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THE PREDICTION OF ACOUSTIC EMISSION BEHAVIOUR OF LARGE STEEL STRUCTURES FROM LABORATORY MEASUREMENTS

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INTRODUCTION

Laboratory tests of ductile steels have shown that most of the detected emissions are associated with plastic deformation and that ductile crack growth is relatively quiet (1). Measurements to detect defects during pressurisation of large steel vessels have given variable results, some workers having detected plastic deformation and crack growth, others not (2,3,4). The direct comparison made here between the emission activity of laboratory specimens and an artificially defected pressure vessel demonstrates how erroneous predictions of pressure vessel emission characteristics may be made from laboratory tests and why emission may be undetectable from large structures.

EXPERIMENTAL PROCEDURE

Laboratory tests Four point bend specimens, 35.5 cm (14 ins.) long of the type shown in Fig. 1 were tested. The straight 'plate' specimens were machined from original vessel plate material and were tested to assess the characteristics of BS 1501-151 steel with the objective of predicting the acoustic emission response of a large (5m x 2m) artificially flawed test pressure vessel made from the same material. The curved specimens were cut from the pressure vessel after it had been pressurised to failure.

An REML, 190 kHz resonance, emission sensor was attached at each end of the specimen. Discrimination against spurious signals originating at the loading points was achieved using a coincidence system. This system validated an emission as coming from the fatigue notch in the specimen only when both sensors were triggered within a fixed gate time (20 s in these tests). Measurements were made of load/COD, ringdown count rate/COD (X-YY), located emission rate/Time (X-T), ringdown count rate/Time (X-T). Reference load values were included on the constant speed (X-T) recorders via an event marker. A tape recorder was used on some tests to record emission for future reference and off line pulse height analysis.

RESULTS

Typical load/COD (crack opening displacement)/Emission ringdown records for plate and vessel specimens are given in Fig. 2. The ringdown emission rate clearly shows the marked difference in emission characteristics (and a 12/1 difference in emission rate) of plate and vessel specimens. Plate material gave maximum activity at general yield, low activity during ductile crack extension and increased activity at maximum load, probably associated with tearing and delamination, evidence of which could be seen on the fracture surface. Vessel material gave almost uniform activity between general yield and maximum load. On the located count records (one count per emission event), the difference in emission rate at yield is not so marked and count rates immediately after yield are higher from vessel specimens, as shown in Fig. 3.

The totalised emissions at three load levels from the 11 specimens tested i.e. general yield, 1.25 x general yield (minimum count rate in plate material) and at maximum load (level at which the test was stopped) are shown in Table 1. Comparison of data up to 1.25 x general yield load shows that the plate specimens were at least twice as active as vessel specimens. Pulse height analysis Fig. 4, shows the emission amplitude distributions at progressively increasing loads. At all levels peak signal amplitudes were lower from vessel than plate specimens, a result which could be inferred from the ringdown count rates. Signals with amplitudes greater than 30 times instrument noise level were infrequent from either type of specimen.

PRESSURE VESSEL TEST (4)

The pressure vessel was fabricated using BS 1501-151 Grade 28A, a low strength C-Mn pressure vessel steel. Three axial partial penetration defects were introduced into the vessel surface and the vessel was pressure cycled to 525 psi to promote fatigue crack growth at the most severe defect. This defect was initially 8 inches long and 0.8 inches deep and after 1142 pressure cycles the defect depth had increased by an estimated 0.08 inches. Of the 1142 pressure cycles, 91 were monitored using the SWEL system (5) but the first cycle was not monitored. Only the defect known to be growing under the cyclic load was monitored for acoustic emission. Emissions were monitored using an array of 190 kHz resonant emission sensors mounted with araldite adhesive. Detection system sensitivity was checked using dummy emission pulses generated by driving an emission sensor with an electrical impulse. During the 91 cycles monitored using SWEL, acoustic emission from the defect region was low; approximately 200 emissions (including background activity) were observed. No localized emission source could be identified positively with the machined defect.

