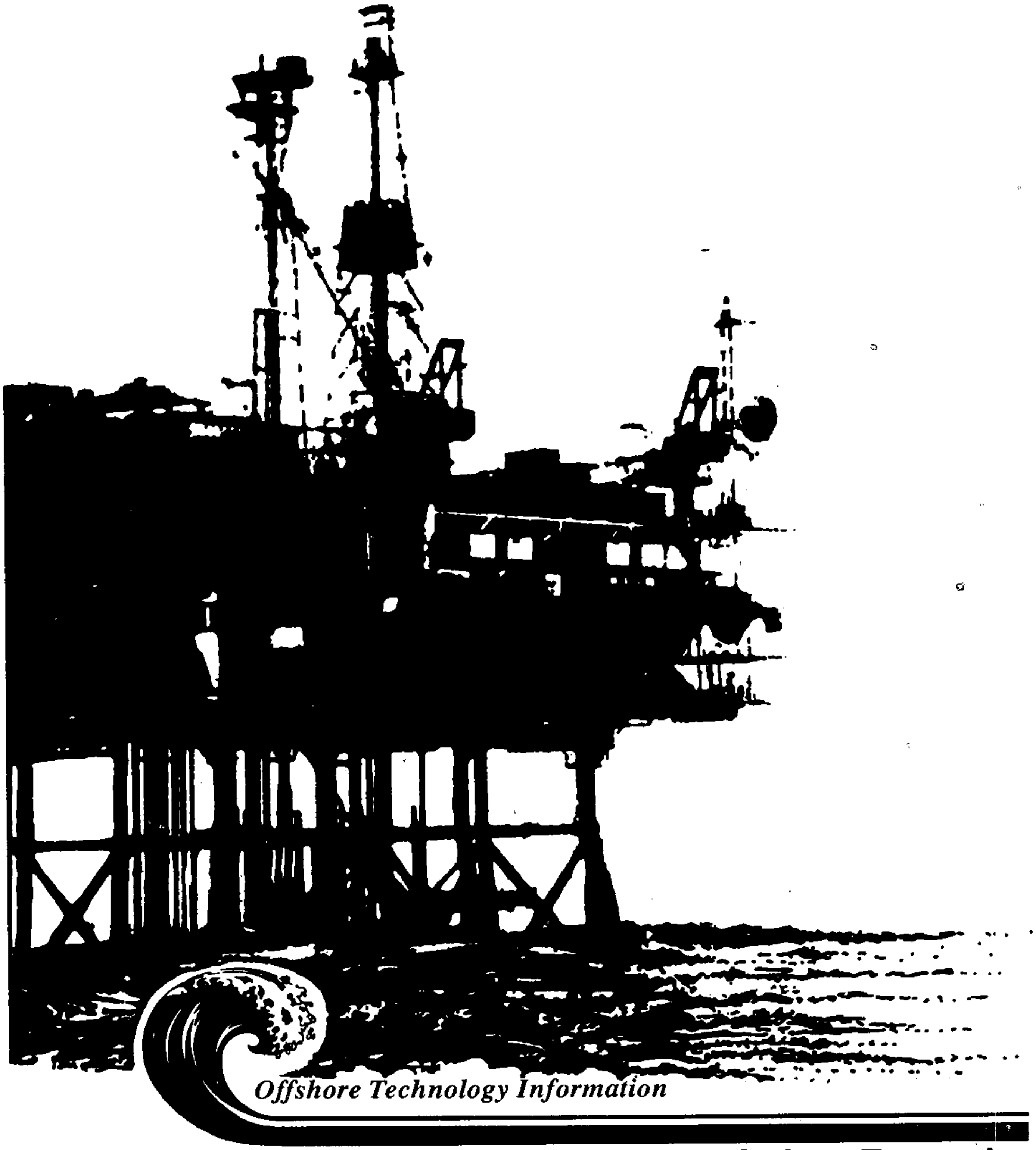
OTI 88 539

HSE Health & Safety Executive

A HANDBOOK FOR UNDERWATER INSPECTORS



Offshore Technology Information

Health and Safety Executive

OTI 88 539

A HANDBOOK FOR UNDERWATER INSPECTORS

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Health and Safety Executive - Offshore Technology Information

First published 1988
Second impression 1992
Third impression 1994

ISBN 0 7176 0848 4

This report is published by the Health and Safety Executive as part of a series of reports of work which has been supported by funds formerly provided by the Department of Energy and lately by the Executive. Neither the Executive, the Department nor the contractors concerned assume any liability for the reports nor do they necessarily reflect the views or policy of the Executive or the Department.

Publications in the Offshore Technology Information (OTI) series are intended to provide background information and data arising from offshore research projects funded by the Department, or the Executive, and major companies.

Results, including detailed evaluation and, where relevant, recommendations stemming from their research projects are published in the OTH series of reports.

FOREWORD

This Handbook has been compiled by ORCA Ltd to bring together, in one volume, all the essential information required for an Underwater Inspection Controller training course. It is based on the 1987 CSWIP syllabus requirements for the 3.3u (Pilot/Observer Inspectors) and 3.4u (Underwater Inspection Controllers) qualifications. The text, mainly in the form of extended notes, follows the format of a typical training course for candidates wishing to obtain these qualifications.

ORCA Ltd wishes to thank those organisations who have given permission for proprietary information or diagrams to be used in this Handbook.

This study was funded by the Department of Energy and completed in 1988. Since then the Offshore Safety Division of the Health and Safety Executive who are publishing this reprint has taken over responsibility for research and development on offshore safety.

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Section 1

INTRODUCTION TO INSPECTION

1. INTRODUCTION TO INSPECTION

Inspection is the process of regularly monitoring any equipment to ensure its continued operation and identify any possible area of premature failure.

With the advent of the discovery of offshore oil and gas and the design, fabrication and installation of structures to exploit this natural resource, subsea inspection of these structures became a necessity.

Subsea inspection is essentially no different from any other type of inspection, the major differences being costs incurred and difficulties involved. The inspection of a weld in a fabrication yard may involve one man, a wire brush and twenty minutes. Inspection of the same weld in 120m of water may require a dynamically positioned vessel, fully crewed with marine and diving crew, six divers in saturation, sophisticated cleaning equipment, video cameras and one days diveable weather. Thus cost of subsea inspection may be 1,000 or more times greater than surface inspection.

The costs involved in subsea inspection mean all inspection programmes must be carefully planned and scheduled. Inspection data collected must be useable, valid and, contain all the necessary details of any defect. Too little detail may require a mobilisation to collect more data, too much detail may waste diving time. Both incur considerable cost to the Operator. Inspection may involve a number of inspection techniques deployed from several dive spreads. It is the job of the Underwater Inspector Controller to ensure data is collected in the most efficient manner possible, to be aware of the limitation of any inspection technique or type of dive intervention, and to report and record the data in a manner which allows the most use to be made of it.

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This section of the manual aims to provide a background to:

- Requirement for inspection
- Philosophy of inspection
- Available methods of inspection, limitations, advantages/disadvantages, need for integration
- Documentation, plans, workscopes, datasheets, numbering systems
- Diver and Inspection Controller qualifications

1.1 REQUIREMENT FOR SUBSEA INSPECTION

1.1.1 INTRODUCTION

The need for subsea inspection is quite simply the need to avoid failure thereby ensuring the safety of personnel and the maximum return from economic investment.

This need is interpreted in many ways by interested parties and many factors are involved in shaping an inspection strategy.

The factors shaping an inspection strategy may be divided into two major groups:

- Government legislation and
- Economic and safety considerations eg. the cost of platform shutdown.

1.1.2 LEGISLATION

1.1.2.1 BACKGROUND TO CURRENT LEGISLATION

Extraordinary deterioration experienced in some offshore structures and a number of catastrophic failures caused the government to produce legislation governing design, fabrication and installation of offshore structures

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In 1971 Parliament enacted the **Mineral Workings (Offshore Installations)** Act to provide for health, safety and welfare of persons working on offshore installations. In 1975, **"The Petroleum and Submarines Pipelines Act"** was passed and provided for all pipelines and offshore installations not covered by the 1971 act.

These acts provide the Department of Energy with authority to issue regulations concerning the construction, installation and survey of installations in UK waters.

1.1.2.2 CERTIFICATION

Using the powers embodied in the 1971 Mineral Workings (Offshore Installations) Act, the Department of Energy authorised the,

The Offshore Installations (Construction and Survey) Regulations 1974 (SI No. 289).

These regulations lay down in broad terms the minimum standards for the design and construction of structures to be used in UK waters, and require each to have a Certificate of Fitness valid for up to five years (see figure 1).

A Certificate of Fitness is issued subject to survey by certain Certifying Authorities approved by the Secretary of State: Lloyds Register of Shipping; The American Bureau of Shipping: Bureau Veritas; Det Norske Veritas; Germanischer Lloyd; and the Offshore Certification Bureau.

Form of Certificate of Fitness

UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
CERTIFICATE OF FITNESS OF OFFSHORE INSTALLATION

Certificate Number ....

