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Underwater Inspection Reliability for Offshore Structures

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Abstract

Safety and maintenance considerations for offshore structures require knowledge of the reliability of inspection techniques for these structures. Fatigue cracks grow under the influence of wind and wave loading and can lead to serious weakness in a structure if allowed to progress without any action being taken. In the first instance these cracks must be detected before they reach a size which may lead to this structural deterioration. Inspection reliability in this case is measured by a probability of detection(POD). The POD is also needed for use in probabilistic based inspection scheduling. Safety considerations are involved when the effect of a known crack on a structure needs to be determined. In this case it is important to know the crack size (i.e. depth) and therefore the reliability of crack sizing techniques becomes important.

UCL Underwater NDE Centre has carried out extensive POD and crack sizing trials. This paper describes the concepts and methodology used to set up and carry out the trials and gives some examples of trial results. European projects involving French, Italian and Dutch partners, which will give a large POD database and analysis of its use in reliability based inspection, are currently in progress and are also described.

Introduction

Inspection reliability trials for underwater NDT equipment are necessary in order to assess the value of and need for underwater NDT of fixed offshore platforms. Both safety and maintenance considerations require an understanding of the performance and reliability of the overall NDT systems used for crack detection and crack sizing. The U.K. Offshore Industry has been aware of this need for some time and about 10 years ago started to prepare for a series of major inspection reliability trials. The trials were supported by U.K. Government and Industry. The companies involved and the list of projects are given in Appendix 1.

The work was undertaken by the University College London Underwater NDE Centre in collaboration with The City University. It has been conducted as a series of joint industry projects and so far has included trials on Magnetic Particle Inspection (MPI), Eddy Current systems (EMDII, Hocking AV100, MOSER), ACFM(U11 Crack Microgauge), ACPD and Ultrasonic Creeping Wave.

For inspection reliability trials it is necessary to have a large number of precracked tubular welded joints, of representative size and shape, containing typical flaws, the size of which must be established. This requirement can lead to very expensive trials and hence the need for joint industry funding and the development of the concept of a library of tubular welded joints. The library, containing joints with well characterized flaws, could be maintained for a series of trials without the need for destructive sectioning. This paper describes the setting up of the library, the trials procedures necessary for obtaining probability of detection (POD) information with a certain confidence level, examples of results obtained and a review of current projects on extending the database and using the data in inspection planning.

Sample Numbers

It is never possible to consider assessing the performance of NDT systems on all cracks that might exist (the population). Instead a sample must be chosen which is representative of the population and of sufficient size to give a desirable confidence level in the result. All types of inspection will have an uncertainty regarding whether they will be successful. The measure of this uncertainty comes from blind trials on the sample and is often expressed as a Probability of Detection (POD) associated with a certain confidence level (C). The blind trials would be on a series of groups of representative defective specimens, of size N, and the simple experimental measure of POD would be the number of successful inspections (S) divided by the number of attempts (N), i.e. the individual values of measured POD (P) are the quotient S/N.

P is related to the lower bound true population value of POD (p) with a certain confidence level (see Packman et al. [1]) as follows.

$$C = 1 - p^N \qquad (1)$$

and this shows that for a confidence level of 95% and a lower bound population POD of 90% one would need 29 defects in each group, which were all detected.

It would be possible to use a smaller number of specimens but in this case either the confidence level or the lower bound estimate of the population POD would have to be less. Take, for example, groups of specimens which are only five in number. If all five were successfully found, giving a measured POD of 100%, one could only have a 95% confidence of a population POD of about 50%.

Library

Having decided that a 90/95 POD is desirable and that to produce a curve relating POD to crack length, or depth, at least six points (or groups) would be required; this leads to a library of some 174 cracks. An unspecified number of uncracked joints would also be required so that the inspector is not aware that he is inspecting a defective weld. In order to set up the library the following steps were necessary.

a Establish representative joint geometry and size

b Establish nature and location of defect

c Establish characterization procedure

d Confirm crack characterization data

The characterization procedure was established with the help of the U.K. Department of Energy (now Health and Safety Executive) [2]. This involved detection and sizing on tubular joints and tee butt welds. All the NDT techniques available at that time were tried on the cracked welds. The sizing results were lodged with HSE and then the joints were destructively sectioned. In this way the two most successful techniques for (a) length measurement and (b) depth measurement, could be determined. For length measurement ACPD and MPI proved to be most successful; for depth measurement time of flight diffraction (TOFD) and ACPD were the best. In both cases it was found that the results from the two techniques had to be combined in order to give an acceptable accuracy.

Finally it was decided that in order to confirm the characterization procedure it would be necessary to periodically remove some specimens from the library, destructively section this subset, and then replace them so that the library was kept at the desired number. This procedure has been adopted and the first attempt at "partial library sectioning" is nearing completion. This work has confirmed the original characterization procedure. Figure 1 shows the comparison of peak crack depths against characterization data obtained as a result of the destructive tests.

Trials Procedure

The basic steps for measuring POD using the library involve:

i) Inspection of component by an agreed operational procedure; measurement of defect

ii) Comparison of measurement with 'known' true size

iii) Decision on success/failure (hit/miss)

iv) Repeat of (i) (ii) and (iii) across whole sample

v) Point estimate of POD for each sample of a certain defect size

vi) Link sample POD to lower bound population POD with specified confidence limit

The trials procedures have developed during the course of trials and are now fully formalized. The organizational structure of a trial and the roles of the personnel are shown in Figure 2.

The sequence of events during a trial is shown in Figure 3. The review process shown for the MOSER eddy current and U11 ACFM systems was not possible for the other techniques because the data was not recorded. Re-examination of the cracked areas by an expert was possible for the EMD III, AV100 and creeping wave techniques but the results of the re-examination are not included in the POD curves because of the necessary change of procedure.

The training received by the operators (i.e. inspection controllers & divers) for each trial was carried out either to known offshore inspection qualifications or by the manufacturer/developer of the equipment under trial.

