interactions of matching asperities on the opposing surfaces, as depicted in Figure 5. Sometimes there are two signals on each cycle, one while the load is approaching its minimum and another when it is rising again. Sometimes the load at which the AE takes place decreases with the passage of time. In this test there was usually just one signal per cycle.

In the tests on the CT specimens a new aspect of the grating phenomenon was discovered. Figure 6 is a scatter plot of amplitude vs time taken from the test on specimen CT-5, 1000 cycles before the test was stopped. At this time the crack was accelerating, from 0.0032 mm/cycle to 0.0076 mm/cycle in the 600 cycles shown in Figure 6. Conspicuously in the amplitude/time scatter plot, several “loops” are seen in which the amplitude systematically rises to a maximum and then falls over a period of time. The best-formed of these loops ran from 480 s to 650 s, 340 cycles during which the crack tip advanced by an estimated 2.5 mm. This large loop was followed by four smaller loops.

In both the CT specimens and the cruciform specimens, increasing amounts of “grating” emission were observed as crack advanced from Stage II to Stage III. Along with this, the fracture surface got rougher. Photographs showing this will be presented in Section 4.
The emission signals in the “loops” showed remarkable reproducibility of waveform from one cycle to the next. Figure 7 shows the waveforms from three consecutive cycles at the point marked with the cross on Figure 6, 520 s into the file. The waveforms are almost identical, even down to the late-arriving reflections more than a millisecond after the first arrival. This is strong evidence that they came from precisely repeated mechanical action at the same “grating” source.

Figure 7  Three waveforms produced in consecutive cycles by the same “grating” source

Figure 8 shows an interesting waveform that was recorded at 717 s on the timescale of Figure 6. In Figure 6, two loops visually intersect at this point, indicating that two asperities were active simultaneously. Indeed, the waveform in Figure 8 clearly shows two components, separated by 500 µs. In the course of ten cycles the amplitude of the first component shrank from 30 mV to 7 mV, while the amplitude of the second component stayed relatively constant at 20-25 mV.

Figure 8  Waveform produced by emissions from two asperities, separated in time by 500µs

In addition to the “loop” signals, the 500-600 s interval of Figure 6 shows several smaller signals. At first sight, these were considered most likely to be signals from crack growth. One might expect grating to be separable from crack growth by having lower frequency content. This is indeed the case, as is shown by Figure 9 which is a scatter plot of frequency centroid versus time. The repetitive emission signals in the grating loops have frequency centroids in the range 160-175 kHz, whereas the smaller intermittent signals have frequency centroids in the range 200-300 kHz.
Figure 9  Frequency centroid vs. time, showing how this feature behaved for the grating loops of Figure 6

On this basis, the strong line of activity from 730 s to 900 s, low in amplitude and high in frequency centroid, might be interpreted as coming from crack tip movement. However on closer examination, it was found that the emissions along this line also had very repetitive waveforms (though they were much shorter in duration than those in the loops). Moreover the signals occurred at low loads, typically 10-11 kN as the load was falling towards its 4 kN minimum. The emissions in the loops also occurred at 10-11 kN, but during the rising-load phase. So it is concluded that despite the low amplitude and high centroid frequency, the strong line of activity from 730 s to 900 s is coming not from forward movement of the crack tip, but from a different kind of crack face interference.

References 2-6 are written on the basis that crack prognostics should be made only from the AE that results from actual growth, i.e. AE that occurs at or close to the peak load of each cycle (according to traditional assumptions). Early prognosis has been a goal of that line of work. In this paper we have taken a different and perhaps complementary direction, focusing on the “grating” AE that is found as the crack is approaching instability (<7000 cycles to failure). It seems that in specimen CT-5, the amount of grating emission was about 70 times greater than the amount of crack growth emission. Because of this and because of its larger amplitude and interestingly recognizable characteristics, this “grating” emission could possibly find use as a second line of warning and diagnosis. Precisely how to do this is not clear, but it could perhaps be used to tell when a crack on a bridge had reached a late stage of growth, in case it had not already been identified at an earlier stage.