After fatigue pre-cracking the severest defect, a fourth partial thickness defect was machined into the vessel wall. The vessel was then subjected to 13 progressively increasing pressure excursions until the 0.88 inch deep fatigue pre-cracked defect penetrated the vessel wall at a pressure of 950 psi and the vessel failed by leakage. The whole vessel was monitored for emissions during this phase of the test. Throughout the test no statistically significant emission source was identified either from the fatigue pre-cracked defect which failed by tearing through the remaining ligament or from any of the other three machined defects, at least two of which were calculated to be yielding(4).

COMPARISON OF SYSTEM SENSITIVITIES

In order to assess the significance of the laboratory emission data an effort was made to compare the system sensitivities on vessel and test pieces. In the absence of an absolute method of calibration, comparisons were made using dummy resonant signals generated by exciting an emission sensor with pulses 10 sec. wide of amplitude 50 mV (test pieces) and 200 mV (pressure vessel). Calibration checks of the pulser system had shown that the received signal amplitude varied linearly with input pulse amplitude for inputs in this range. Measurements on the vessel were made both by exciting sensors in the detector array and by exciting separately attached 'pulsing' sensors. Sensitivity checks on specimens were made by exciting each sensor in turn and measuring the peak received signal at the other. Measurements were also made to estimate errors caused by differences in sensor construction and coupling between vessel and specimens. The result of these measurements indicated a reduction of sensitivity of 26 db on the vessel compared with specimen tests.

DISCUSSION

These results have particular relevance to the use of laboratory tests in the prediction of the emission behaviour of large structures.

Firstly the differences in emission characteristics of vessel and plate specimens (made from the same material) show that laboratory tests should be made on specimens which have undergone the same forming processes as the structure. The most likely reason for the differences between the specimen types if the different heat treatments seen by plate and vessel material. The plate was in the 'as rolled' condition whereas the pressure vessel had been formed and stress relieved for 2 hours at 625°C after fabrication. Other workers have reported that slight changes in heat treatment produced significant differences in acoustic response(6). The differences between plate and vessel specimens are not thought to be attributable to the amount of prior stress seen by the vessel specimens for the following reasons. The vessel failed at a hoop stress of approximately 13 tsi and as the yield strength was 16 tsi regions remote from the defects from which the specimens were cut would have suffered no previous plastic deformation. That this was the case is shown by the well defined yielding plateau (indicative of freshly yielding material) in the load/COD record for the vessel specimen (Fig.2).

Secondly there is a large discrepancy in emission activity and detection sensitivity between vessel and specimens. The loss of sensitivity on the vessel has been attributed mainly to attenuation and dispersion, which reduce signal amplitude with distance from the signal source and variations in sensor sensitivity. These factors may produce high losses, since unambiguous location of an emission source on a large structure or vessel requires signal detection by both the least sensitive and most remote of an array of sensors. The discrepancy between the emission activity of vessel and specimens may be accounted for by comparing the indicated difference in sensitivity with the results of pulse height analysis.

Only 1 (approximately) of the signals from the vessel specimens exceeded background by 26 db and less than 0.2 by 30 db. Taking into account the loss of 26 db indicated by the sensitivity tests this means that very few signals would be detectable on the vessel, e.g. perhaps 10 at yield, of the order of 100 before failure occurred, spread over 13 pressurisations. These few signals, if detected, would be of low amplitude and any clear emission source indication obscured by scattered surface activity and errors in location analysis. The conclusions to be drawn from these measurements are firstly that erroneous predictions of emission behaviour of a structure may be made unless specimens of the actual structural material are tested. Secondly, even if this is done, the prediction of emission activity of a large structure requires some means of comparing system sensitivity between field and laboratory measurements.