Name or other designation of the offshore installation ....

Description of installation ....

Name(s) of owner(s) ....

THIS IS TO CERTIFY pursuant to Regulation 9(1) of the Offshore Installations (Construction and Survey) Regulations 1974 that the above-described offshore installation is fit to be * established/stationed and maintained in waters to which the Mineral Workings (Offshore Installations) Act 1971 applies, † subject to the following limitations:

This Certificate remains valid subject to annual and additional surveys in accordance with the Regulations until .... unless previously terminated by the Secretary of State.

Issued at .... on .... 19 ....

Signed ....

Designation ....

on behalf of ....
A Certifying Authority
appointed pursuant to the Regulations.

*delete whichever is inapplicable
†delete if inapplicable

Figure 1

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1.1.2.3 GUIDELINES

The Offshore Installations (Construction and Survey) Regulations 1974, does not provide guidelines as to what must be inspected to obtain a Certificate of fitness. These guidelines are provided by the certifying authorities and are based on the Department of Energy guidelines:

"Offshore Installations: Guidance on Design and Construction", April 1984.

These Department of Energy guidelines are constantly under review and regular revisions are made. The current set of guidelines is the third edition.

The guidelines produced by the Department of Energy and Certifying Authorities provide the basis for an inspection programme. The way these guidelines affect the inspection programme are dealt with in Section 1.2 Philosophy of Inspection.

1.1.3 ECONOMICS AND SAFETY

In addition to satisfying legislative requirements, Operators perform subsea structural inspection to protect their investment.

Three major cost considerations must be taken into account by any Operator planning an inspection strategy:

- The cost of any disruption to or shutdown of production to effect structural repair results in a tremendous loss of revenue.

- The cost of repair itself can be very expensive especially underwater repairs.

- An offshore structure has a predicted design life throughout which it is expected to produce enough revenue to cover design, fabrication, installation and running costs. Any reduction in design life can have a serious effect on the installations profitability.

An Operator, therefore, seeks to introduce an efficient inspection programme which minimises the possibility of disruption at minimum inspection cost.

1.2 PHILOSOPHY OF INSPECTION

1.2.1 LEGISLATION

As previously detailed in order to qualify for a Certificate of Fitness a structure must be surveyed at regular intervals as specified by the certifying authority. Typically an installation must undergo an initial major survey prior to issue of a Certificate of Fitness and thereafter undergo inspection designed to meet the requirements for survey as laid down in SI No 289.

The requirements for each major survey are agreed with the certifying authority and vary from installation to installation depending on design and previous inspection findings. The specifications for each type of survey however normally follow a similar general type.

The first major survey, ensures a) the installation is correctly positioned b) that no damage has been sustained during installation and c) a structural condition report to which all other surveys can be referenced. It involves:

- visual survey of all members and attachments
- visual survey of foundations and seabed

To obtain recertification of the installation, a major survey of the installation must be completed within the five year period of the current certificate. However, where a Certificate is in force, annual surveys, may be accepted in lieu of a subsequent major survey. The first annual survey is to be performed not less than nine and not more than eighteen months after the date of issue of the Certificate of Fitness. Thereafter, similar surveys shall be carried out not less than nine nor more than fifteen months of each anniversary of the date of issue.

Any structural damage, major alterations to or deterioration likely to impair the safety, strength and stability of an installation must be reported to the Certifying Authority, who can request further survey or can invalidate the Certificate of Fitness, thereby prohibiting further operations depending on the severity.

Although flexible, authorities do expect Operators to complete a sufficient amount of approved inspection in any one year to comply with the Annual Surveys Ruling and also to accumulate findings on a progressive basis towards the nulling of the requirement of a major survey, should this be the route chosen by the operator company. Typically surveys will comprise of:

- Close visual inspection or re-inspection of a representative number of welds.
- A general corrosion survey, including cathodic potential readings, and protection system assessment, (anodes, electrodes).
- A seabed condition and scour survey around the structure.
- A physical damage/structural integrity survey.
- A debris survey.
- A marine growth survey.
- A full survey of marine export risers, conductors and caissons and their supports and protection systems.

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Multi-Year Inspection Programmes

The need for systematic re-inspection of various structural components and the impossibility of inspecting all parts of large structures every year have led to the adoption of multi-year programmes, as provided for in the Regulations.

1.2.2 INTERVENTION TECHNIQUES

Five basic methods of intervention are currently used to inspect or to deploy inspection equipment on subsea structures.

These are:

REMOTELY OPERATED VEHICLE (ROV)
AIR DIVING
SATURATION DIVING
MANNED SUBMERSIBLE
REMOTELY APPLIED INSPECTION SYSTEMS

Each of these techniques has advantages/disadvantages and limitations in capability. An inspection scheme will normally involve the use of several complimentary systems to carry out the inspection requirement.

This section is intended to briefly introduce each intervention technique and show how these may be integrated to provide a complete inspection. The techniques themselves are described in greater detail in Section 7.

ROV Systems

ROV's are machines powered by several thrusters and linked to surface via a control and power umbilical. ROV's vary from the very simple "flying eyeball", with a single video camera, to the very complex which may carry a variety of sophisticated cleaning, inspection or tracking equipment.

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ADVANTAGES of ROV's include:

- they are able to work at depths and in sea conditions where diving would be hazardous
- ROV spreads are considerably cheaper than saturation diving spreads
- as no bell turnaround time etc is required the ROV can be more time efficient than a dive spread

DISADVANTAGES include:

- a video camera cannot "perceive" the same detail as the human eye
- most manipulative tasks remain too complex for even the most sophisticated ROV manipulator
- expensive tooling packages need to be designed for each type of function required
- work at shallow depths 0m to -10m is often very difficult due to the effects of swell etc.

Whilst ROV's have been designed to carry out many inspection tasks including cleaning, flooded member detection and radiography, the most common use of an ROV is visual photographic and CP inspection.

Typical use of an ROV in an annual inspection programme would be:

- Visual inspection of the entire structure to identify any areas of damage, or areas which may warrant more detailed inspection
- Marine Growth Survey
- Seabed and Mudmound Survey
- Photographic Survey
- CP and Current Density Survey

ROV inspection is typically the first task to be undertaken in an annual inspection programme. This allows identification of possible areas for other spreads to investigate. The ROV is also able to perform in weather conditions other spreads may deem unacceptable and is, therefore, suitable to operate earlier in the year.

Saturation and Air Diving

These two intervention techniques are similar since they involve a human being equipped to dive as the survey tool. The major difference is basically the increased cost and complexity of the hardware necessary to support a saturation diver on the job.

ADVANTAGES of Diving include:

- The human eye is much more observant than a CCTV camera
- Manipulative tasks are more readily undertaken
- Divers can work in the splash zone

DISADVANTAGES include:

- Depths and sea conditions present more constraints to divers than ROV's
- Bell turnaround times etc reduce operational time
- Diving is generally more expensive than ROV operations

Divers can be used to carry out almost all inspection tasks. Under certain conditions ROV's are rarely used, eg particularly in the shallower Southern North Sea, divers still carry out most inspection. However, in the deep Northern North Sea ROV intervention is more frequent, divers are normally used to carry out jobs which make use of the manipulative and observation capability of the human body.

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These tasks include:

- Cleaning, all forms of general and specific cleaning
- Close Visual Inspection, inspection which requires prior cleaning and/or is too detailed to be carried out by ROV
- NDT techniques eg. MPI, ultrasonics etc
- Sampling - marine growth and deposits.

<u>Manned Submersibles</u>

In a manned submersible the pilot and/or the observor/inspector remain at atmospheric pressure.

They may be connected to surface support via a lift wire and umbilical or may be freeswimming. Manned submersibles commonly have thrusters to move the vehicle and have manipulators to give the vehicle some manipulative capability.

Manned submersibles are not as common as ROV's in the North Sea. They are most frequently used in deep water for specialist inspection and construction tasks.

ADVANTAGES of such a vehicle include:

- They can be used at depths and sea conditions which are considered to hazardous to divers
- A human observer and manipulator operator "on-site" can be more effective than a remote ROV Pilot/Observor inspector

DISADVANTAGES include:

- Vehicles are large, requiring costly deployment systems, and several operating personnel
- Manipulators are not as sensitive or functional as human hands and cannot be used for most NDT techniques

Remotely Applied Inspection System

These systems cannot be considered intervention techniques in the true sense. Unlike the techniques described earlier they do not deploy themselves to a worksite gather required data and return. The systems outlined here are those deployed at the fabrication stage or by ROV's or divers and left in position to supply a regular stream of inspection data to surface.