4.  Cruciform Specimens: Use of Other NDT Methods (UT, PT, VT)

In the CT specimens, the position of the crack front was directly visible as it grew across the specimen width. With the cruciform specimens the position of the crack front was not directly visible, except sometimes at the specimen edges. It is the same with bridges. Sometimes the local geometry makes it easy to see the crack’s significant dimensions, sometimes not.

Sizing cracks is important for assessing their structural significance. Sizing is accomplished by visual inspection or more sophisticated NDT methods. Significance is determined by code and/or by fracture mechanics techniques (starting with determination of the stress intensity factor). It is true that acoustic emission offers the potential to assess stress intensity factor and crack growth rate directly, without knowledge of the actual crack size. But we were not quite ready for that; for current purposes, we wanted to keep all factors in sight.
In bringing additional NDT methods to bear on the cruciform specimens, we wanted to mimic or model the following bridge inspection scenario: (a) AE monitoring is established on a bridge component; (b) AE gives some kind of a warning to the bridge engineers; (c) the area is inspected with other NDT methods; (d) prognosis methods are applied, based on one or both of the above; (e) a decision on next actions is taken by the bridge engineer. To achieve a parallel to this scenario, it was desirable to stop the cruciform test before failure, assess the position of the crack front using NDT, perform prognosis, and then proceed to failure to assess the effectiveness of the whole process.

The cruciform design represents a common bridge weld detail. Figure 10 shows a representative specimen. This specimen type differs from the CT specimen in several important respects. First, there is a weld involved. Second, the amount of crack growth before failure is much less: only about 9 mm, compared with 200 mm in the CT specimen.

Fatigue cracks in these specimens usually initiate at the weld toe where there is a strong stress concentration, and will then propagate through the thickness of the long (load bearing) leg as shown in Figure 11. Crack initiation may be accelerated in the presence of flaws or other discontinuities. Once initiated, a crack will tend to assume a semi-elliptical profile and to advance in the thickness and width directions simultaneously. Cracks may initiate at multiple sites and join up as they grow. If the specimen is precisely aligned and perfectly gripped so that the stress field is uniform across the width, the advancing crack front tends to become a straight line across the width of the specimen. However if there is any asymmetry in the loading or gripping conditions, the crack front may take on a less regular profile.

Out of the full suite of major NDT methods, ultrasonic testing (UT) was selected as the best candidate for sizing these cracks. Estimation of the crack profile is the main point of interest. In ultrasonic testing, crack sizing is an important topic and much has been written about it. Sizing is much harder than detection. Older techniques, based on changes in signal amplitude as the sensor is scanned, have been largely replaced by modern techniques such as crack tip diffraction and TOFD. But here we ran into some difficulty. The basic concept of crack tip diffraction is not hard to grasp, but it is another matter to pin down a specific technique that will work for a particular combination of geometry and material thickness, and crack position, size and orientation.

In this case, after preliminary study it was decided to use an advanced UT search unit from Olympus Inc., a combination of a 5 MHz 3/8” transducer with a CDS wedge. This probe simultaneously introduces several waves into the part. One of these waves is a 30° shear wave, which on reaching the opposite face mode-converts to a 70° longitudinal wave. This wave is
reflected from the crack, producing a return signal at the probe as shown in Figure 11 (left). This is called the “30-70-70” path. A second path, whose nature has been described differently by different authors, was shown by Blanshan and Ginzel [7] to involve the head wave indicated in Figure 11 (right), which on reaching the crack produces a strong “corner trap” return signal. A third path is obtained when the 70° longitudinal wave is diffracted directly back from the crack tip, but this is only observable when the crack is very deep. It must be understood that Figure 11 is simplistic because in fact, there is considerable beam spreading which has a strong influence on the observed return signals.

To facilitate development of a sizing technique for the toe cracks in the cruciform specimens, a special calibration bar was fabricated. This was made from an offcut from one of the 12.7-mm thick cruciform specimens. The offcut was sent to PH Tool Inc., who machined three narrow EDM notches across its width, having depths 1 mm, 4 mm and 8 mm, respectively. Return signals from these notches were investigated using the above-described search unit in conjunction with a MISTRAS Pocket UT instrument. A typical instrument display is shown in Figure 12. The indication at 28 µs is the “30-70-70” path and the indication at 31 µs is the “corner trap” path.