The importance of the operational procedure cannot be overemphasized and this is approved by the Steering Committee prior to the trial. Modification to operational procedure is not allowed during a trial, however subsequent analysis or information may require a retrial and this was carried out on one occasion.

Results Analysis Procedures

Before discussing the detailed methods of results analysis, it is necessary to detail the limitations of the results obtained. These are:

the results of the trials are a comparison of the underwater trial and laboratory NDT measurements of the cracks(characterization) and are limited by the accuracy of the techniques available for this characterization [2]

the results are only applicable to the trials range of test samples, environmental conditions, procedures used and model of equipment available at the time of the trials

this paper includes only a fraction of the results obtained and further reference should be made to the full reports before data is used.

Crack Characterization and Detection Definition

The question of what constitutes a crack and how to measure its dimensions for the purposes of POD is not an easy one in the case of fatigue cracks in tubular joints. The crack can have a very complicated structure which makes simple definitions impossible.

In order to approach this problem the UCL Underwater Centre Steering Committee agreed on a set of rules of crack definition (see Rudlin and Dover [3]), which are applicable for different uses of the data. Other definitions can be used and this depends on the requirements of the user. In this paper a comparison of techniques for "first pass detection" is included as an example of the results obtained. For this purpose it is necessary to use a definition which can reasonably be used by the methods under comparison. It should therefore be noted that this does not show that additional data could be available from the technique.

The definition used is called Classification B1(Figure 4). This refers to a dominant (i.e. longest) crack of a set of cracks within a cracked region. The length of the dominant crack is used. Parallel cracks within the cracked region (interbead or opposite toe) are not considered separate cracks. The minimum separation between cracked areas is one clock position on a brace.

Detection of a defect also requires definition. In Classification B1 a crack is defined as detected if there is an indication from the trial within the cracked region. The other alternatives are missed crack (m) and a report where there is no crack called a spurious indication (s). These are shown diagrammatically in Figure 5.

POD Curve Presentation

For the POD data presentation agreed upon by the Steering Committee, each point on the POD curve is plotted at the end of a crack length range. These crack length ranges were decided by counting in groups of 29 from the longest crack. In addition a point is plotted at the longest crack length in a group of 29 cracks in length sequence where the experimental POD reaches 100% (i.e. the lower bound of the population POD is 90% with 95% confidence). The position of this point is dependent on the crack distribution in the library, a missed crack at value X length would give a point plotted on the curve at X + 29 length. When a depth threshold to the cracks is applied (i.e. cracks with an ACPD depth below a certain figure are removed from the database), the crack size ranges have been kept the same. This tends to reduce the lower bound estimate of the population, particularly in the smaller crack size ranges.

An example of the data for the lower bound population POD with 95% confidence compared with the experimental POD with reduced numbers of cracks is shown for MPI in Figure 6.

The effect of Depth Thresholds is given in Figure 7. The POD curve itself usually appears higher as the depth threshold is increased.

POD Curves

The lower bound population POD curves for Class B1 characterization for EMD III, AV100, MOSER (after review) and U11 ACFM (after review) for cracks > 2mm deep are given with the similar curve for MPI in Figures 8 -11.

The results show that the AV100, MOSER and ACFM techniques all closely approach or exceed the MPI on the basis of these Classification B1 results. The statistical difference is not large and suggests that only occasionally will a crack be missed by one technique and found by others.

Therefore for "first pass detection," these three methods are candidates for replacing MPI and it becomes possible to take advantage of other features of these techniques such as depth estimation computer based records, detection through coatings and reduced cleaning.

Further Analysis of Trials

An analysis of missed cracks and spurious data is always carried out. This allows a check on the characterization. In fact in the whole series of trials only one spurious indication was found to be a crack and in addition a clerical error was identified by this process. Neither of these caused any change in the overall conclusions of the trials.

The analysis of the missed cracks is also important to understand the results for individual techniques. The analysis showed that for several of the techniques the largest missed cracks were due either to a procedure problem or had identifiable characteristics which could be guarded against. Such information appears in the POD reports but does not appear in the curves unless identified at the review stage.

The spurious indication data is also of interest in a comparison between techniques, although mainly from the point of view of inspection economy than inspection scheduling. The results are shown in Table 1. and show MPI to be at a disadvantage compared to the electromagnetic techniques.

TECHNIQUE	No of INDICATIONS
MPI	39
EMD III	7
AV100	6
MOSER	18
U11 ACFM	10

Table 1
Number of Spurious Indications in Each Trial

Although the work carried out by the Underwater Centre has produced POD data for the techniques described, it is restricted in its possible use because of queries about the transfer of data to real offshore situations. Also although several techniques were investigated other techniques are used in different situations. Also the use of the information contained in the POD data for inspection scheduling is not simple. In order to address these problems the projects ICON (Inter Calibration of Offshore NDT), and RISC (Reliability based Inspection SCheduling) were initiated. These projects, undertaken with partners from France, the Netherlands and Italy, were approved by the EEC and commenced in 1991.

The ICON Project, when complete, will establish performance characteristics for most underwater NDT techniques available (Table 2) when used in a small freshwater tank, a large seawater tank and in actual offshore conditions. Techniques will be applied by both diver and by ROV deployed computer aided telemanipulators.

TECHNIQUE or SUPPLIER	EQUIPMENT LIBRARY	MAN CAT
MPI Coils	OIS	MAN
MPI Coils	B. GAS	MAN
MPI Yoke	B. GAS	MAN/CAT
MPI Single Leg	COMEX	MAN/CAT
ACPD	B. GAS	MAN
ACPD	OSEL	MAN
ACPD	TSC (U11)	MAN
E.C.	COMEX (Hocking)	MAN/CAT
E.C.	MILSTRONG (Lizard)	MAN/CAT
TOFD	RTD	MAN
TOFD	SONOMATIC	MAN
ACFM	TSC	MAN/CAT
ACFM	TRAVOCEAN	MAN
ACFM Arrays	TSC	MAN/CAT
VISUAL	Still Photography	MAN
VISUAL	TV Trackmeter	MAN
THICKNESS	CYGNUS (US)	MAN/CAT
THICKNESS	US Ligament	MAN
THICKNESS	Replication	MAN
Creeping Wave (US)	RTD	MAN
US FMD	GASCOSONIC	MAN
US FMD (ROV)	BAUGH & WEEDON	MAN
FMD (ROV)	OIS Gamma.	CAT

Techniques	
MPI	Magnetite Particle Inspection
ACPD	Alternative Current Potential Drop
EC	Eddy Current
TOFD	Time of Flight Diffraction
FMD	Flooded Member Detection

Table 2
List of Equipment and Trials

The RISC project will combine stress analysis, fatigue and fracture mechanics analysis and NDT data in probabilistic terms to give reliability based inspection scheduling. The project incorporates earlier studies which produced the FACTS Dharmavasan et al. [4] and reliability Faber et al [5] software.

