THE DETECTION AND MONITORING OF CRACKS IN STRUCTURES, PROCESS VESSELS AND PIPEWORK BY ACOUSTIC EMISSION

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Acoustic Emission monitoring of low fatigue life joints and defective weldments on offshore structures is providing new insight into the mechanism of fatigue crack propagation in these structures and strong evidence of the reliability of the method for the remote detection and monitoring of cracks. Results obtained during 1984/85 on three offshore structures are presented and compared with data from laboratory tests on large scale weldments. Hitherto problems with the subsea installation of transducers, background noise, data condensation, equipment supervision and operational reliability have been solved by the development of new measurement and analysis instrumentation. This equipment is described.

Key Words: Stress waves, Cracks, Monitoring, Offshore Structures

INTRODUCTION

When inspection is difficult, as is often the case with important areas of process plant and structures, particularly offshore, such work is either not done or when it is done, the scale of the task, bad light, difficult access, shortage of time, hazardous and uncomfortable working environment, inadequate preparation etc. throw a major question mark over the reliability of the results obtained.

The scale of the inspection will generally be reduced by consideration of the important structural design features from which regions of hot spot stress or high vulnerability to damage, are identified and listed as areas of special interest. However, these zones are often inaccessible or may themselves constitute 'enormous' areas for conventional Non Destructive Testing, e.g. the transition pieces of a concrete production platform and the principal nodes (branch to chord joints) of a semisubmersible or platform jacket. Sometimes the structure can be divided into repeat units of similar design, performing similar functions and experiencing similar loads. In such cases a procedure might be followed in which most of the available resources are concentrated on one such unit, and should defects be revealed during the comprehensive inspection of that unit, only these areas would be inspected on the other units.

Knowledge of the structurally significant defects in all critical areas and their relative propagation rates under known service conditions would provide all the information necessary to prove adequacy of design and guide maintenance and repair work for optimum effectiveness at minimum cost.

Acoustic emission monitoring is potentially a most powerful method for obtaining such information. The slow and intermittent nature of crack growth due to such mechanisms as fatigue and stress corrosion in structural steel weldments produces acoustic emission which can be located and characterised in many

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industrial applications (1,2). However, until now, long term unattended monitoring has been impractical due to technical limitations or unacceptably high cost.

The paper describes a new method of acoustic emission analysis and gives results of performance evaluation trials onshore and offshore:-

(i) on a production platform jacket node joint

(ii) on a transition joint of a single point mooring (SPM)

(iii) on a semi-submersible rig node joint.

ADVANTAGES OF ACOUSTIC EMISSION TESTING

It has been known since the early 1950's that metals when stressed to yield and beyond produce stress waves or acoustic emission (AE) which is a measure of incipient damage and a warning of failure. These bursts of vibrational energy can be detected over distances of several metres using piezoelectric transducers bonded to the surface. Most non destructive methods rely on some form of excitation at a point or points on the surface and measurement of the response of the material at these points. Acoustic emission analysis is unique* in non destructive testing since it is the process of crack extension itself which produces the signals that are measured.

Its advantages over other NDT methods for offshore applications are:-

1. Large search zone.
2. Overcomes problems of difficult access.
3. Crack detection and monitoring can be carried out remotely and automatically e.g. subsea without the use of a diver.
4. Determines whether a pre-existing crack is propagating.
5. No cleaning required e.g. removal of marine growth.
6. An estimate of the area of new crack growth and in certain cases the increase in length and depth can be given as a function of the stressing and environmental conditions prevailing at the time.

APPLICABILITY OF AE TESTING

Problem areas which would benefit from AE monitoring include:-

1. Welds which are cracked where it is not known if the defect is propagating.
2. Cracks which cannot be repaired without extreme difficulty and high cost.
3. Suspect areas e.g. welds identical to those which have cracked.
4. Repaired joints which may have a defect or where the defect is likely to redevelop.
5. Joints which have been strengthened without the crack being removed.
6. Areas with restricted or no physical access.

* With the exception of fracto emission (FE) which has yet to be implemented for practical NDT.

7. Cranes for heavy lifts.

8. Areas where the cost of routine inspection is high and where operational utilisation can be increased by reducing the number and scope of such inspections.