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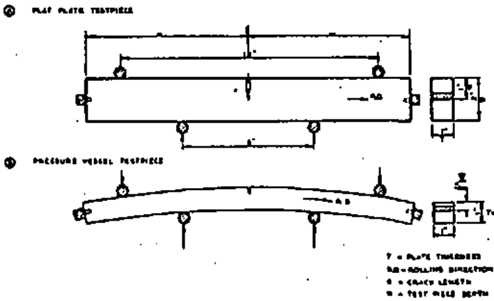


FIG. 1 TESTPIECE TYPES USED IN COINCIDENCE WORK

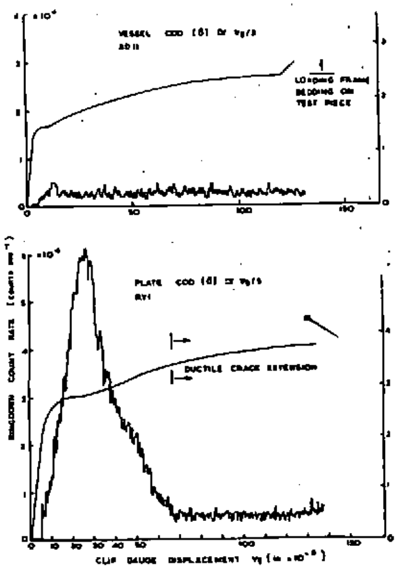


FIG.2 RINGDOWN / COD AND LOAD / COD TEST RECORDS FOR 'PLATE' AND 'VESSEL' TEST PIECES

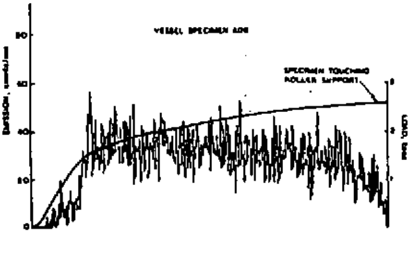


FIG.3 LOCATED EMISSION RATE. BS 1501/151/28A STEEL SPECIMENS

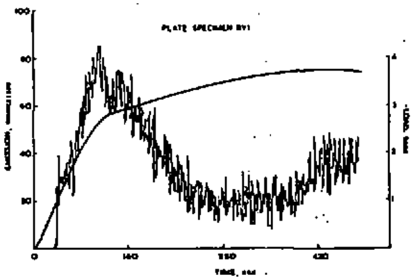
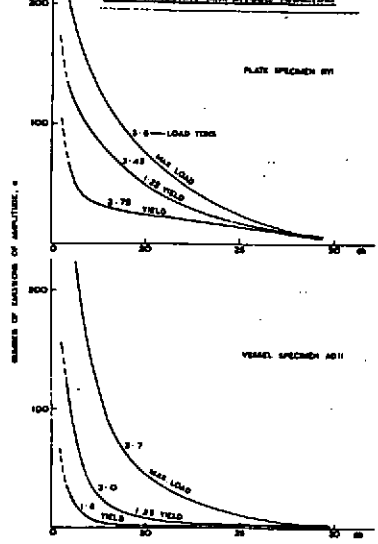


FIG.4 EMISSION AMPLITUDE ANALYSIS



ACOUSTIC EMISSION AND THE ASME PROPOSED STANDARD: A CRITIQUE

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Within the United States the Boiler and Pressure Vessel Codesof the American Society of Mechanical Engineers are the law in 48 of the 50 states. No further commentary is necessary to exnound on this point. It is will advised for any new and promising nondestructive inspection technique to seek acceptance through ASME codification. Such is the case with acoustic emission; ASME document E00096 is a Recommended Practice for "Acoustic Emission Examination During Application of Pressure." This RP has been developed by an Ad Hoc Working Group on Acoustic Emission of ASME whose members are to be complimented on their perseverance and perspicacity. The author believes that portions of the document are too far-reaching and currently somewhat beyond the demonstrated capacity of the technique. Indeed, valuable functions of AE are absent and thus degrade the applicational use of the technique.

To the reader it should be ovbious that acceptance of AE methods and techniques will be of major economic importance to AET Corp. and our competitors, even so our enthusiasm for the technique must be tempered by conservative engineering or else these same techniques will never make a technology.

The views presented here should be considered merely juxtaposed rather than in controposition to some of those recommended. Following through the actual document is one way to point out my position. For example, the Foreward speaks of the proposed standard's purpose as "...to provide industry with a common basis." I question -- basis for what? Is this standard a foundation (or base) for establishing structural integrity, detecting flaws, locating flaws, assisting other NDE techniques, or what? The Foreward continues with gaining experience "...to establish the credence of acoustic emission technology." Again I question -- belief in what?