At first it was hoped to find a measurement technique based on time differences. Time-based techniques are generally considered superior to amplitude-based techniques for crack sizing. But no such technique could be found that would work effectively with this specimen thickness and these notch crack depths. Eventually after much experimentation, an amplitude-based technique was defined. The amplitudes of both paths were very sensitive to the surface distance between crack and probe, so it was necessary to standardize this distance by placing the probe so as to bring the “corner trap” return to a specific point on the time base. This
done, it was found that the amplitude of the “corner trap” return was relatively independent of notch depth, whereas the amplitude of the 30-70-70 path was strongly dependent on notch depth. The ratio of the amplitudes could thus be used for estimating the crack size. From study of the amplitudes and their ratio using the calibration bar, the procedure for estimating the size of the cracks in the cruciform specimens was finalized.

To assess the validity of this technique, the test on cruciform specimen SC-5 at USC was stopped when the AE indicated significant crack growth. The crack was visible on one edge, where its depth was measured as 5.7 mm (i.e. nearly half the thickness). However, without NDT there was no way of telling how the crack depth varied across the specimen width. The specimen was sent to Mistras Group for crack sizing according to the above-described UT procedure. The result is shown in Figure 13. Next, dye penetrant testing (PT) was performed following the requirements of ASTM E 1417, with the results shown in Figure 14.

![Figure 13](image1.png)  
Figure 13  Mid-test crack profile estimated by ultrasonic testing, specimen SC-5 (left edge known visually)

![Figure 14](image2.png)  
Figure 14  Results of dye penetrant inspection after performing ultrasonic testing, specimen SC-5

![Figure 15](image3.png)  
Figure 15  Mid-test position of crack front revealed by completing the test after applying dye penetrant
The penetrant testing indications shown in Figure 14 are broadly compatible with the UT results. As an important side benefit of the PT, it was anticipated that the red dye would penetrate to the crack front and provide a definitive profile when the crack was broken open. The specimen was returned to USC and the fatigue cycling was resumed until the specimen failed. The resulting fracture surface is shown in Figure 15. The dye penetrant line on the fracture surface was an excellent confirmation of the effectiveness of the UT sizing procedure.

With a measure of confidence in the UT sizing thus established, a more elaborate process was applied to a second cruciform specimen. Again the test was arrested when AE showed structurally significant cracking. Again the cracked specimen was sent for UT and PT. But this time the results have been referred for prognosis, further fatigue cycling has been conducted, and the specimen is being returned for a second round of UT. In this way we are mimicking the crack management process that is proposed for use on bridges.

To further illustrate the general features of fatigue fracture in steel weldments of this kind, photographs were taken of one of the first tested cruciform specimens. Figure 16 (left) shows the fracture surface, oriented with the crack front advancing from bottom to top (like Figure 15, but different specimen). From bottom to top, there is first a short angled lip corresponding to the smoothing out of the remaining irregularities in the bead of this very well fabricated weld. Then after the first 1.5 mm of slow propagation there is a 1 mm dark coloration associated with the heat affected zone. Next there is a 4 mm smooth region of Stage II fatigue. In the following 4 mm the surface becomes increasingly rough. Finally, a ridge running across the upper part of the field of view marks the boundary between the flat surface formed by the cyclic loading and the ductile shear lip formed during the final rapid fracture of the specimen.

Figure 16 (right) is an enlarged and differently illuminated view of the transition from late Stage II through Stage III (lighter area at bottom) to the final rapid fracture (darker area at top). The increase in surface roughness is very much in evidence and since this corresponded with increasing AE, it is very probable that some of these asperities were being detected as AE sources. There are also some indications of beach marks associated with individual cycles shortly before failure.
5. A Simple Active Sensor Technique for Crack Length Measurement

Techniques for pulsing AE sensors electronically, known as Automatic Sensor Test or AST, have been in existence for at least fifteen years. The main purpose for developing these techniques was to provide a means of checking sensor coupling and mounting, quickly and remotely. AST is used as an alternate or complement to the long-established pencil lead break techniques, which requires the presence of a technician at the sensor location. A second application of the same technology is to use the pulse to interrogate the actual structure. In the language of structural health monitoring, this is called “active sensor” technique in contrast to “passive sensor” technique, which refers to the conventional AE monitoring mode. As part of this study on the CT specimen, a simple active sensor technique was applied to see how well it could measure crack length.