IMPROVEMENTS IN AE TEST METHODS

The main reasons why AE has not been used on offshore structures in the past are:-

1. Background signal noise.
2. Large number of transducers required.
3. Hard wiring between sensors and instrumentation through hazardous areas e.g. the splash zone on offshore structures.
4. Equipment not engineered for long term unattended operation on site.
5. Results have been inconclusive and only limited success has been demonstrated (3).

The remainder of this paper is directed to showing that for many applications these problems have now been overcome and we can at last begin to realise the true potential of acoustic emission monitoring as an industrial defect detection and diagnostic aid.

VULCAN

The AVT Group have developed new acoustic emission analysis instrumentation for unattended, automatic monitoring of local areas of hot spot stress in process vessels and structures. Called the Vulcan 8 series, Figure 1, the equipment is specially engineered for applications onshore and offshore.

Briefly the Vulcan system comprises:

(i) An array of 8 transducers which sense the acoustic emission in the structure. For subsea applications, the transducer cables are gathered at an underwater header which is clamped or strapped to the structure close to the node(s) being monitored. The signals are then brought through the splash zone by the 'tension cable' principle, see Figure 2.

(ii) A compact 8 channel stand alone data acquisition and processing computer which resides permanently on or near the installation. Data acquisition is continuous with on-line validation (noise rejection) carried out by a new method of pattern recognition using an 'intelligent' block filter. The method is so effective in identifying statistically significant occurrences characteristic of the micro-displacements associated with crack growth that in extremely 'noisy' environments such as the splash zone of offshore structures further data reduction is usually unnecessary before secure mass storage on bubble memory cassette. Re-boot after power failure and complete system verification from the transducers to the main processor is performed automatically. The transducers are capable of both sensing and pulsing (calibration) roles.

(iii) An office reporting computer (at present either IBM/HP/Motorola) which can communicate directly with the site computer is used for displaying the crack growth information on developments of the structure and for long term trend analysis. Welds are displayed on a 2D development of the structure with the location and extent of cracking shown in plan and relative depth of cracking (concentration of acoustic emission) shown in colour e.g. see Figure 3.

Since the crack growth acoustic emission relates to the change in state of the crack with time, the history of crack growth is represented by a series of histogram plots, superimposed on a 360 degree linear development of the weld e.g. see Figure 5, which shows the build up of cracks at 6 day intervals to the final state, shown in Figure 3.

In addition to the picture of crack length, relative depth and rate of growth, it is important to relate the growth to the loading on the structure e.g. wave height and direction or process parameters. Up to 8 analogue and 3 digital parameters can be logged and processed simultaneously with the AE.

FATIGUE TESTING OF FULL SCALE TUBULAR JOINTS

Signal to Noise Considerations

The primary objective of these measurements was to fully evaluate the method of on-line filtering used to recognise fatigue crack acoustic emission in large scale tubular weldments of the type used in the construction of offshore production platform jackets and in levels of background noise similar to that which might be expected close to the splash zone on such structures.

Examples of the noise recorded on each of 6 sensing transducers during testing of a tubular K joint are given in Figure 5. The peak noise (electronic) on each transducer with the specimen off-load was around 18 to 20 dB. On load it reached 60 dB and was of both continuous and burst type character (4). Hidden in the noise is the emission from the crack. It has since been learned that this level of background mechanical noise, originating from the actuator bearings and associated hydraulics, exceeded that experienced in the Northern North Sea at -12m during hurricane conditions, where the AE signals from propagating subcritical fatigue cracks reach 60 to 70 dB at 0.20m distance (with extreme values 80 to 90 dB) reducing to around 30 dB at 4 to 5m distances from source.*

An additional problem with the laboratory simulation was the unrealistic acoustic emission data rate arising from the high rate of fatigue testing and the consequent extremely high rate of crack growth relative to what would normally occur in service.

Results

Several large scale tubular joints were tested. The AE monitoring was carried our remotely and independently of the non destructive examination and the AE results were reported with no knowledge of the true state of cracking in the specimens.

The fatigue data on the specimens is confidential at the time of writing; but it is possible to give an example of the good correlation that has been obtained.

* Results obtained on a semisubmersible drilling rig and a production platform jacket, see section on "Offshore Experience".

Figure 6. shows the cumulative history of acoustic emission from the start of one test on a tubular T joint, which lasted 90 days. The first clear evidence of the onset of cracking from the AE measurements obtained close to the N2 point, i.e. the point when the crack is visible.