During the course of these projects crack growth data from long term corrosion fatigue data under simulated offshore conditions became available (Figure 12) (from Dover and Austin) [6] and this shows an increased importance for detection of small depth cracks (below 2mm). It can be seen from Figure 1 that the initial characterization data for the POD projects did not include this area of crack depth and a project to establish the performance of characterization techniques in this area has also commenced. The outcome from the project will be a measure of the accuracy of sizing shallow cracks. This will be used to reassess the current library of fatigue cracks so that improved POD data can be obtained for lower crack size thresholds. It is expected that work will continue to include inspection of subsea developments and with ROVs.

Conclusions

Establishment of a library method for determination of the inspection reliability of underwater techniques has been carried out.

In the first group of trials it was shown that, for the purposes of "first pass detection" and the conditions of the trials, the AV100 and MOSER eddy current and U11 ACFM produced POD curves approaching or exceeding the equivalent curve for Underwater MPI.

References

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Acknowledgment

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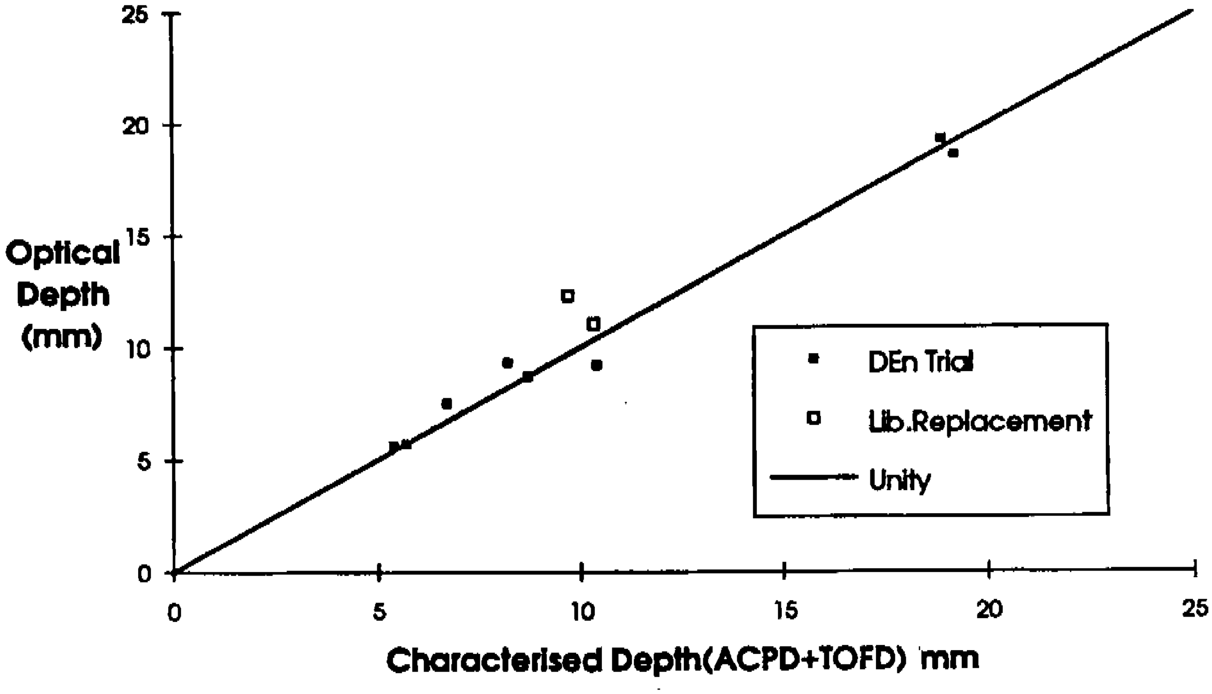

Figure 1
Comparison of Destructive Tests and Characterization (ACPD+TOFD)