A good portion of my views on the proposed standard evolve because of the lack of objective definition as to the benefits to be accrued and the rationale for applying an AE examination. As practitioners-of-the-art we are possibly too close to fully comprehend, from a users viewpoint, why AE monitoring should be accomplished. The Foreward, to continue my example, goes on to state that AE examination has been successfully used and also that it has potential advantages over other nondestructive examination methods for certain applications. What type of success and advantages are not explicitly stated, nor to my interpretation are they implicate in the body of the proposed standard. I say that if we have made successful applications and if we have advantages we had better say what they 'were' and 'are' and be prepared to back them up with cold, hard facts which are predicated upon accepted NDE and engineering practices. Without this information, if I were a potential user of AE I would be interested only academically. Industrial response to the proposed standard has been mild, to say the lease, and the Foreward's request to use and evaluate, without reference to how to evaluate, is only a vacant supplication.

The principle objectives, defined as "...to locate, monitor and grade emission sources..." are rather inconspicuously placed in subparagraph 1122.1 under General

* The views expressed in this presentation represent those of the author and may not be construed as the position of AET Corporation.

Requirements. Monitor, as an objective, is not defined and yet should be one of the major functions of an AE examination principally with respect to leak detection and localized yielding.

Preliminary Information is not a realistic or properly strong section of the recommended standard. I find it lacking in its inability to take an assertive position with respect to the pressure application program and means of assuring elimination of potential noise sources. We are all aware that if experimental stress analysis techniques such as strain gages or NDT methods such as ultrasonics or radiography were being used that certain steps, procedures, and schedules would have to be implemented for their successful utilization. These would be specified and might consist of such items as surface preparation for strain gages and UT, unrestricted and sole accessibility to the test article for radiography, and possibly modification to the pressure schedule to suit strain gage readings. Yet in the proposed AE standard the passive role almost assures difficulties in properly accomplishing a creditable test.

If AE techniques are to be applied we should insist upon them being applied properly and with every consideration given to producing clear and unequivocable results. Thus pretest accessibility to the vessel should be a requirement, as should proper surface preparation for sensor attachment. Scaffolds, belts, chains, and other paraphernalia contacting the test structure, but not absolutely necessary for the test or operation, should be eliminated. Similarly experience has established that pressure accumulations, flexible pressure lines, downstream check valves and implementation of other such items can usually reduce the background noise levels to insignificance.

Quite possibly the strongest single item to be insisted upon by the AE examiner is the pressure application program. Merely allowing the pressurization to occur at an uncontrolled rate (usually predicated by the pump system) and without serious consideration of the AE monitoring is ludicrous. I, and in this instance AET Corp., have always proposed a pressurization schedule such as shown in Figure 1. While some modification of the schedule is negotiable the viable features should be retained. These are: 1) pressurization rates to be constant (or as nearly as possible) in order to minimize strain rate induced variations in the AE data. 2) Plateaus to be selected with no less than three nor more than burdensome. Hold periods to be on the order of five minutes, or until AE data dissipates. This feature generally enables the AE examiner an opportunity to operate the monitoring system under the best signal-to-noise ratio condition. Further, it is self sorting with respect to flaw growth and continued emission at increasing pressure plateaus and also enables the possible monitoring for leaks and localized yielding to be accomplished. 3) The pressure decreases with repeated increases through previously applied pressure increments enables the "Kaiser Effect" to be used in its fullest capacity. Firstly, this procedure will verify extraneous mechanical noises, thus increasing credence in the monitoring and secondly it will also self sort (and thus help to rank) the emission locations. We do not suscribe to a pressurization test philosophy with AE monitoring that does not propound a pressurization program such as shown in Figure 1 or a modified program as shown in Figure 2.

Usage of such words as "relevant, acceptable, energy, representative, and evaluated" must be clearly defined as to their purpose and intent and method(s) of accomplishment. Detection sensitivity calibration (1123-2a) which describes gain adjustment to provide a minimum specified artificial source signal response as detailed in the examination procedure is not discussed in same. Sensitivity sufficient to detect a simulated AE source may be insufficient to detect a real AE source. Detection levels should probably be specified with respect to the sensor output and in my judgement (other AET Corp. staff members concur) system sensitivity should generally be run as high as possible. It is easy to discard data based upon amplitude level but impossible to recover the same if never captured.