Subsequent examination of the AE results showed that there was evidence of emission from the same region of the weld further back in time close to the N1 point, i.e. the first sign of cracking as determined by non destructive examination. The point when the principal crack went through wall thickness was also clearly evident from a sudden increase in large amplitude signals, up to 90 dB on the first transducer of the sensing array to be struck by the AE stress waves.

Figure 7 shows the cumulative emission (during tensile and compressive loading) as a function of angular position on the weld. Also shown are the cracks present and their depth as measured by the alternating current potential drop method. Ignoring the small numbers of emission up to the first 10 per degree of weld, the correlation between the AE and the NDT results is very good. Similar correlations were obtained at different stages throughout the test.

When considering only the emission occuring on the upper 90% of the tensile part of the loading cycle the correlation was even better; although the numbers of occurrences was considerably less than the total emission from the weld, as observed by other workers (5,6). The difference is attributed to other emission mechanisms e.g. point and line contact friction.

Our results suggest that these secondary effects are closely allied to primary crack growth and in the absence of further growth would decay relatively quickly. Noise resulting from corrosion products and compliance from a non propagating crack is of different character and under normal operation is filtered out by the equipment.

OFFSHORE EXPERIENCE

Jacket Subsea Node Joint

The entire topside and underwater installation of cables and sensors was completed inside 2 hours during marginal diving weather conditions. The transducers survived severe hurricane conditions during the Winter of 1984/85 and continued to operate to performance specification after recovery.

Defects in two branches of a nine branch node, see Figure 8, were detected immediately during the first storm following installation. The rate of propagation of these defects as a function of wave height and wind speed was monitored.

Data cassettes, recovered weekly from the platform, were analysed onshore using an HP9836 computer. Because most of the data reduction is carried out on-line, the onshore computer is used simply to verify data on crack growth and to report the defect location and rate of growth.

The analyses programs allow a graphical representation of the chord (any dia.) and branches (any dia. and any angle), e.g. see Figure 9, from which developments of the chord and branches are produced showing the welds and transducer positions, see Figures 10 (a) and 10 (b). The location of the emission (increase in crack length) and density (increases in crack depth) is displayed on the appropriate development, see Figure 11 which is an example of the cumulative crack growth emission over a 24 hour period encompassing hurricane winds and 10m waves.

In the above offshore application the reported location, increase in crack length and depth measured remotely during the Winter of 1984/85 were fully consistent with subsequent subsea N.D.T.

Single Point Mooring

Acoustic emission monitoring of a 4m wide cylindrical section of the cone/chimney transition region of a single point mooring, see Figure 12, with known defects has been carried out. High sensitivity coverage was achieved using an interlaced lattice of 16 sensors with 4m maximum inter-transducer spacing. A pattern of emission was quickly established during the early storms and this pattern began to repeat itself during subsequent periods of bad weather. One source was found to be by far the most intense of any detected over the monitoring period, regularly reaching high levels of activity (2 to 3 AE bursts per minute) whenever the weather conditions produced waves of significant height approximately 3m or greater.

Following ultrasonic inspection of the source of this emission, it was found that two previously reported sub-surface defect indications had joined up to produce an 85mm long crack of unknown depth. The crack was in an area previously thought to be relatively defect free, after dressing. In addition, certain known defects were found not to be propagating whereas other areas, not included in the NDT schedule, were shown to be defective. These results were later confirmed when the structure was withdrawn from service.

Semisubmersible

Eight sensors were used to provide coverage of all welds associated with the horizontal and diagonal branch penetrations of one of the main structural columns at 6 to 12m below the sea surface, see Figure 13. During severe weather conditions, strong 'crack growth' acoustic emission was detected from the extremities of a previous weld repair at the 6 o'clock position in the horizontal branch penetration with the column, which was subsequently traced to recurrence of a fatigue cracking problem. The AE signals were detected at distances up to 4.5m from the crack in background noise originating from wave splash, support vessels, location sonar, pumping operations, chain and rope impacts with the column and general drilling activity on and around the rig. The defect was propagating from the seaward side into the column.

CONCLUSIONS

The acoustic emission method is capable of detecting and locating propagating fatigue cracks in structural steel weldments sufficiently early to allow low cost repairs e.g. weld dressing. This is particularly important in offshore structures where the cost of subsea inspection and the failure to detect cracks before they develop to the stage where clamping or hyperbaric welding is required are extremely high. The method is not restricted to fatigue cracks, but will detect a variety of fracture mechanisms, e.g. stress corrosion cracking, lamellar tearing in the HAZ of steel weldments.