Typical systems in use would include:

- Cathodic Protection System reference electrodes
- Forced and Natural Acoustic Emission Systems
- Fixed CCTV cameras, looking at a specific area of interest

ADVANTAGES of such system are:

- they provide constant monitoring of the structure and allow automatic feedback
- they may be used to predict areas requiring further inspection

DISADVANTAGES include:

- systems are fixed and cannot easily be adjusted to give better coverage of the structure
- systems can only supply one type of information
- control lines are prone to breakdown at the splash zone

An inspection scheme may make use of any one or all of the above intervention techniques. The choice of intervention technique used for any particular task will depend upon a number of factors:

- environment in which inspection is to take place (ie. depth, predicted weather conditions)
- the type of NDT technique used
- detail of required results

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A stated objective is to reduce the cost of inspection as much as possible. Taking all of the factors discussed into account most operators will schedule as much work as possible to be carried out by the cheapest available option.

1.2.3 DOCUMENTATION

A considerable number of documents are generated for and by a subsea inspection programme. In the preceding sections various types of documents have been mentioned, government legislation, reports etc.

This section aims to provide an introduction to the type and use of documents with which the Inspection Controller may be involved.

All operating companies have their own system of organising the documentation necessary to ensure continued certification of their offshore installation. Typical documentation would include:

A 5 year Certification Plan
Annual Workscope or Inspection Programme
Workbook or Workpacks
Annual Inspection Reports
5 year Certification Reports

5 Year Certification Plan

The 5 year Certification Plan details how the operating company intends to fulfil the Department of Energy requirements for a major survey within the five year recertification period. This document is compiled taking account of the guidelines issued by the Department of Energy and by the selected certifying authority and with recourse to the DFI (Design/Fabrication/Installation) manual and to previous inspection reports. The Plan is presented to the certifying authority for approval and on gaining approval provides the basis for planning the next five years inspection.

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The Annual Workscope or Inspection Programme, is drawn principally from the approved 5 Year Plan. This programme is designed to fulfil the requirements of an annual survey and a portion of the major survey. In addition to work drawn from the five year plan, the annual workscope will normally contain inspection of any remedial work undertaken the previous year. Inspection of areas of interest which had not been identified at the time of compilation of the 5 year plan may also be included. The annual workscope is normally discussed with the certifying authority for approval.

<u>Workbook, Workpack</u>

The workbook or workpack is the most important document to the Inspection Controller. All operators have their own approach to the workpack and subsequently a large variety of formats exist. In this instance, we are considering the workpack to comprise all the documentation necessary to carry out the inspection offshore.

The workpack will normally contain:

- The Inspection Programme, allowing the Inspection Controller to schedule and plan the inspection activities.
- Platform drawings indicating areas to be inspected.
- Inspection Procedures - detailing how to inspect, with what equipment and using which technique.
- Datasheets, for recording of inspection data, normally tailored to suit the particular inspection being undertaken, and general non-specific datasheets, video logs, photologs etc.

Depending on the Operator many other pieces of information may be contained in the workpack. Amongst these could be:

- Diving Operations procedures and logs
- Equipment listings and charging logs
- Task Code listings

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Annual Reports

Annual Reports are produced at the end of the inspection programme. Again these will be in many different formats depending on the requirement of the Operator, but all will contain a summary of the years inspection results and identification of possible problem areas and will detail any repairs carried out during the programme. This report may be submitted to the certifying authority for their information and approval.

5 Year Certification Reports

In a similar manner to the annual inspection report this report will summarise the inspection results over a five year period, identify problem areas and report on repairs. This report will be presented to the certifying authority as the basis for recertification.

1.2.4 DIVER QUALIFICATIONS

1.2.4.1 BACKGROUND

In the early to mid 1970's no official subsea inspection qualifications existed, diving personnel requiring NDT qualifications attended courses in surface NDT practice. Gradually specialised subsea qualifications were introduced primarily by Det Norske Veritas, Lloyds and CSWIP (Certification Scheme for Weldment Inspection Personnel).

The CSWIP Phase 7 3.1D Diver Inspector qualification introduced in 1979 became regarded as the industry standard. The CSWIP Diver Inspector qualification scheme was upgraded in 1983 with the introduction of the 3.1u and 3.2u qualifications. These qualifications are now accepted as standard throughout the industry and certificates from other qualifying bodies are rarely accepted.

1.2.4.2 3.1U AND 3.2U QUALIFICATIONS

The 3.1u qualification is the lower of the two qualifications and must be successfully completed before the 3.2u qualifications can be attempted. The 3.1u qualification concentrates on the following areas:

- Close and General Visual Inspection
- CP measurement
- Digital Wall Thickness Measurement
- Photography
- Video Recording Techniques

Most operating companies require a diver to hold a 3.1u certificate before they can carry out any subsea inspection and limit the inspection carried out by the diver to those techniques studied in the 3.1u course.

The 3.2u qualification concentrates on more advanced NDT techniques, these include:

- A-Scan ultrasonics, for wall thickness and lamination checking
- Magnetic Particle Inspection

1.2.4.3 NDT QUALIFICATIONS

The highest diver inspector qualification is the 3.2u this qualification covers only the basics of ultrasonic inspection and involves no radiography or eddy current testing. Diver inspectors wishing be qualified in any of the above NDT techniques must take the appropriate surface qualification.

The diagram overleaf (fig 2) details the CSWIP inspection qualifications for both u/w and surface NDT.

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In addition to the CSWIP NDT qualifications some other topside certification schemes exist. These schemes include:

ERS - Engineering Research Station
ASNT - American Society for Non-Destructive Testing
AINDT - Australian Institute for Non-Destructive Testing
CGSB - Canadian Government Specification Board

1.2.5 INSPECTOR CONTROLLER AND PILOT/OBSERVER INSPECTOR QUALIFICATIONS

In 1987 CSWIP introduced 3.3u, and 3.4u qualifications.

The 3.3u qualification is designed to qualify Pilot/Observer Inspectors involved in ROV inspection of offshore structures. An additional module is available as a supplement to qualify inspectors for pipeline inspection. This adds the suffix P to the qualification.

The 3.4u qualification is designed to qualify Underwater Inspector Controllers involved in controlling both diver and ROV inspection of offshore structures. This qualification includes the theory involved in both 3.1u and 3.2u qualifications in addition to quality assurance, inspection planning and briefing, data recording and processing modules. This qualification also has an additional module available as a supplement to qualify underwater inspector controllers for pipeline inspection. This adds the suffix P to the qualification.

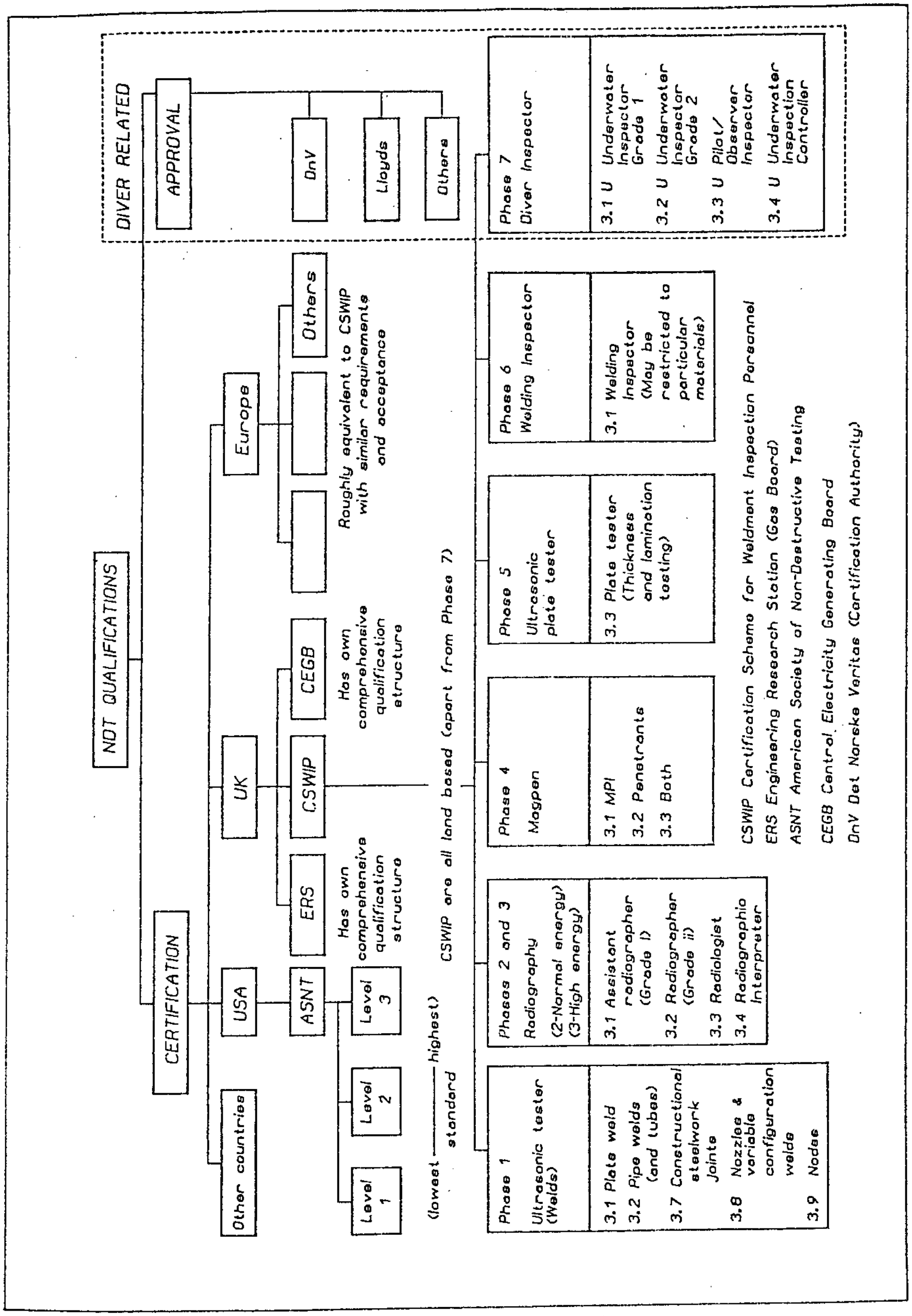

Fig. 2

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1.2.6 AVAILABLE METHODS OF INSPECTION