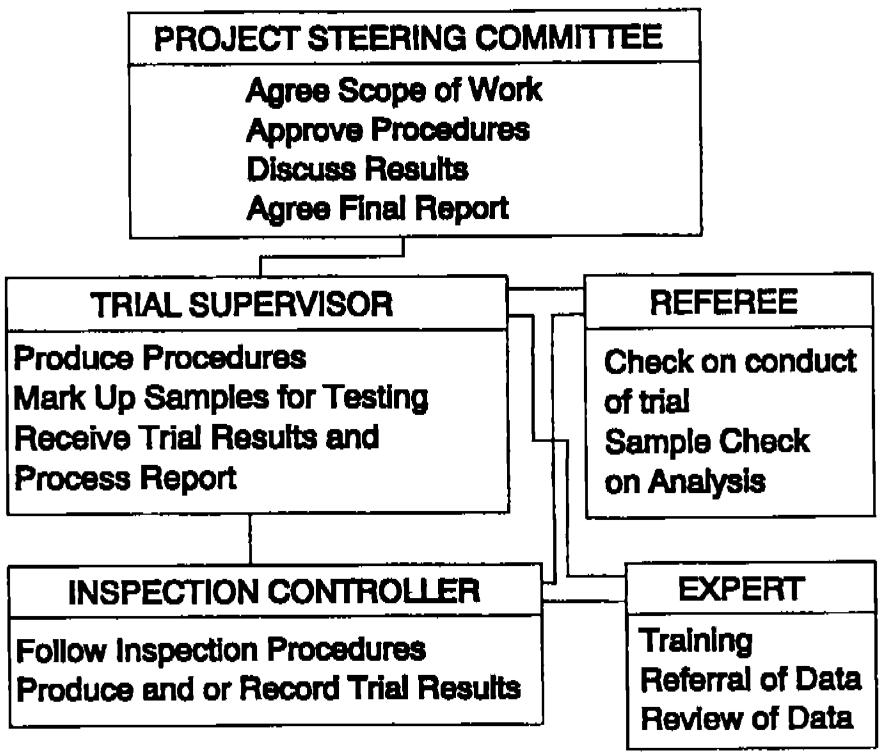

Figure 2
Structure of Trial Organization

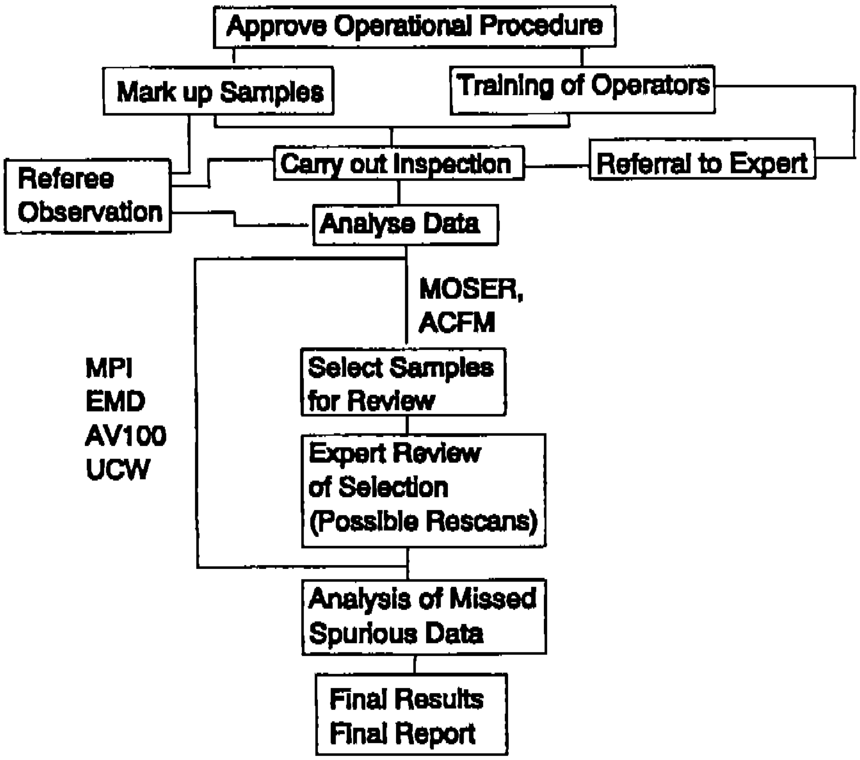

Figure 3
Sequence of Events in a POD Trial

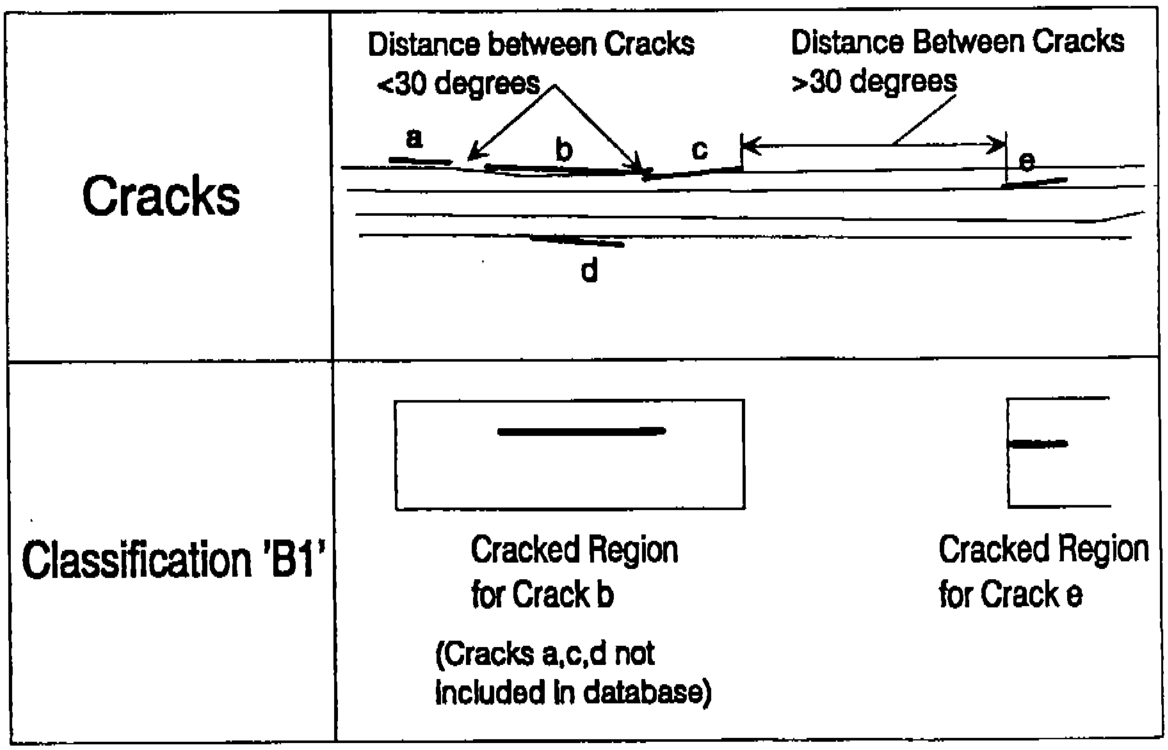

Figure 4