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Figure 1. Vulcan is designed to detect locate and continuously monitor propagating cracks in process vessels, pipework and structures.

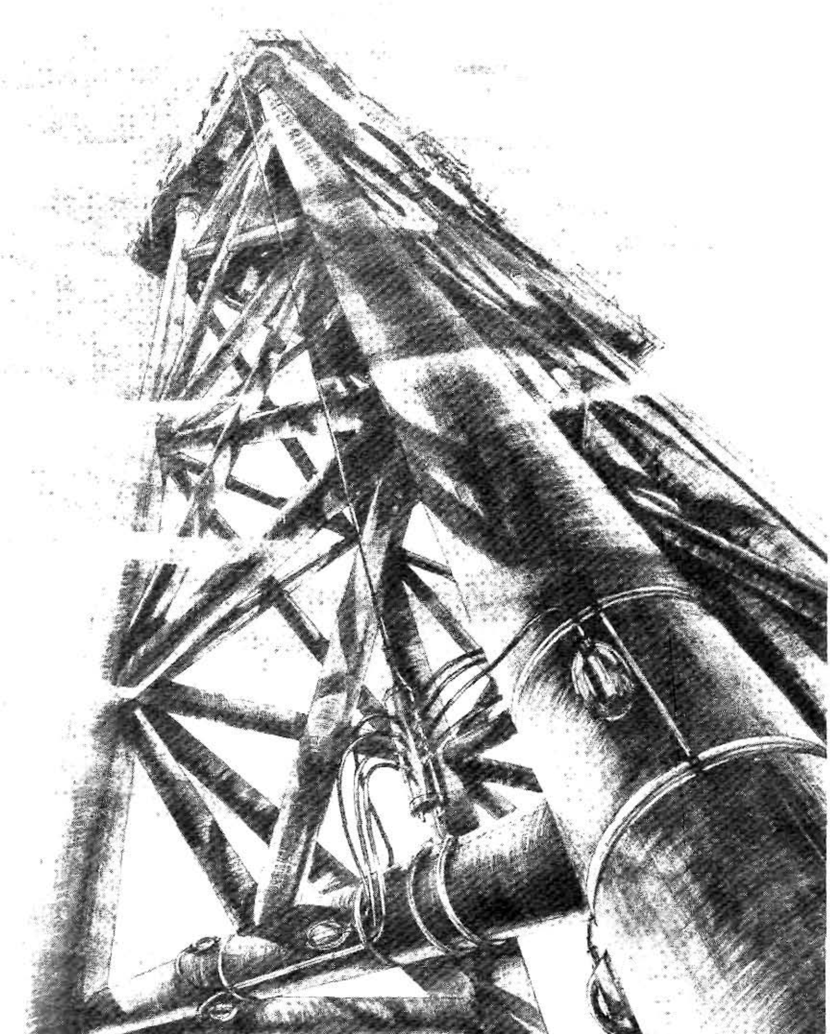


Figure 2. Impression of subsea transducers and tension cable assembly monitoring two node joints of a production platform jacket.

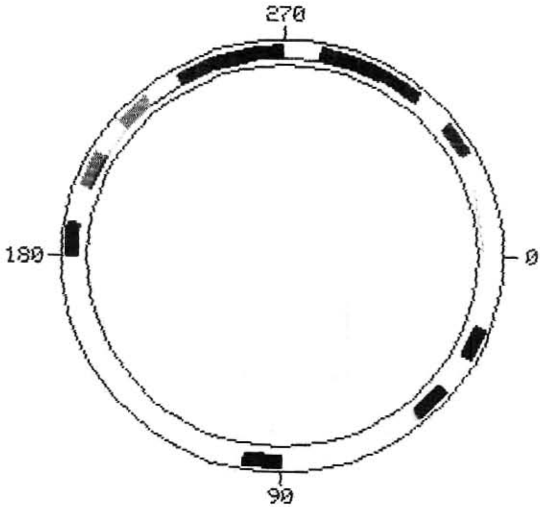


Figure 3. Location (crack length) and density (relative depth) of acoustic emission from fatigue cracks in a full scale tubular T branch weld. The plot gives the cumulative picture of AE from crack initiation to just prior to going through wall thickness at 270 degrees.