A great variety of methods are available for the inspection of offshore installations, some suitable for both concrete and steel structures, some for only one or other type of structure. All types of inspection methods have advantages/disadvantages and limitations. One technique may not be sufficient to inspect fully a component, inspection may need two or three integrated techniques to give the desired results.

1.2.6.1 VISUAL INSPECTION

The most commonly used inspection technique is visual inspection. This is commonly considered as divided into two separate disciplines, General Visual Inspection (GVI) and Close Visual Inspection (CVI). Some operators consider a further subdivision, Detailed Visual Inspection (DVI) falling between GVI and CVI. Visual inspection techniques are used with both forms of structure, concrete and steel, and on all types of installation. Exactly what is looked for during the visual inspection is obviously dependant on structure type and anticipated deterioration mode, but basic procedures remain similar.

General Visual Inspection

May be carried out by either diver or ROV. The inspection normally takes the form of a damage and debris survey to determine areas which may require further inspection. Cleaning is not normally required prior to this technique. The technique is used on all areas of any type of installation. Inspection may or may not be recorded on CCTV.

Close Visual Inspection

Is normally carried out by diver. The inspection normally taking the form of a detailed examination of an area of interest, requiring precise measurement of defects sizes and locations. Cleaning is normally required prior to this technique. The technique is normally carried out on welded joints in steel structures and areas of damage on both steel and concrete structures.

Detailed Visual Inspection

Many operators consider DVI a sub-technique of GVI however some treat it as a technique in its own right. DVI may be carried out by diver or ROV, but is normally carried out by diver. The inspection normally takes the form of visual inspection of a tightly defined area eg. a clamp, node, etc. Cleaning may or may not be required prior to inspection.

1.2.6.2 INSPECTION OF CATHODIC PROTECTION SYSTEMS

Primary inspection of CP systems will be carried out using visual means to identify condition of anodes, reference electrodes etc. Two forms of specialist measurement may be used to measure the function of a Cathodic Protection Systems these are Cathodic Potential Measurement and Current Density Measurement. These techniques will only be used on steel jackets or on steel appurtenances on concrete jackets.

Cathodic Potential Measurement

Is the most common of the two techniques, and may be carried out by either ROV or diver. The technique uses the principal that any metal in an aqueous solution will adopt an electrical potential, by altering this potential using a CP system corrosion of the metal can be effectively halted. If we can measure the potential of the metal we can determine whether or not the CP system is working and preventing corrosion.

Measurement is carried out by comparing the potential of a structure with an Ag/AgCl cell of known potential, if the difference between the two is between -800mV to -1100mV the CP system is functioning adequately.

Use of this technique allows identification of areas of possible corrosion damage to the structure.

Current Density

This technique can again be carried out be either diver or ROV although is most commonly carried out be ROV. The principal behind the technique is that the cathodic protection system must be able to supply a certain current per unit area of steel to prevent corrosion. In the Northern North Sea this is around $150mA/m^2$. Using specialist probes to measure current density we can determine any areas where the CP system is not providing sufficient density to prevent corrosion.

1.2.6.3 WALL THICKNESS MEASUREMENT

Wall thickness measurement to determine any reduction in wall thickness of metallic components, caused by corrosion or physical damage.

Digital Wall Thickness Measurement

Is primarily carried out by divers. Recently, however, several ROV's have become equipped with wall thickness measurement capability.

Digital wall thickness measurement is an ultrasonic technique. Ultrasonic techniques make use of the principle that a portion of the sound travelling through a medium will be reflected at the interface between the medium and another medium. Then by measuring the time between a transmitted pulse of sound and a reflected pulse and knowing the velocity of the ultrasound in a given medium the position of the interface and hence wall thickness can be calculated.

The digital wall thickness meter uses this principle to give a direct read out of steel thickness with an accuracy of ±0.1mm. The degree of surface cleaning required is dependant on the type of meter used.

A-Scan Wall Thickness Measurement

This technique is only carried out by a suitably qualified diver. The technique is again an ultrasonic technique and uses the same principles as the digital wall thickness meter. In this case the wall thickness is not given as a digital readout but has to be interpreted from a trace on a Cathode Ray Tube (CRT). The technique requires the surface to be prepared to a clean metal finish.

1.2.6.4 FLOODED MEMBER DETECTION (FMD)

Flooded member detection is carried out on steel tubular members. Principally, if a member is detected as flooded then a through thickness defect must be present. By checking all members in a jacket, detailed inspection can be focused in those areas where potential through thickness defects exist. Two methods of flooded member detection are currently available ultrasonic FMD an Radiographic FMD.

Ultrasonic FMD

A variety of types of ultrasonic FMD apparatus is available, some for ROV and some for diver use, however, all use the same ultrasonic principles. As mentioned previously ultrasound travelling through any medium will be reflected at the interface between that medium and any other medium, the ratio of the ultrasound reflected to that transmitted depends on the relative densities of the two media, the denser the second medium the greater the percentage of ultrasound transmitted.

Flooded member detection makes use of this principle. If the member is not flooded the difference in density of the steel and air is so great almost all the ultrasound is reflected back to the probe from the back wall of the steel tubular. If the member is flooded a portion of the ultrasound is transmitted into the water in the tubular, travels across the tubular is reflected from the opposite wall and is picked up on return to the probe.

The degree of surface cleaning required prior to use of ultrasonic FMD equipment is dependent of the make of equipment used.

Radiographic FMD

Radiographic FMD apparatus is again available for use by either ROV or diver. The principle behind its operation is that the amount of radiation which is absorbed as a stream of radiation passes between a source and a detector is directly related to the amount of mass through which the stream has to pass. Thus if a source and detector are at opposite sides of a flooded member less radiation will be picked up by the detector, than if they are at opposite sides of a non-flooded member. No cleaning is necessary prior to use of this technique.

1.2.6.5 WELD INSPECTION TECHNIQUES

Almost all weld inspection techniques are currently carried out solely by diver although some attempts have been made recently to carry out some techniques with an ROV.

The most popular weld inspection technique is close visual inspection. However, close visual inspection cannot always give a full analysis of a welds condition. Results are very subjective and difficult to quantify, fatigue cracks are often not visible, and no sub-surface defects can be observed. The problems associated with visual inspection have led to considerable time and effort being spent developing a variety of techniques for detecting and sizing weld defects. Techniques developed have made use of ultrasonic, radiographic magnetic and electronic principles.

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Magnetic Particle Inspection

This is the second most common weld inspection technique. This technique uses the principle that magnetic flux leakage occurs at a surface discontinuity in steel, eg. a crack and that this flux leakage will attract a magnetisable powder hence displaying the point of flux leakage. The technique requires the surface of the weld to be well cleaned, Sa 2.5. Problems with MPI include; it can only be used to detect surface breaking flaws, length of flaws can be detected but depths cannot, results are very subjective and weld profile can make interpretation difficult.

Radiography

Two radiation sources may be used to carry out radiographic techniques gamma or x-rays, however, the fundamental principles remain the same for each source. Radiographic techniques make use of the principle that the proportion of radiation absorbed as it passes through a medium from source to detector is dependant on the mass through which it passes. In the case of examination of welds the detector is suitable photographic film. The film is placed at the opposite side of the weld from the source, then exposed for a pre-determined time. When the film is developed areas allowing a disproportionately large amount of radiation to pass through can be identified. These will be areas of cavity, slag inclusions or similar defects in the weld. Radiography is used to detect volumetric weld defects, but will not easily detect fatigue cracks. A radiograph of a badly pitted surface can be difficult to interprate.

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A-Scan Ultrasonics

This weld inspection technique utilises the same principles as ultrasonic techniques mentioned earlier, reflection of ultrasound at an interface. In this case making use of special probes the operator examines the metal making up the weld and surrounding area. The ultrasound is reflected from cracks, inclusions, holes, etc, in the area of metal under examination. The operator interprets these reflections from a display on a cathode ray tube and maps the position of any weld defects.

