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The Monitoring of Fatigue Cracks in Welded Tubular Joints

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ABSTRACT

An investigation to determine the feasibility of using acoustic emission to detect and locate fatigue cracking in welded tubular joints is in progress. Tests have been carried out on T-joints in air under laboratory conditions employing both constant and random amplitude loading. In addition, a test rig has been constructed which enables T-joints to be fatigued underwater by using the random amplitude loading of wave action. Fatigue cracking has been detected prior to catastrophic failure in both air and marine environments.

INTRODUCTION

One of the most likely failure modes of offshore structures is fatigue in the welded joints connecting tubular members. Many tubular members may be joined in one area, this being known as a node. The structural integrity of a node is difficult to ascertain because of the inherent problems in working underwater and the complex geometry of many of the nodes. Consequently, a programme of research has been initiated to determine the feasibility of using acoustic emission for in-service surveillance of offshore structures. This paper reports the preliminary results of monitoring the failure of tubular welded T-joints by fatigue in air and in a marine environment.

EXPERIMENTAL PROCEDURE

Identical specimens were used for both the tests in air and in the marine environment. The specimens consisted of a 2.375 in. O/D brace tube welded at right-angles to the midpoint of a 30 in. long, 4.5 in. O/D, chord. The material for the brace tube and the chord was BS 4360 43C structural steel, which has carbon and manganese contents of approximately 0.22% and 1.60% respectively and a sulphur content of less than .05%. Thus, this steel is similar in composition and mechanical properties to the grade 50D material used for offshore production platforms. The joint configuration reproduces the fatigue failure mode of the nodes in such structures.

Tests in air

Fatigue tests were carried out at the National Engineering Laboratory (N.E.L.) under constant amplitude and random amplitude loading in a 100KN servo-hydraulic machine. An air pressure of 1.434 KN/m^2 was maintained inside the specimen. Once a through crack had developed the reduction in internal air pressure stopped the test; the number of fatigue cycles at this point was termed the lifetime of the specimen.

A six channel acoustic emission system was used to monitor the specimen and also to measure the background noise associated with the test machine. Two transducers (Dunegan 5140B) were mounted at the specimen ends enabling a one dimensional location of the emissions. Spacial filtering was used so that only emissions that originated from the weld were accepted. Further spurious emissions were eliminated by employing a load controlled gate in order that only those emissions which occurred within a few per cent. of the maximum load were processed. The gate level was set to 10% of peak load for the constant amplitude tests and at the RMS load value for the tests carried out under random loading.

Tests in a marine environment

A testing rig has been constructed to fatigue welded T-joints in a marine environment using the wave loading on a large disc to produce loading forces on the specimen. The disc, which is 1.5 m diameter, is connected to a lever system which magnifies the forces applied to it by wave action by up to 100 times (Fig. 1). The rig is situated in 5 m of water, 100 m off Totland Pier on the Isle of Wight.

The acoustic emission system is similar to that used for the tests in air and both the T-joint specimens and the rig are being monitored. The amplifiers are situated in a water tight container, which is inserted inside the specimen, and are connected to the instrumentation on shore via a multiway pressurised cable.

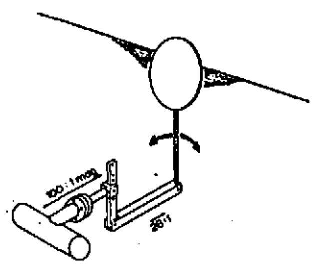

Fig 1 Schematic diagram of the environmental fatigue test rig

RESULTS AND DISCUSSION

The results of the tests in air are presented in Table 1 and Figure 2. Also shown in the S/N curve of Figure 2 are the results of previous tests carried out by N.E.L. at constant amplitude and zero mean load. From the limited amount of data available it would appear that: i) there is no difference in the lifetime under random or constant amplitude loading conditions if the root mean square load is used as a measure of amplitude, and ii) although there is a marked reduction in fatigue life when the mean load is increased from zero to 29 or 40 kN, there is little difference in the lifetime at these high mean loads.