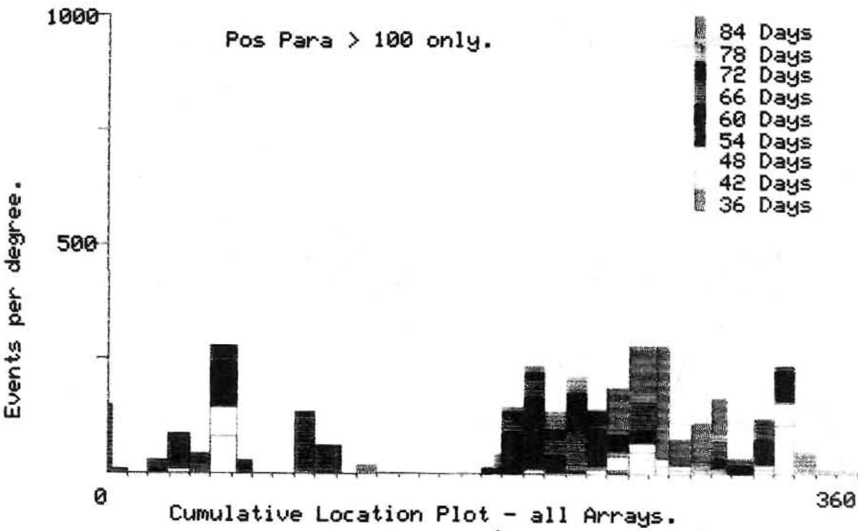


Figure 4. Histogram showing build-up of acoustic emission in approx. 10 deg. steps around the same branch weld from crack initiation.

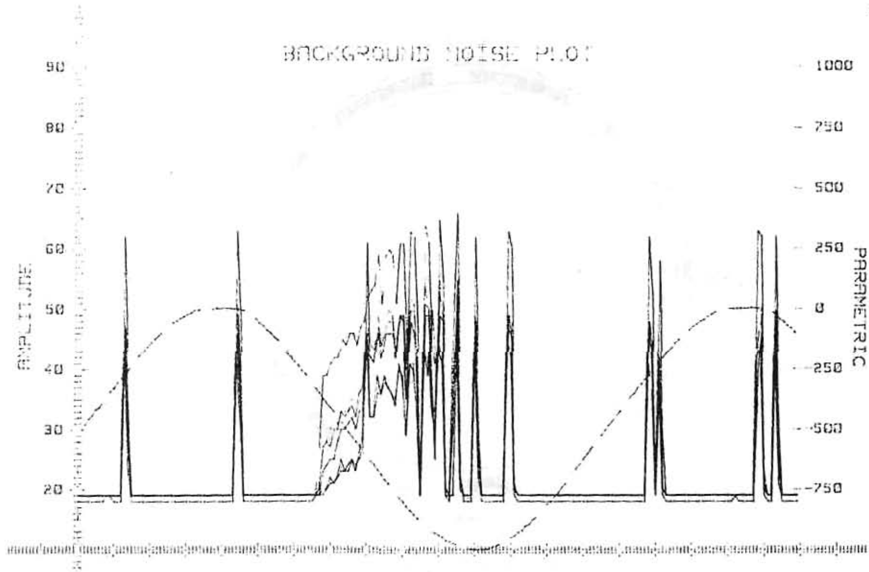


Figure 5. Example of the variation in peak noise (dB) with time (resolution 8m sec.) and loading parametric (sinusoidal curve) on each of 6 sensing transducers during a tubular K joint fatigue test.