A-Scan ultrasonics is probably the most comprehensive NDT technique used for weld inspection but still has many limitations. The technique is not very effective at detecting or sizing surface breaking cracks. The metal surface must be in good condition to allow ultrasonic probe manipulation, complex node and weld geometry can make interpretation of results very difficult.

Alternating Current Potential Drop (ACPD)

The technique utilises the 'skin' effect of a high-frequency alternating current passing through a conductive material whereby the current flows in the very near surface of the material and, if a defect breaks the metal surface, the field will follow the profile of that defect. The fall in potential is proportional to the current path length.

ACPD is a specialised technique and is used mainly to measure the depth of surface breaking defects, normally fatigue cracks. Metal surface must be cleaned to Sa 2.5 to allow use of ACPD.

Electromagnetic Detection (EMD)

This technique is more commonly known as Eddy Current Testing. The technique uses the principle that a coil carrying an alternating current produces an alternating magnetic field. If the coil is placed in close proximity to a conductive metal surface the magnetic field will induce "eddy currents" to flow in the metal, these eddy currents will produce their own magnetic field. The magnitude of this magnetic field varies as changes in the structure of the metal are encountered eg. cracks. Therefore by measuring the magnetic field we can detect defects in the metal.

The technique can only be used to detect and size surface breaking or near surface defects.

The above techniques are the most commonly encountered specialised weld inspection techniques. During a conventional weld inspection other general inspection techniques, photography, moulding etc may be used.

In addition to all the above techniques many new weld inspection processes are at various stages of development and may in the future become commonly used offshore. Techniques currently under development include, time of flight ultrasonics, x-ray flouroscopy thermographic FMD and several others.

1.2.6.6 MOULDING TECHNIQUES

Moulding is a technique used to obtain an accurate 3D copy of a surface under investigation from which measurements may be taken. The technique may be used for both types of structure and normally requires surface cleaning of the site to be moulded. The two most commonly used moulding compounds are Epophen and Aquaprint, both are two part polymers which are applied to the area to be moulded and allowed to cure.

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1.2.6.7 PHOTOGRAPHY

Still photography is an important inspection technique. It is used in association with virtually all inspection techniques to provide a permanent high quality visual record of the subjects condition at the time of inspection. Photography is commonly considered to be split into close-up and stand-off photography. In close up photography the camera lens is normally 150mm to 500mm from the subject, typically this type of photography is used for weld mosaics. In stand-off photography the camera lens is normally more than 500mm from the subject, typical applications include photographs of anodes, clamps, nodes, etc.

1.2.6.8 STEREOPHOTOGRAPHY AND PHOTOGRAMMETRY

A stereophotograph is one that allows three dimensional viewing. It is produced by overlapping a pair of photographs taken of a subject with identical lenses of known separation. Photogrammetry is the science of taking accurate measurements from stereo photographs. Photogrammetry can yield very accurate measurements in three dimensions.

This technique can be used for both steel and concrete structures. The subject generally being cleaned before photographs are taken.

1.2.6.9 SAMPLING

This technique may be used on concrete or steel structures. The object of the technique is to obtain a sample of some area of interest for further investigation. Samples are commonly taken of marine growth, corrosion products and areas of failed concrete for example.

2. OFFSHORE STRUCTURES

2.1 BASIC TERMINOLOGY

2.1.1 INTRODUCTION

The need to develop and support offshore drilling and production operations has led to the construction and installation of several types of offshore structures. These include for example, mobile "jack-ups" and semi submersible "rigs", fixed platforms, single point mooring buoys and pipelines.

Production facilities and pipelines are of primary interest since the majority of offshore inspection is concentrated here. There are various types of offshore production facilities operating, to a lesser or greater extent, in the North Sea. In the main these are:

- Piled Structures
- Gravity Structures
- Anchored Structures

Each type is briefly discussed as follows:

2.1.2 PILED STRUCTURES

Most offshore production platforms operating in the British Sector of the North Sea are of the steel piled type. Constructed from tubular steel sections which are welded together to form a lattice framework with vertical legs. They are secured to the seabed with tubular steel piles driven into the seabed either through or around the main legs. The basic components comprising the subsea structure, or jacket, of a steel platform are defined below:

Node — a point on the welded steel structure where two or more members meet.

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Leg — the main vertical component, constructed from a number of sections ('cans') welded together.

Member — horizontal, vertical or diagonal component of the jacket.

Conductor Guide Frame — horizontal sections of framework which support and guide the conductors used during the drilling operations.

Pile Guides — Steel cylinder in which the pile is supported while it is driven into the seabed. Pile guides are mounted in clusters around each leg at various levels. They are often removed on completion of the piling operation.

In addition to the components of the jacket itself, there are jacket appurtenances (attachments) which also have to be inspected. The major appurtenances include:

Caissons — open bottomed tubulars terminating at various depths for the purpose of the intake or discharge of water.

Conductors — tubulars for drilling purposes connecting seabed wells to the topside platform production wellheads.

Oil and Gas Risers — vertical pipeline extending the full height of the jacket and used for transporting oil or gas. Production risers carry oil or gas up from the wellhead while the export risers take the processed oil or gas down to the pipelines.

Flowline Riser Bundles — bring oil/gas from satellite wellheads to the platform.

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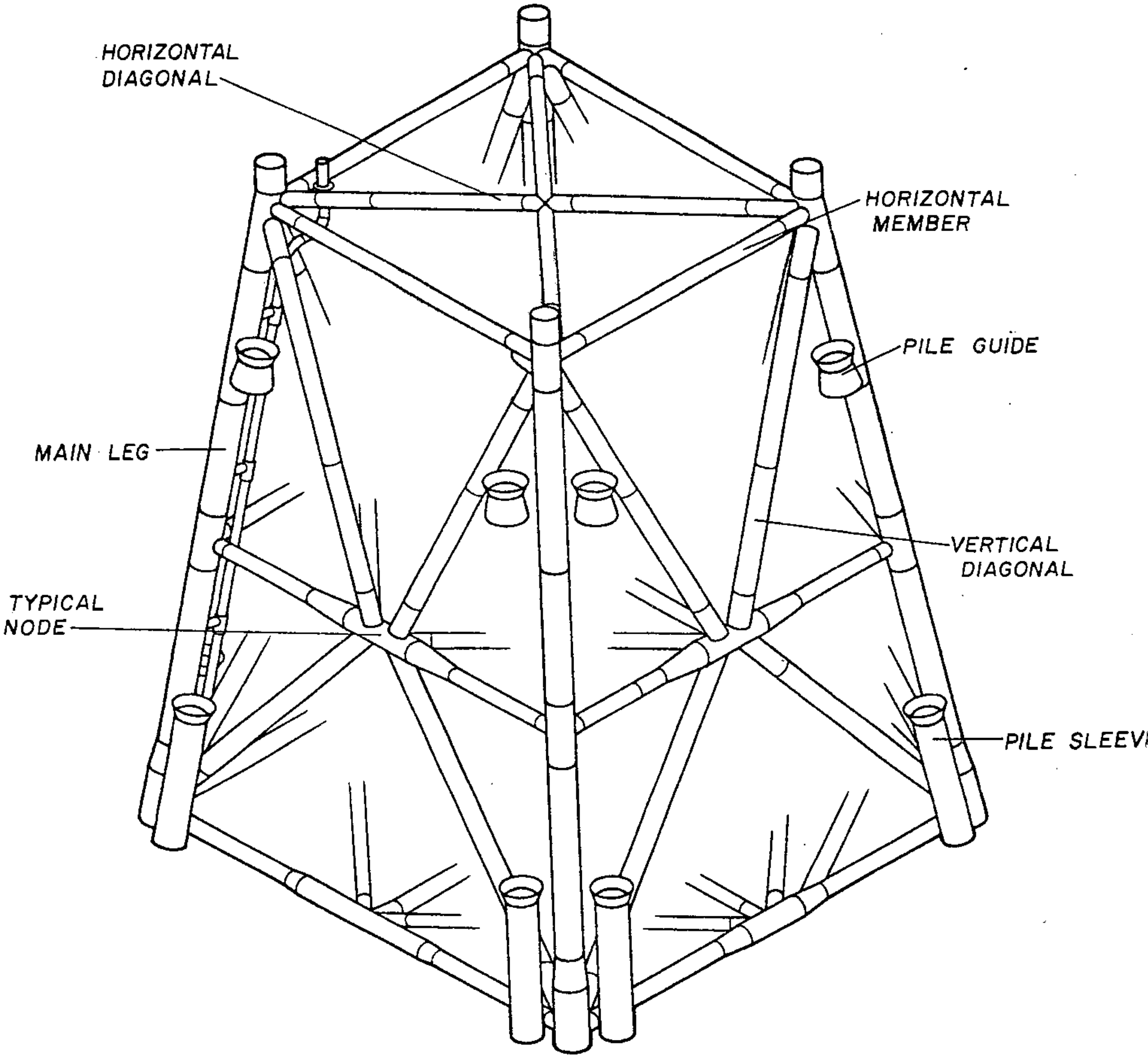

Typical Features of a Steel Jacket

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2.1.3 GRAVITY STRUCTURES

Gravity structures constructed of steel, concrete or hybrid steel/concrete, are supported directly on the seabed, by their own weight, without pile foundations. This type of structure consists of large diameter steel or concrete columns with a number of large ballast tanks at the base. Once the structure has been floated to its installation site some of the buoyancy tanks are flooded with water. Thereafter, the tanks may then be used for storage of, for example, petroleum products, drill water etc.