Definition of Crack Classification B1

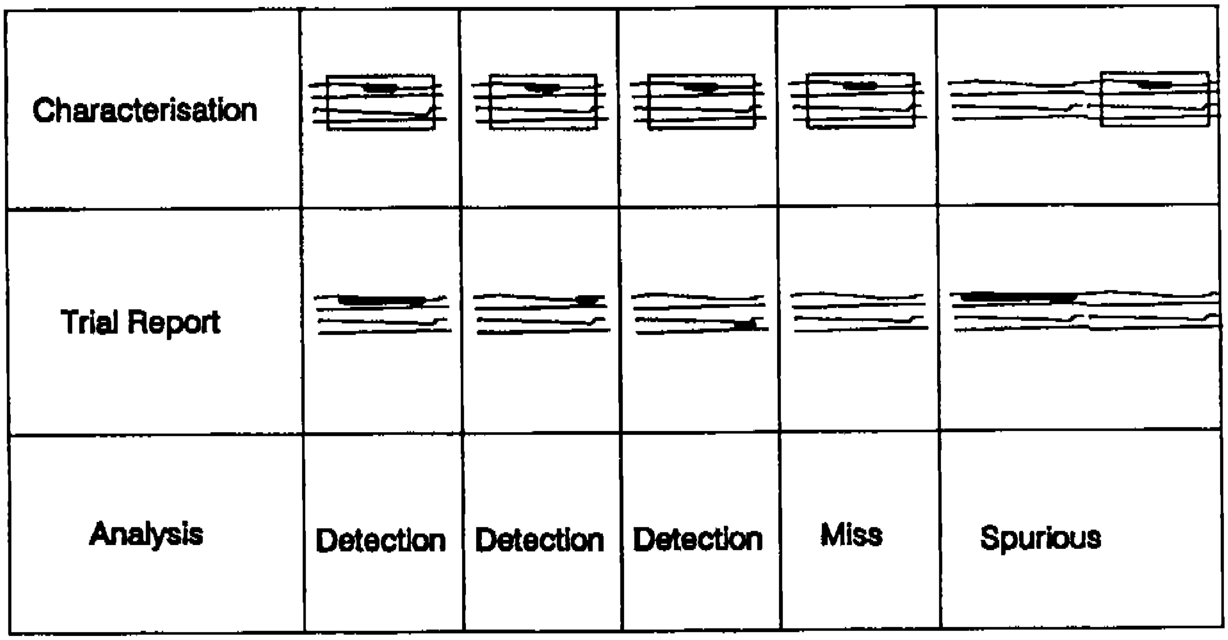

Figure 5
Possible Results of Trial

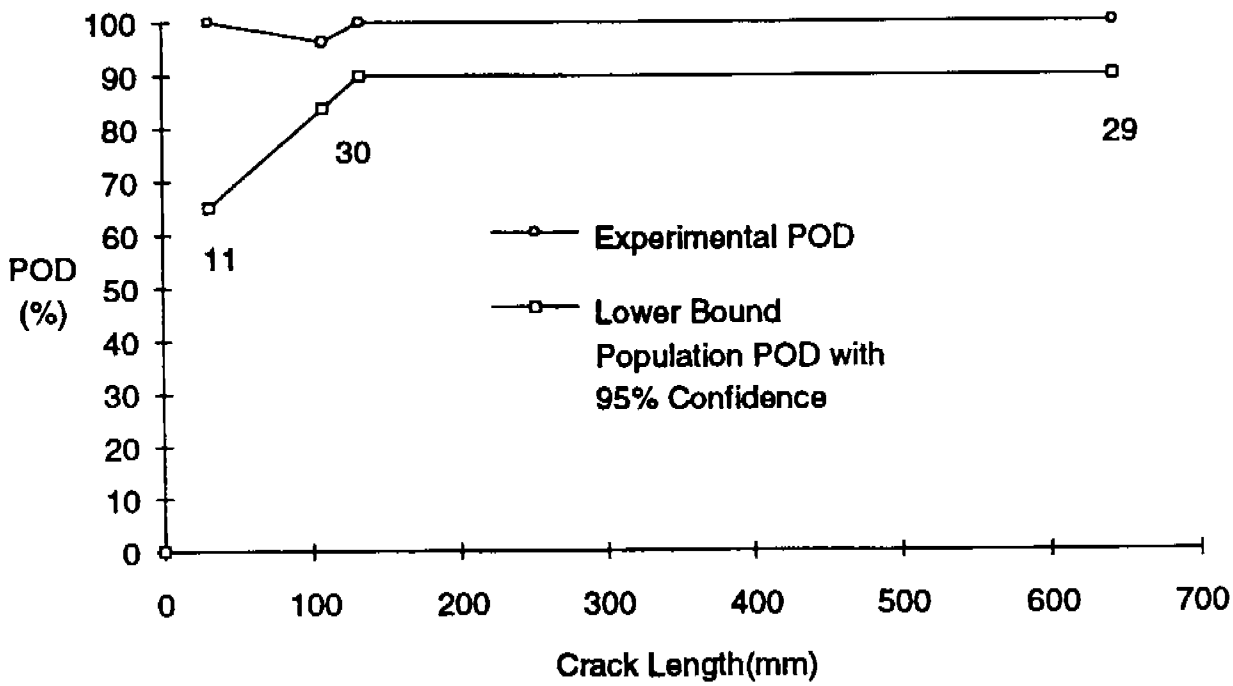

Figure 6
Effect of Crack Numbers on Lower Bound Population Estimate (MPI - Classification B)