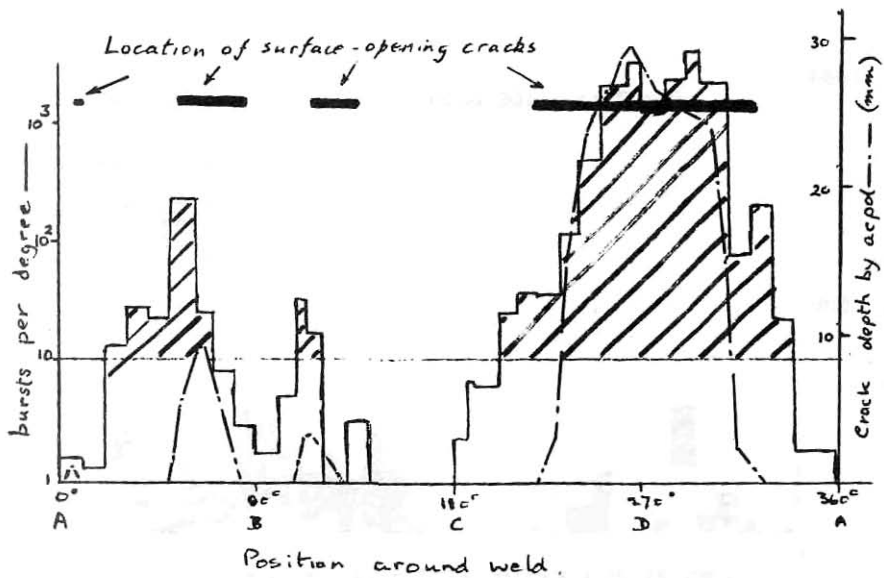
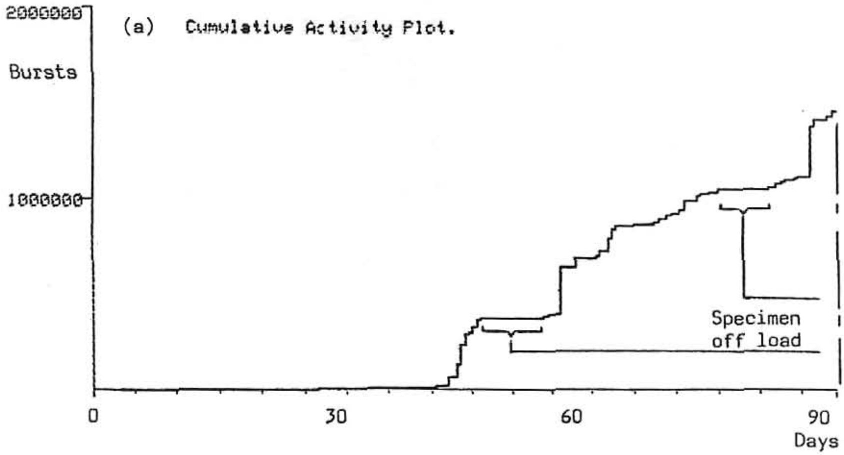


Figure 7. Correlation of located AE on branch weld (logarithm of cumulative bursts to day 57) with the visible length and depth of cracking measured by the ACPD method on that day.



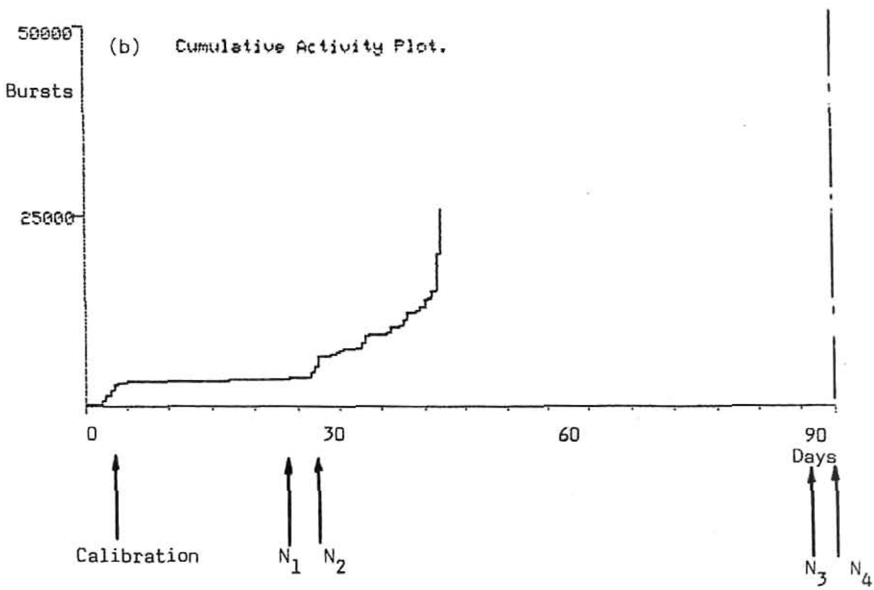
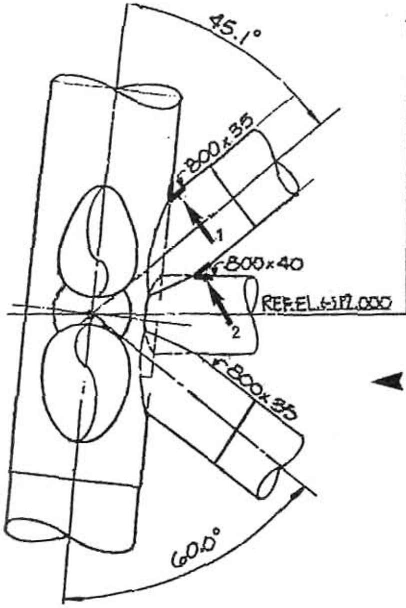
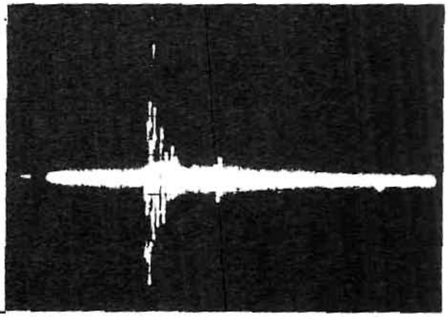