There are several different designs of gravity structures, the most common consisting of a reinforced concrete base and column arrangement supporting the topside deck structure. Different types of concrete structures include Doris, Sea-Tank, Condeep and Andoc. Some of the common components of a gravity structure are listed below:

Support Columns	the concrete or steel columns supporting the deck.
Storage Domes	tanks at the base of a gravity structure which serve as storage for oil, water or drilling mud.
Breakwater Walls	walls in the splash zone, generally comprising arrays of concrete holes (jarlan holes) which dissipate waves and thus protect the structure within the wall area.
Anchorage Point (Cachetage Point)	Essential component of post-tensioning equipment, cast into the concrete at the end of a tendon or bundle (group) of tendons. Grips tendon and transfers load from the steel to the concrete. Offshore, will usually be encased in protective mortar domes.

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As with steel structures, the concrete structure will also consist of appurtenances such as caissons, risers etc.

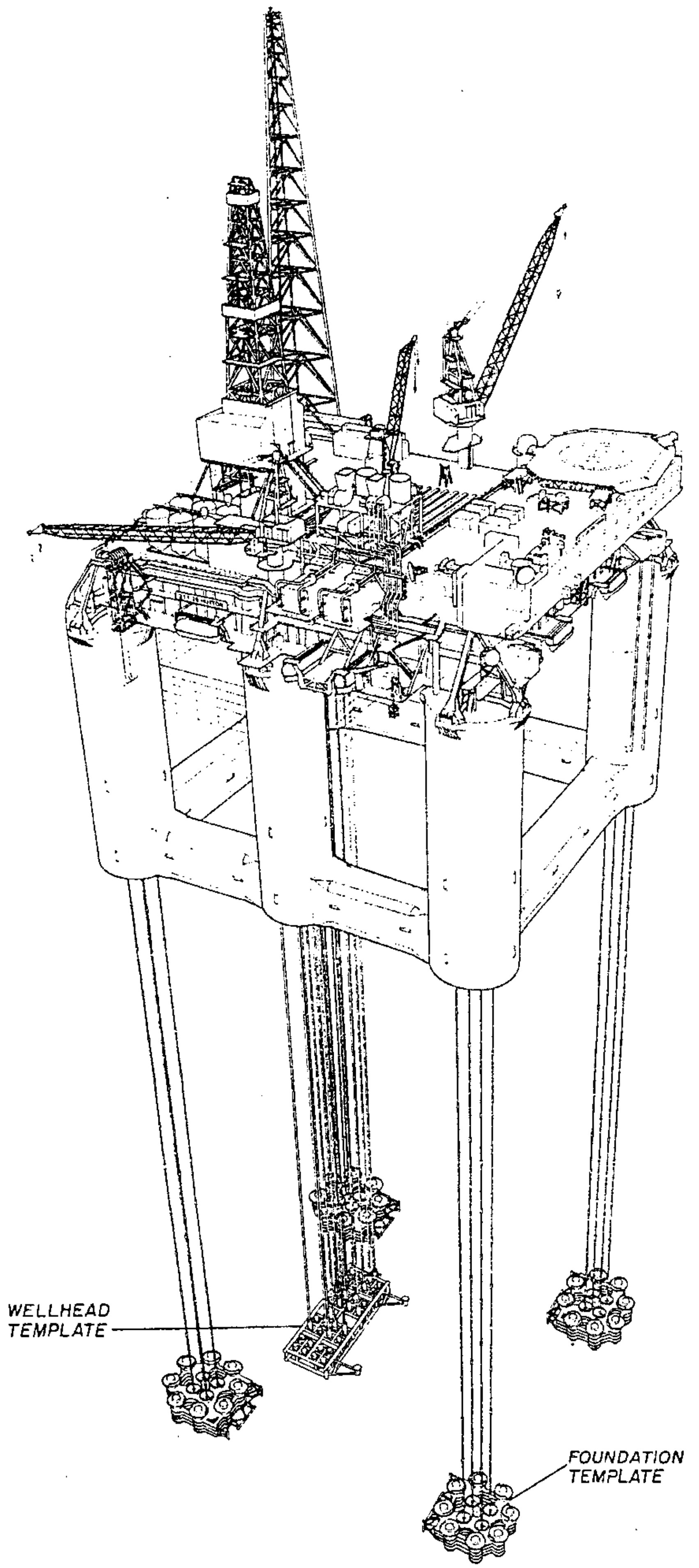
Since the majority of gravity structures in the North Sea are made from concrete, a list of common concrete terms is given below:

Concrete	a mixture of sand, stone (aggregate), and binder (cement) which hardens to a stone like mass.
Aggregate	broken stone, gravel, sand or similar material which forms a substantial part of the concrete mass.
Cement	a powder which, mixed with water, binds a mixture of stones and sand into a strong concrete (usually Portland Cement).
Reinforcement	steel rods embedded into the concrete to strengthen it.
Construction Joint	joint between successive pours.
Shrinkage	contraction of concrete during early stages of hardening.

2.1.4 ANCHORED STRUCTURES

These are floating production platforms held in place by a low tension chain mooring system. Most of the anchored structures are semi-submersibles converted for production. However, the purpose built Tension Leg Platform (TLP) is the latest development of this theme consisting of a floating structure moored to foundation templates on the seabed.

In conclusion, the type of platform design will depend on a number of contributory factors; size of reservoir , depth of water, sea bottom conditions, historical policy and ultimately, capital investment costs.



TENSION LEG PLATFORM (TLP)

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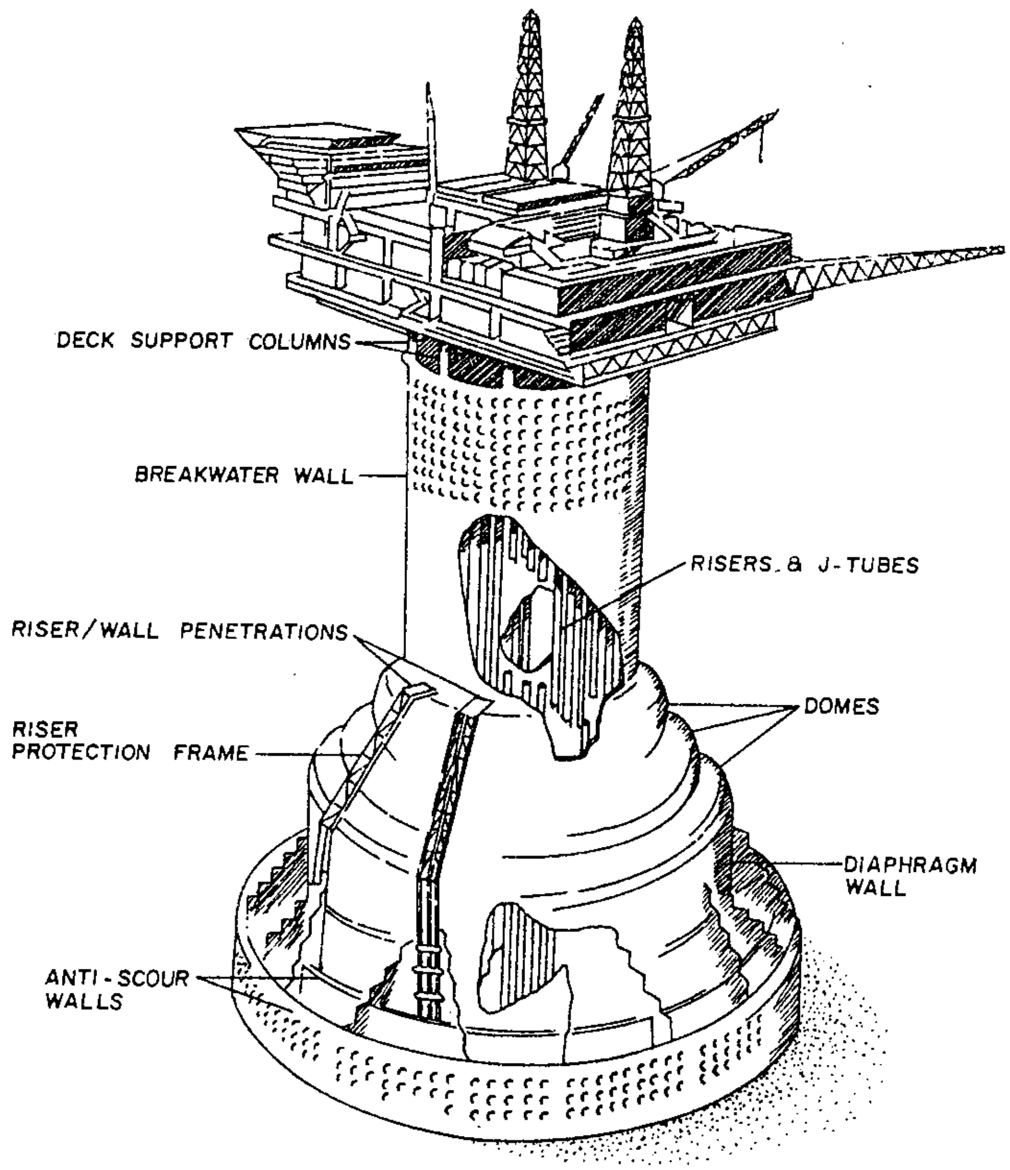