Comments on the verification of the system source location function concern themselves with the possible ability to "beat the specification" based upon selection of "representative locations." This locational capability should possibly be denoted in terms of percent of total surface area or by mutual agreement with the owner. Locational accuracy beyond that absolutely required usually increases test cost in direct proportion (at least) to the number of channels.

It is somewhat difficult to imagine how one might force the artificial source signal to background noise ratio to remain acceptable upon pressurization as stated in 1132.1. Consideration of this potential problem area has been discussed previously as an item to be accounted for well in advance of the actual test performance. I do not believe that many project engineers will currently accept the philosophy expressed in 1132.3 and controlled by 1144 regarding nonscheduled pressure hold periods required when Grade A signals occur, and Grade A signals being those occurring during pressure build-up. This is when the overwhelming majority of the signals do occur and thus it would be almost impossible to complete the test particularly if other NDE methods (plural is in the standard) such as radiography or manual UT are required (particularly if pressure decreases were necessitated because of safety requirements). Under the same section, 1132.4 discusses "...selected hold in pressurization..." and does not define the selection process. I again suggest the predesignated pressure program of either Figure 1 or Figure 2. It is disconcerting to see references to taking necessary action to influence control of background noise at this point. AE test procedures should be assertive to these potential problem areas as a preventative approach rather than responsive to problems after they develop.

Categorically paragraph 1132.5, which allows the examiner to descretionally select whether or not he accumulates AE data during hold periods, is ill advised. Pressure plateaus, as previously discussed, are one of the more meaningful and least troublesome of the AE data periods. It should be mandatory to acquire data during hold pressure intervals.

Section 1143, Grading of Signals, presents the strongest reason why this Proposed Standard will not readily be accepted and rightly so. An entire treatise might be developed of rationale suggesting the prematurity of this concept on an absolute basis rather than on a comparative ranking. Variations in material(s), welds, attenuation, temperature, and numerous other factors can and probably will affect this effort. It is possible that the method(s) presented in ASTM's Acoustic Emission Monitoring of Structures During Controlled Stimulation (E596-76) is a currently better and more viable approach.

Appendix A on Calibration Procedures I choose to delete from this discussion and proceed to Appendix B, Interpretation of Results. B-1132 requires that AE source location be performed on signals detected by a minimum of two sensors. Except for pipe or other such lineal source location procedures, planar location cannot be accomplished by a two-sensor array. Allowing the analysis of the AE data over a parameter of time, as expressed in B-1133, is also ill advised unless time and pressure (for example) had a one-to-one correspondence. The example of stress range increments should most likely designate which principle axis of stress.

The data reporting of B-1134 is impractical and indeed almost impossible without the pressurization schedule I propose. The interpretation of AE activity as described in B-1135 is inconsistent with the 1144 Grade A definitions as is B-1137.

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PERSONAL RECOMMENDATIONS:

My analysis of the status of Acoustic Emission suggests that a more reasonable approach toward acceptance would be to concentrate on those areas in which acoustic emission monitoring has been proven with demonstratable results. These are: 1) locating the origin of detected signals; 2) detecting leaks; 3) locating leaks; 4) detecting loose parts (usually under flow conditions); 5) detecting localized yielding (under suitable conditions); and finally, a possible inclusion of 6) ranking of AE locations with respect to that test vessel only in terms of AE data such as: a) Events per location. b) Cumulative peak amplitude per location (normalized for distance if important). c) Ringdown counts per location. d) Amplitude distribution per location (normalized if important) and at various percentages of pressure. All of the forementioned should be on a normalized parametric scale (pressure, for example) for both rising pressure and hold periods. I reserve the right to change my thoughts on Item 6 above at any time.

In essence, I believe that we are capable of producing separable standards, one for the demonstratable and viable utilization of AE monitoring to augment the test performance (leak detection), possibly prevent catastrophic or premature failure (yield detection and continued AE from specific locations during hold periods) and to assure that active flaws are detected and located (so as to be more thoroughly inspected by currently accepted NDE practices). The second standard should be proposed as to evaluating the various methods of grading (ranking) the Acoustic Emission locations and corroborating them with code defined practices.