Figure 6. Cumulative activity plot (a) complete test (b) start only (note change of scale). N1 first detectable crack by NDT, N2 first visible crack, N3 crack through wall thickness, N4 end of test due to joint instability.

(a)





(b) x = 0.5ms/div.; y = 0.1v/div.

Figure 8. (a) Nine branch node on an offshore platform at 12m below surface. The arrows point to subject cracking. (b) Example of one-burst-acoustic-emission signal measured at 0.5m from the propagating fatigue crack (1) measured during hurricane conditions.

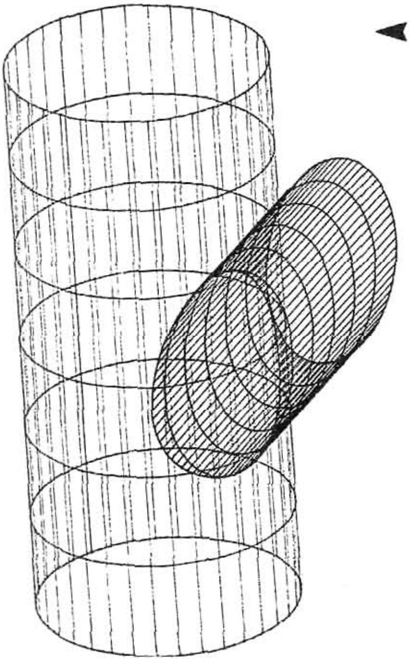


Figure 9. Example of graphical reconstruction of node joint reproducable for any branch to chord configuration.

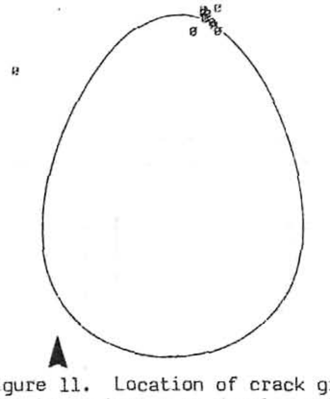


Figure 11. Location of crack growth acoustic emission on development of branch weld, see Fig. 10(a), detected during a 24 hour period during severe weather conditions.