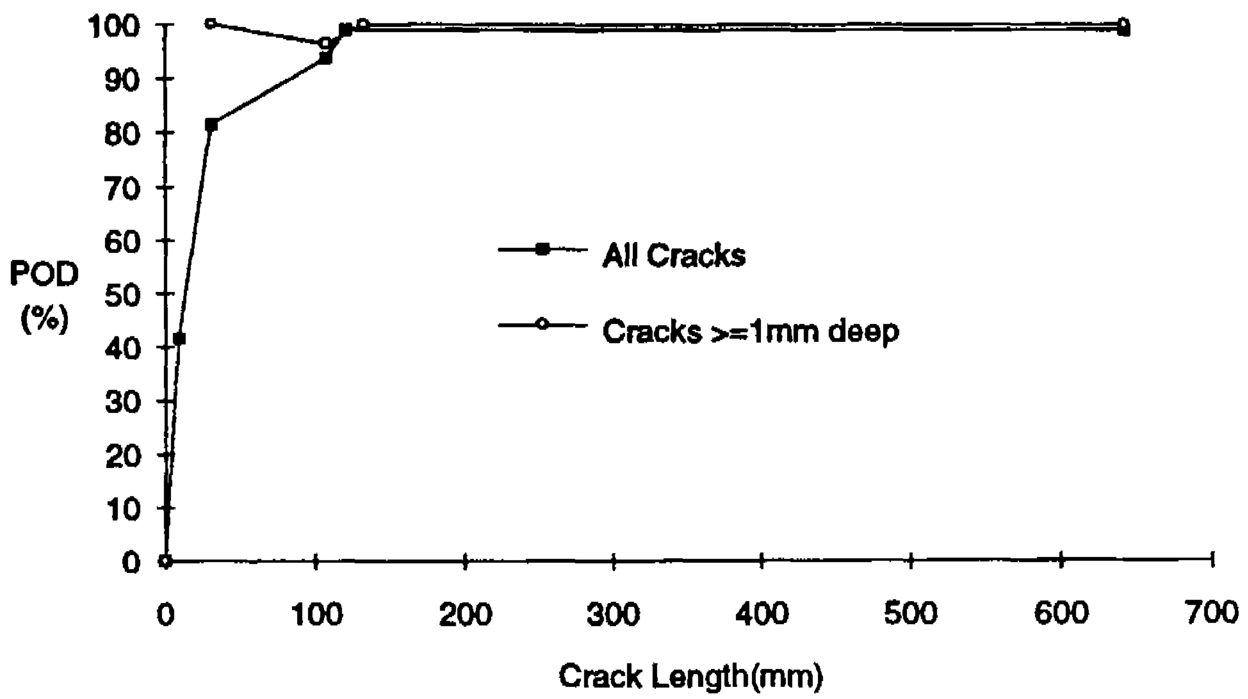

Figure 7
Effect of Depth Threshold (MPI - Classification B)

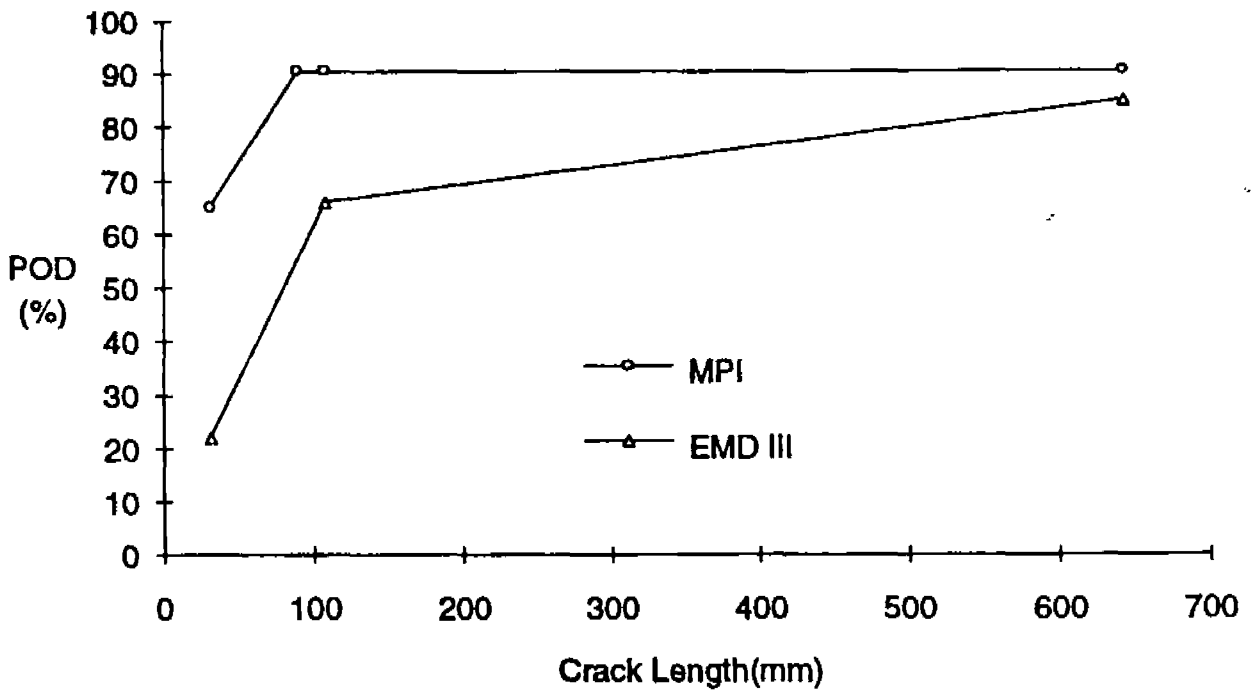

Figure 8
Comparison of Lower Bound Population POD Estimates for MPI and EMD III
(Classification B1 Cracks >= 2 mm deep)