Finally, we should most thoroughly display in bold letters that Acoustic Emission source locations are from active flaws (indications?) and that passive discontinuities may indeed become the critical element in successful operation of the structure. Passive flaws cannot be detected by AE. Further, we do not yet know the full limits or horizons of Acoustic Emission and thus regular review of proposed and accepted standards should be continued. Joint participation of U.S., European, and Japanese Working Group members with the Ad Hoc ASME Committee is vital to the further acceptance of the technology.

I again wish to express that many of these comments are purely my own views. However, they may well have originated through discussions with the knowledgeable members of the AET Corporation staff, and a wide variety of personal contacts with the literature, clients, and other practitioners of the technology -- friends, competitors, and both.

ACOUSTIC EMISSION AND THE PROPOSED ASME STANDARD: A CRITIQUE

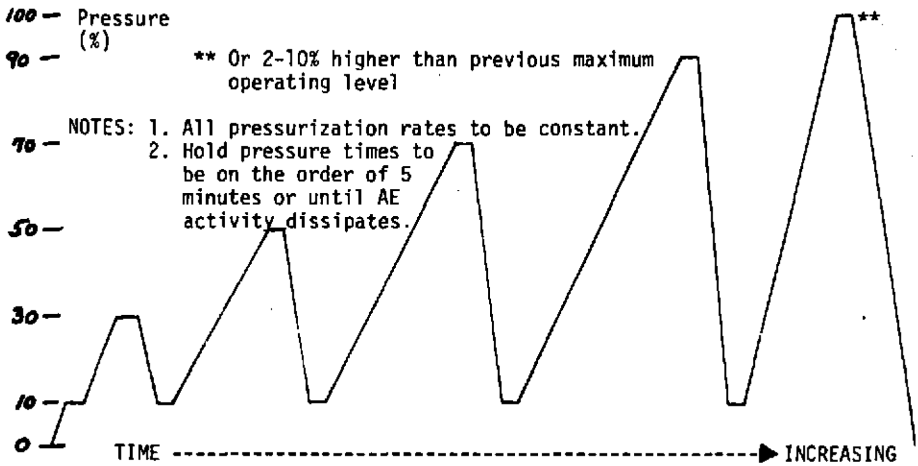

FIGURE 1: SUGGESTED PRESSURE TEST SCHEDULE

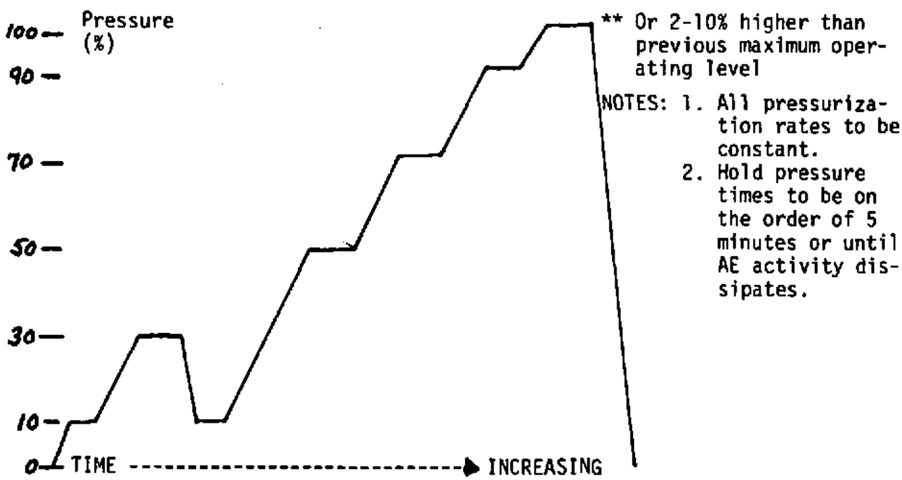

FIGURE 2: SUGGESTED PRESSURE TEST SCHEDULE (ALTERNATE)