C.G.DORIS

Ninian Central Platform built by Howard Doris for Chevron UK

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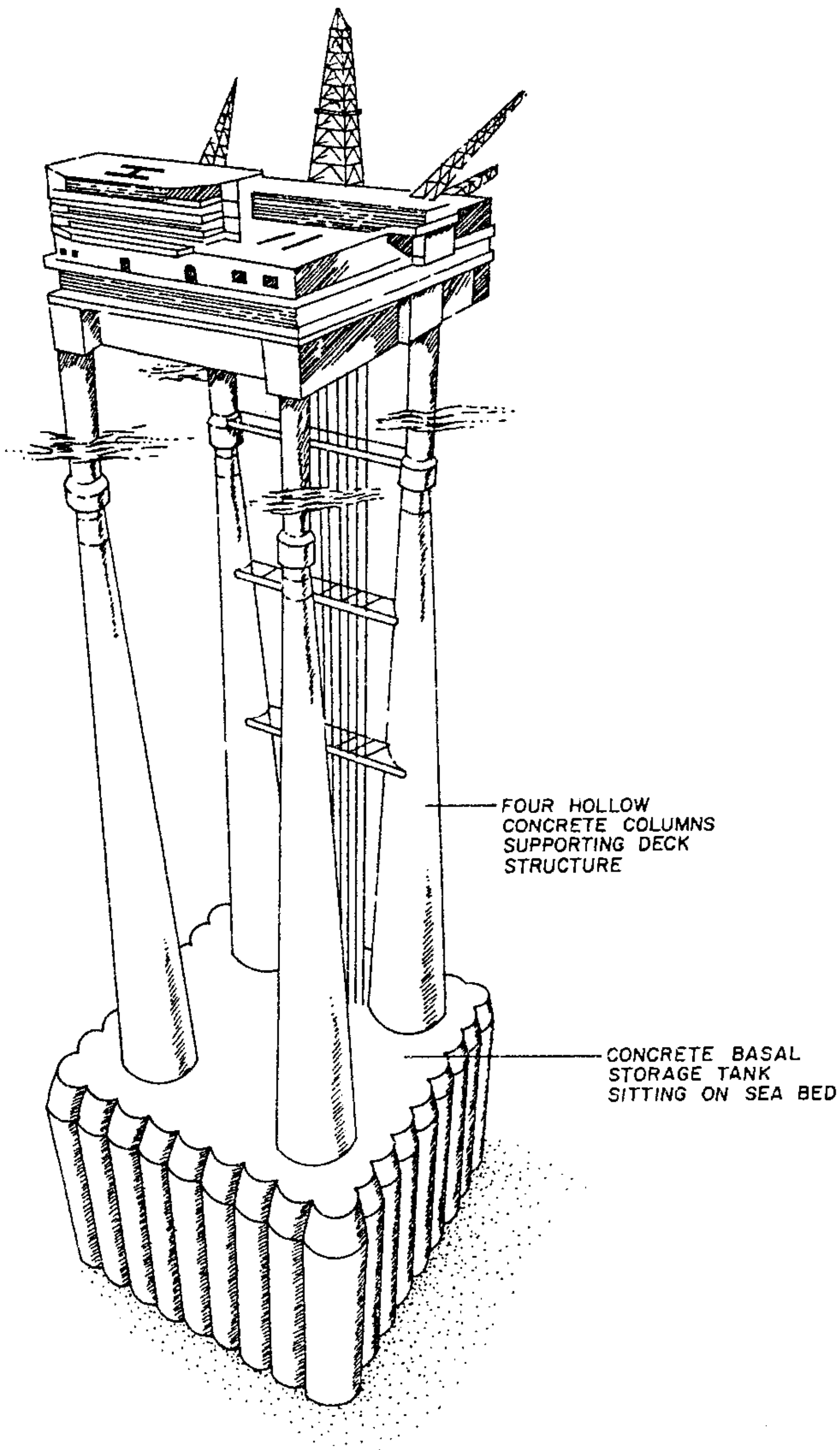

ANDOC

Drawing courtesy of ANDOC

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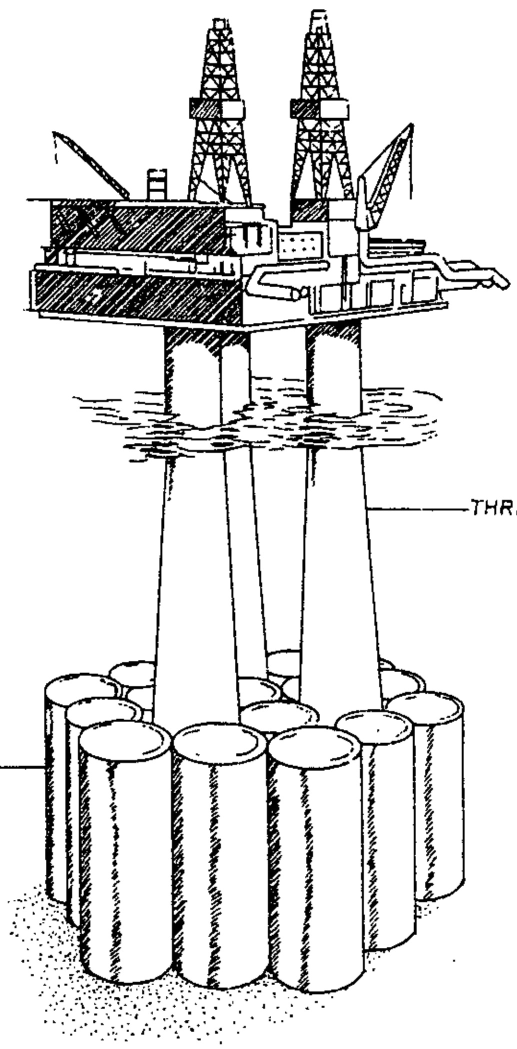

CONDEEP

Drawing courtesy of Nowegian Contractors

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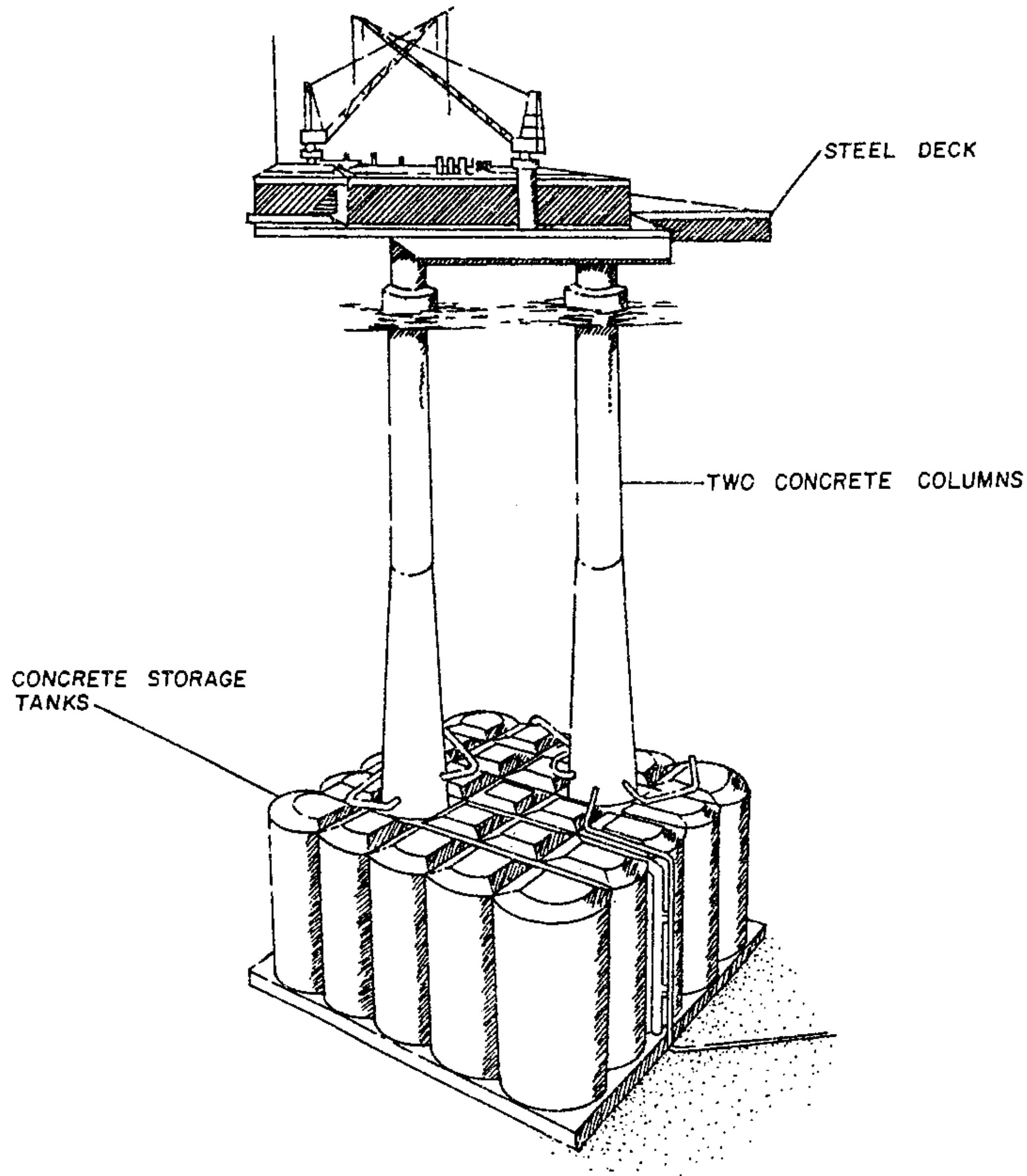