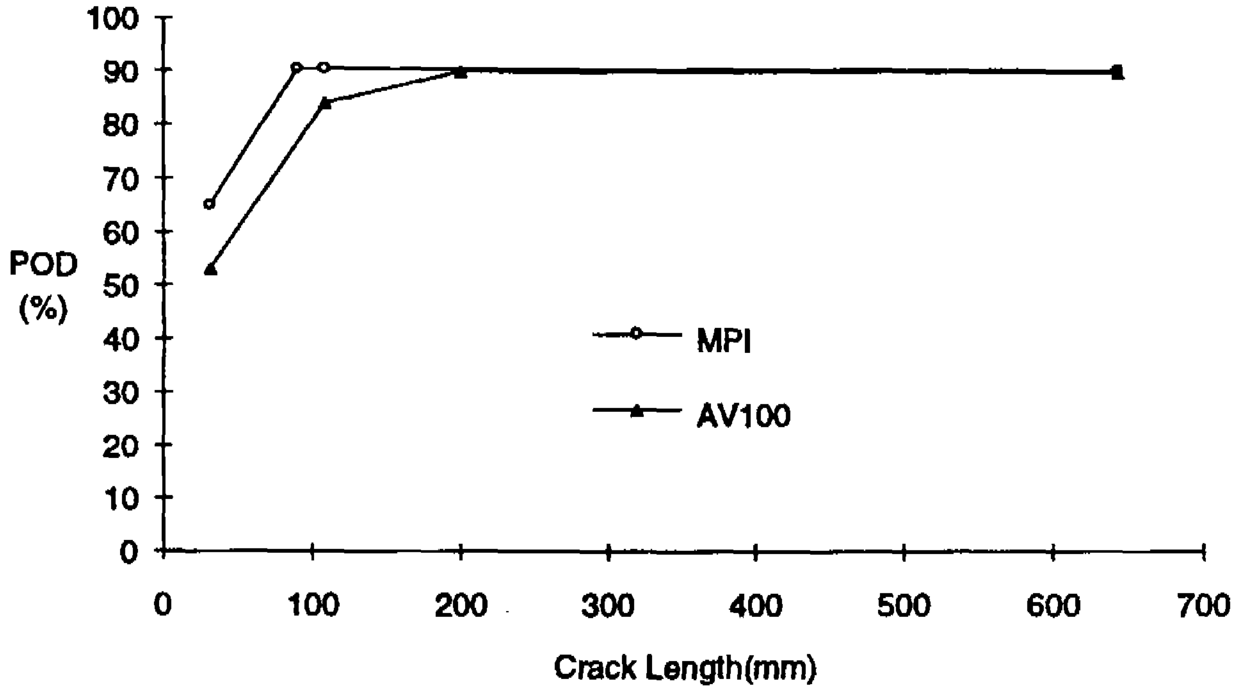

Figure 9
Comparison of Lower Bound Population POD Estimates for MPI and AV100 (topside display only)
(Classification B1 Cracks >= 2 mm deep)

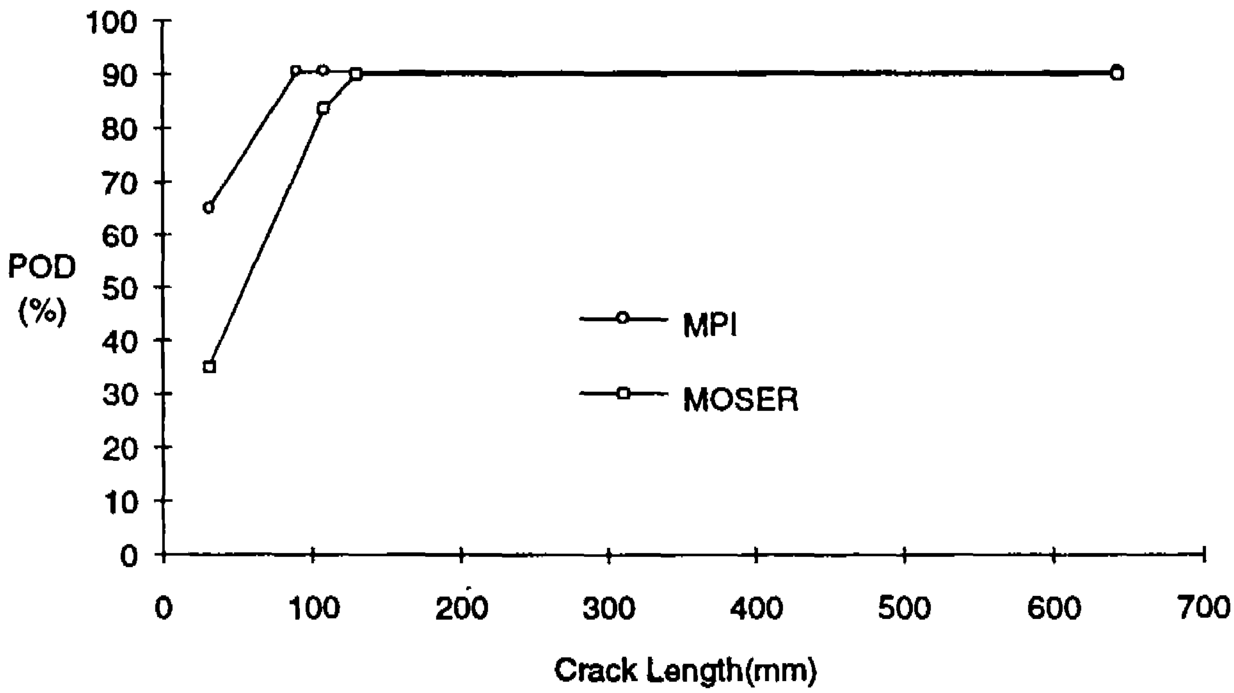

Figure 10
Comparison of Lower Bound Population POD Estimates for MPI and MOSER
(Classification B1 Cracks > 2 mm deep)