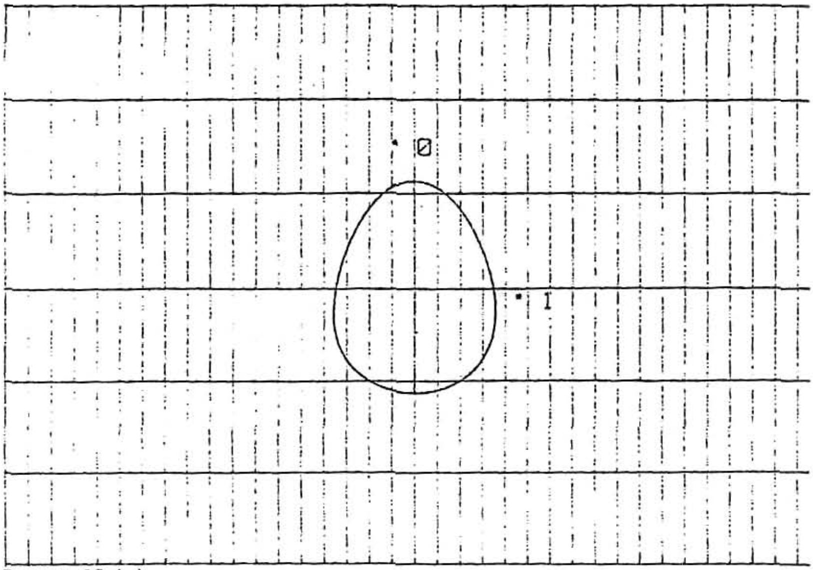


FIGURE 10.(a)
DEVELOPMENT ABOUT CHORD SHOWING BRANCH WELD AND TRANSDUCER POSITIONS

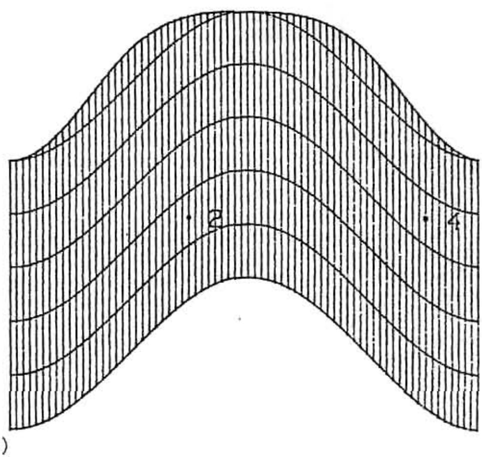


FIGURE 10. (b)
DEVELOPMENT ABOUT BRANCH SHOWING BRANCH/WELD AND TRANSDUCER POSITIONS

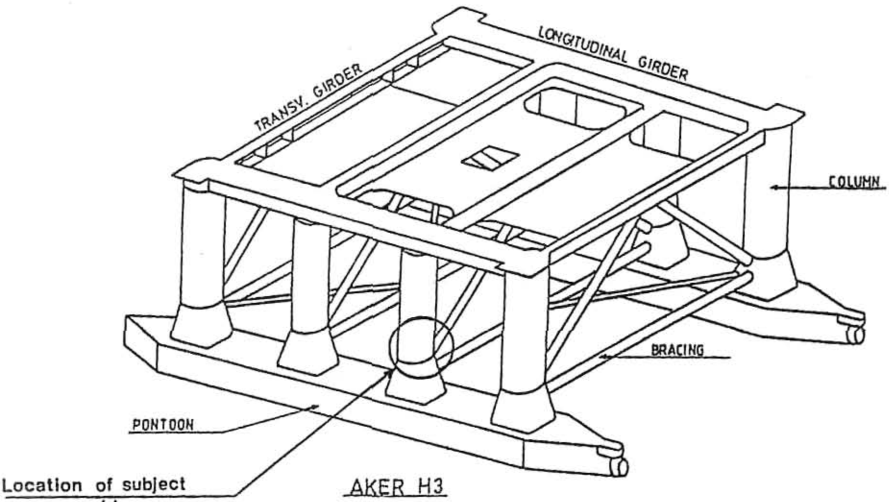


Figure 13. Schematic of drilling rig showing location of subject cracking.

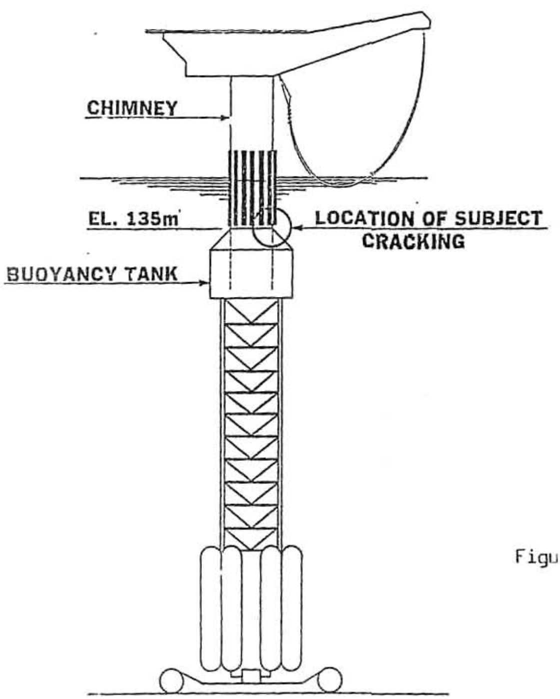


Figure 12. Schematic of single point mooring (SPM) showing location of subject cracking.