Figure 17  “Active sensor” technique: sensors and propagation path used for crack sizing in CT specimens

Figure 17 shows the CT specimen geometry (in millimetres) and the positions of the 150kHz sensors used in the fatigue tests. In a typical AST sequence, all the sensors are pulsed in turn. For each pulse the responses of all the sensors are measured and recorded. As a safeguard, several pulses are usually applied before moving on to the next pulser. Once the necessary details have been specified in the software, the whole measurement sequence is initiated with just a few keystrokes.

Pulsing any sensor produces a complex response at all the others. This response includes the effects of many wave paths and echoes within the specimen. These will be affected by the crack length. Many ways can be imagined for determining crack length from this rich set of data. We examined only the simplest and most straightforward way, derived as follows.

In the study of AE waveforms, the early parts are the most informative and the most useful to analyze. The sensor configuration used on the CT specimens was examined to see which sensor-receiver pair whose shortest propagation path would show the greatest change in travel time as the crack grew. Sensors 1 and 5 were identified as having the best characteristics from this standpoint, as shown in Figure 17. Analysis was limited to this sensor-receiver pair.

To collect data using active sensor technique, the fatigue test on specimen number CT-12 was interrupted at intervals to take AST data and to measure the crack tip position. To minimize
variability due to crack closure effects, the AST data was always taken with the load at about 80% of its maximum.

Figure 18 shows time of flight versus crack tip position, for six such interventions in the course of the fatigue test. The times of flight, based on the first threshold crossing, are transcribed directly from the AST section of the AEwin software. Signals from AST look similar to signals from natural acoustic emission. In a later attempt to improve accuracy, the first motion times derived from visual inspection of the waveforms were used instead of the first threshold crossing times. But this did not make a useful difference.

![Figure 18 Active sensor technique: time of flight for the diffracted wave path, as a function of crack length](image)

The good correlation shown in Figure 18 shows the feasibility of using the geodesic diffracted path for estimating crack length. The scatter appears to be greater at shorter crack lengths, which is consistent with the geometrical situation shown in Figure 17. The nature of the wave propagation processes under these test conditions is complex and unclear. The shear wavelength is close to the specimen thickness, and the path lengths are only ten to twenty times greater. Under these circumstances the classical analyses in terms of longitudinal, shear and Lamb waves do not work well. But elastodynamic analyses were not readily available. The resolution and accuracy of this approach would probably be improved by working at higher frequencies. Further work is needed to build more experience, decide how to handle the theoretical issues, and test this possible technology on an actual bridge.

**Conclusions**

1. Polishing the surface of a CT specimen permitted a remarkable view of the development of plasticity around the tip of the advancing fatigue crack. The observed plastic zone size was consistent with fracture mechanics calculations.
2. AE source locations tracked the crack quite accurately as it accelerated across the CT specimen in the later stages of the test. Post-test threshold adjustment was an important factor in achieving tight clustering of the located sources.
3. A large increase in AE activity late in the test was matched by an increase in surface roughness. “Grating sources” (asperities on the fracture surface) created remarkably repeatable waveforms and “amplitude loops”, behaviours that might have diagnostic value.
4. With cruciform specimens, the position of the crack front could not be visually observed. An ultrasonic testing procedure was therefore developed to determine the crack profile prior
to fracture. The effectiveness of this procedure was confirmed by using dye penetrant as a crack front marker and then taking the specimen to fracture. Continuing work along these lines is mimicking potential bridge scenarios: AE monitoring gives a warning, which is followed up with other NDT and/or AE-based prognosis techniques to help manage the crack.

5. A new and simple 150-kHz “active sensor” technique, using crack tip diffraction, was explored and indications of its capabilities and limitations were obtained.

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References