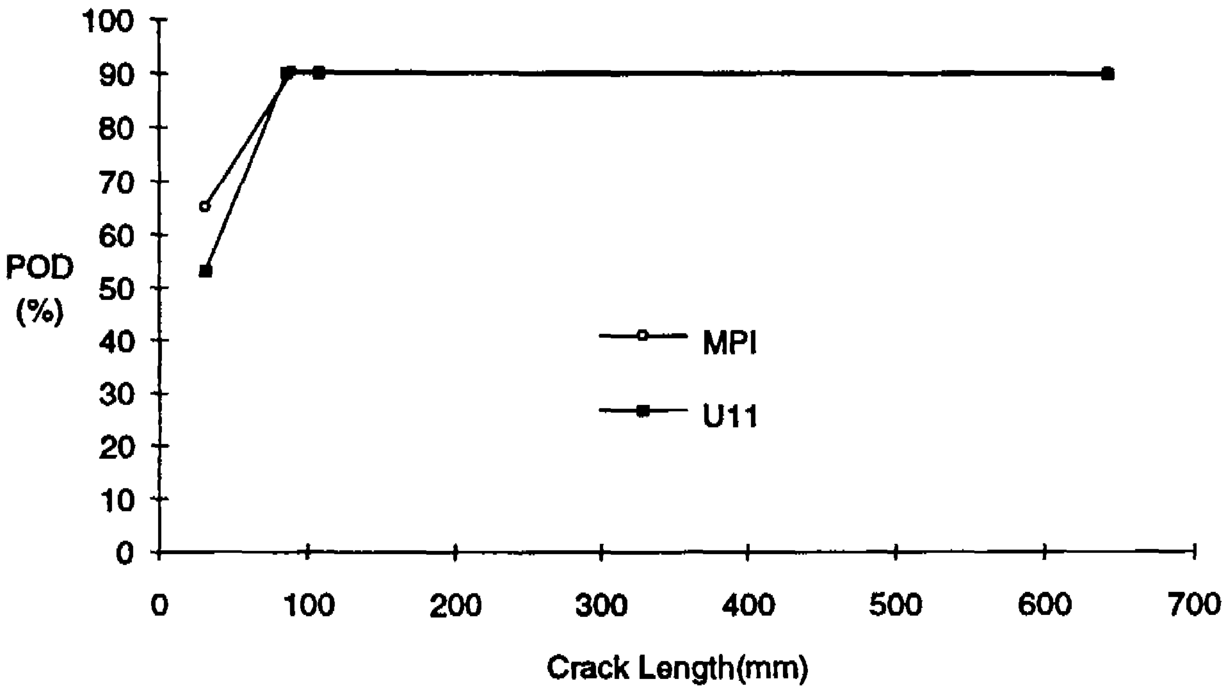

Figure 11
Comparison of Lower Bound Population POD Estimate for MPI and U11
(Classification B1 Cracks ≥ 2 mm deep)

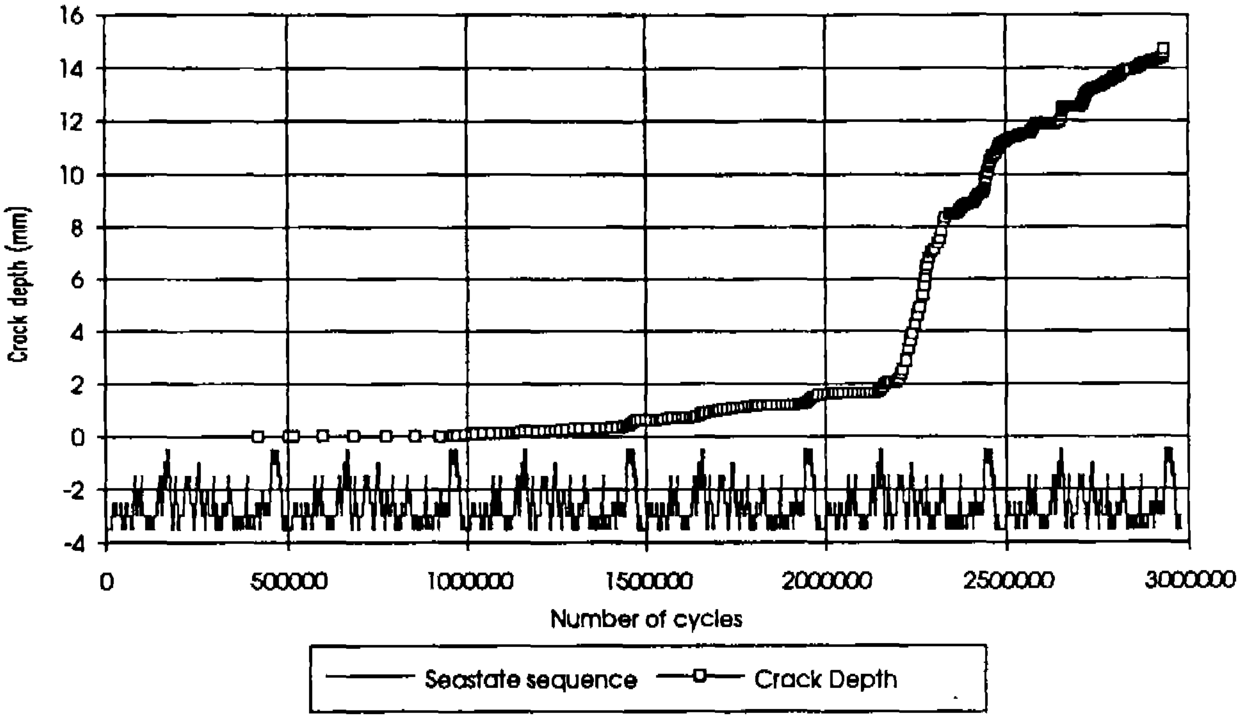

Figure 12
Crack Growth Curve for Corrosion Fatigue Test with Simulated Offshore Loading

Appendix 1
List of Sponsoring Organizations

	MPI	EMD III AV100	POS OSEL/DnV UCW	MOSER	ACFM	LIBRARY REPLACE MENT	COATED NODES
Agip	•	•					
British Gas	•	•	•	•	•	•	•
BP	•	•	•	•			
Britoil	•	•					
Conoco	•	•	•				
Chevron					•		
DnV	•						
HSE (DEn)	•	•	• (ucw)	•		•	•
Elf Norge				•	•	•	•
EE Caledonia (Occidental)	•	•		•	•	•	
Lloyds	•			•			
Marathon	•	•	•				
Nuclear Electric (CEGB)	•			•	•	•	
Oceaneering	•			•	•		
OSEL	•						
Mobil	•	•					
Norsk Hydro	•	•	• (ucw)	•		•	
Phillips	•	•		•	•	•	
Rockwater (2W)				•	•	•	
Shell	•	•	•	•	•	•	•
SERC/MTD	•	•					
US Coast Guard			•				