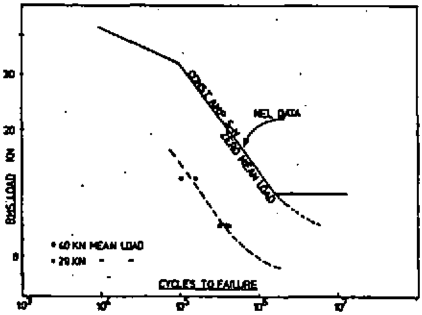

Fig 2 Fatigue data for welded T-joints

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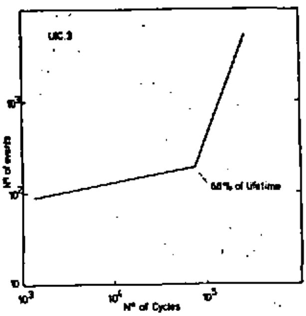
Table 1 Fatigue and acoustic emission data from tests in air (R = random, C = constant amplitude, A.E. = % lifetime at which increased acoustic emission activity was observed)

Loading	Lifetime (cycles)	Frequency (Hz)	RMS Load (kN)	Mean Load (kN)	Min. Load / Max. Load	A.E. (%)
R	16.5×10^4	15	14	40	-	-
C	39.4×10^4	15	10	29	0.33	92
C	20.9×10^4	5	14	40	0.33	68
C	44.6×10^4	15	10	29	0.33	83
R	43.1×10^4	15	10	29	0.33	87

It was found that the acoustic emission count rate increased markedly before the lifetime of the specimen was reached. This is illustrated in Figure 3 and the percentage of the lifetime at which this increased acoustic activity was detected is given in the last column of Table 1. Clearly under these conditions acoustic emission is capable of detecting fatigue cracking in a welded joint at a relatively early stage (it should be remembered that lifetime has been defined as the number of cycles to the first through crack and not to catastrophic failure).

Fig 3 Graph showing the marked increase in count rate before the lifetime of the specimen



Scanning electron microscopy of the fracture surfaces of the through cracks revealed three fracture modes. The first mode was the normal striation fatigue mode which was initiated at a number of sites at the weld toe. The striation mode cracking followed the weld metal/heat-affected zone interface for typically 1.5 mm. The second period of crack propagation was a mixed striation plus cleavage or lamellae tearing mode. The crack path was through the heat-affected zone to a depth of about 4.5 mm. The final failure was ductile rupture of the remaining thin ligaments and resulted in the formation of small shear lips.

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The fatigue life of welded specimens is determined mainly by the propagation of the cracks as initiation occurs at a very early stage at stress concentrations and inherent defects due to the welding. As no increase in acoustic activity was observed before 68% lifetime it must be assumed that the initiation events and the striation propagation mode were not detected.

Figure 4 is a histogram of the number of events recorded as a function of the distance between the receiver transducers. A peak in the distribution was observed within the 'location window' around the weld. The width of this distribution correlated well with the crack length as measured by dye penetrant. The two small peaks on either side of the main distribution were found to be due to reflection of emissions from the ends of the specimen.

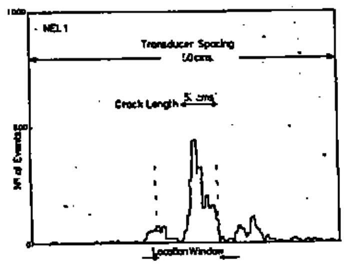

Fig 4 Location plot of emissions showing good correspondence with the measured crack length

At the time of writing only one specimen has been tested in the environmental rig. This specimen was in the rig for 10 weeks before it failed in a catastrophic manner. Although the acoustic data have not yet been fully analysed, it is clear that an increase in acoustic activity to above the background level was recorded at least 4 weeks prior to failure.

CONCLUSIONS

Fatigue tests on welded T-joints, carried out in air under laboratory conditions, have shown that cracks can be detected by increased acoustic activity at a relatively easy stage. These cracks can also be located.

Preliminary results from a test in a more demanding marine environment indicated that a fatigue crack can be detected well before catastrophic failure of the welded joint.

ACKNOWLEDGEMENTS

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