McALPINE SEATANK

Drawing courtesy of McALPINE SEATANK

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2.2 MODES OF FAILURE AND DETERIORATION

Although a typical installation can be subject to severe environmental stresses before entering service, it is the deterioration during the major part of the lifetime of the structures which is of most concern.

During all stages in the life of a structure (both steel and concrete), defects can be initiated, develop and propagate resulting in deterioration and eventual failure if left unchecked. The need for inspection, therefore, is quite simply the need to avoid failure. The earlier a possible failure site is located and identified the cheaper and more effective will be the remedial action.

2.2.1 FACTORS INFLUENCING DETERIORATION/FAILURE

The majority of in-service inspections concentrate on the detection and monitoring of cracks, corrosion, overloading and accidental damage. Some of the more common causes of deterioration in both steel and concrete structures are as follows:

2.2.1.1 LOADING

The effects of overloading can be considerable and may result in cracking, buckling and ultimately, local structural failure. Loading can be categorised as:

- Static loading due to the weight of the structure including topside modules, attachments, etc.

- Dynamic loading due to the hydrodynamic (environmental) forces exerted by the wind, waves and water currents. Operational loads which occur due to the operation and functional activities of the installation. Dynamic loading produces cyclic stressing which may lead to fatigue damage situations.

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Marine growth cover affects both static and dynamic loading effects.

2.2.1.2 IMPACT DAMAGE

Impact of various types is the commonest cause of damage to offshore structures due mainly to:

- collision between vessels and structures
- dropped objects (debris)
- anchor dragging in the case of pipelines

2.2.1.3 CORROSION ATTACK

Seawater presents a hostile environment to both steel and concrete structures. Corrosion is an electrochemical form of deterioration and affects steel structures, exposed re-bars etc.

2.2.1.4 SEABED FOUNDATION PROBLEMS

Scour - the presence of a structure on the seabed affects the normal flow pattern of seawater and causes the shifting of seabed levels. Scour may leave portions of the structure (or pipeline) unsupported resulting in movement, displacement or even rupture in the case of pipelines.

Two modes of failure which are of particular importance to steel structures are; Fatigue and Brittle failure.

2.2.1.5 FATIGUE FAILURE

Cracks are the most serious defects that can occur in a structure. They are indicative of the fact that the structure has already failed - albeit locally. Fatigue is the most common cause of cracking in offshore structures.

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Fatigue occurs when the structure (or component of a structure) is subjected to alternating (cyclic) loads over a prolonged period of time. Cyclic stresses are produced which may result in the initiating of cracks. If high stress concentrations exist in the areas of cracking, the cracks may propagate and lead to complete failure of the component. The problems of fatigue are enhanced in the presence of a corrosive environment such as seawater (see corrosion fatigue section 5.4).

Fatigue failures in welded joints often occur because residual stresses may be present and/or weld defects can introduce stress raisers which combine to increase the local stress above the yield point for the material. For this reason, many welds are profile ground (dressed) to reduce or remove any stress concentrations produced as a result of welding.

2.2.1.6 <u>BRITTLE FAILURE</u>

Brittle failure occurs in materials with reduced ductility due to local hardening and is a potentially catastrophic form of crack failure. Reduced ductility can result from hydrogen embrittlement or a susceptible microstructure due to incorrect steel composition or cooling rate during fabrication.

The temperature of the environment affects the brittle behaviour of steel. Brittle fracture is much more likely to occur at low temperatures.

2.2.2 DEFECTS IN STEEL STRUCTURES

In the construction of a structure, particularly the fabrication of structural components (ie. nodal joints and conductor guide frames), defects may result from poor machining and welding techniques, inadequate heat treatment and residual fabrication stresses. Ideally these should have been discovered, and repairs carried out, prior to installation. Frequently, however, defects of this nature escape detection, pass initial tests and certification, and subsequently contribute to deterioration of the structure after installation. When discovered by the diver, these defects are treated similarly to in-service defects.

In-service defects of concern are:

Cracks	generally due to fatigue loading. Welded joints are particularly susceptible.
Corrosion Attack	general and local.
Physical Damage	usually accidental (collision, dropped debris).
Scour	due to wave/current action affecting seabed components.

Although not a defect, debris is potentially hazardous. Debris obstructs inspection, may be a potential cause of damage and may cause a drain on the CP system if present in large amounts.

2.2.3 DEFECTS COMMON TO STEEL AND CONCRETE STRUCTURES

All of the above defects are common to both types of structure. The splash zone region of both steel and concrete structures requires special attention. It is an area particularly vulnerable to physical damage, excessive wave loading, marine growth and corrosion.

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Risers are common to both concrete and steel structures. Because of their importance to production, they are subjected to intense visual inspection. Particular attention is paid to the levels of cathodic protection and the extent of internal and external corrosion.

Riser clamps and flanges are also subjected to close visual inspection for disintegrity. Specific descriptions include missing, loose (relative movement), misaligned, or deteriorating items such as clamps and their sub-components (ie. stubs, bolts, nuts, hinges and bond wires). The reporting of disintegrity is important as it may predict imminent failure.

Since structures are seldom all steel or all concrete, inspection personnel must be capable of recognising defects particular to both. For example, some platforms are hybrids, and pipelines are often concrete coated.

2.2.4 DEFECTS AND DETERIORATION SPECIFIC TO CONCRETE

Deterioration of concrete is the result of disruptive chemical or physical effects, either external or internal. Concrete is a permeable substance through which various electrochemical ions in solution can be carried. The lower the permeability the more durable (and stronger) the concrete. This section outlines firstly the factors influencing deterioration and then goes on to define specific concrete defects. A simplified classification of defects is provided in the table at the end of this section.

2.2.4.1 DETERIORATION OF CONCRETE

The two methods of deterioration in concrete structures are:

- Chemical Attack

and - Physical Attack

Contents

(1) CHEMICAL ATTACK

(a) Alkali/Aggregate Reactions

Reactions at the surface of the aggregate may improve the bond but alternatively may produce expansive products.
Alkali/Aggregate Reaction (AAR) is an expansive reaction between the alkalis in cement and certain susceptible aggregates (mainly siliceous materials). Not a great deal is known about these reactions, but the process of disruption takes many years to develop. It is typified in its later stages by cracking and spalling (concrete loss). Fortunately not common in the UK.

(b) Sulphate Attack

Chemical attack due to the ingress of sulphates into the interior of the cement face. Sodium sulphate attacks the C_3A (tricalcium aluminate) hydrate resulting in softening or disruption, by expansion, of the concrete. Sulphates also attack the calcium hydroxide ($Ca(OH)_2$) component of the hardened cement binder.

The severity of attack is dependant on the type of sulphate and the strength of solution. The problem can be prevented by use of normal aggregates in conjunction with sulphate resisting cement which has a low C_3A content (approximately 3% by weight, as compared to the normal 11% in Ordinary Portland Cement).

(c) Attack of Steel in Concrete

The pH of concrete is approximately 12.5 due to the highly alkaline environment of the surrounding cement paste. The alkaline pore water within the concrete chemically reacts with the steel reinforcing in contact with it to form hydrated iron-oxide (Fe_2O_3). This iron oxide is insoluble in the high alkaline environment and forms a protective film (coating) on the steel. This results in passivation of the steel making it electrochemically inert. (Refer to the Pourbaix Diagram, overpage).

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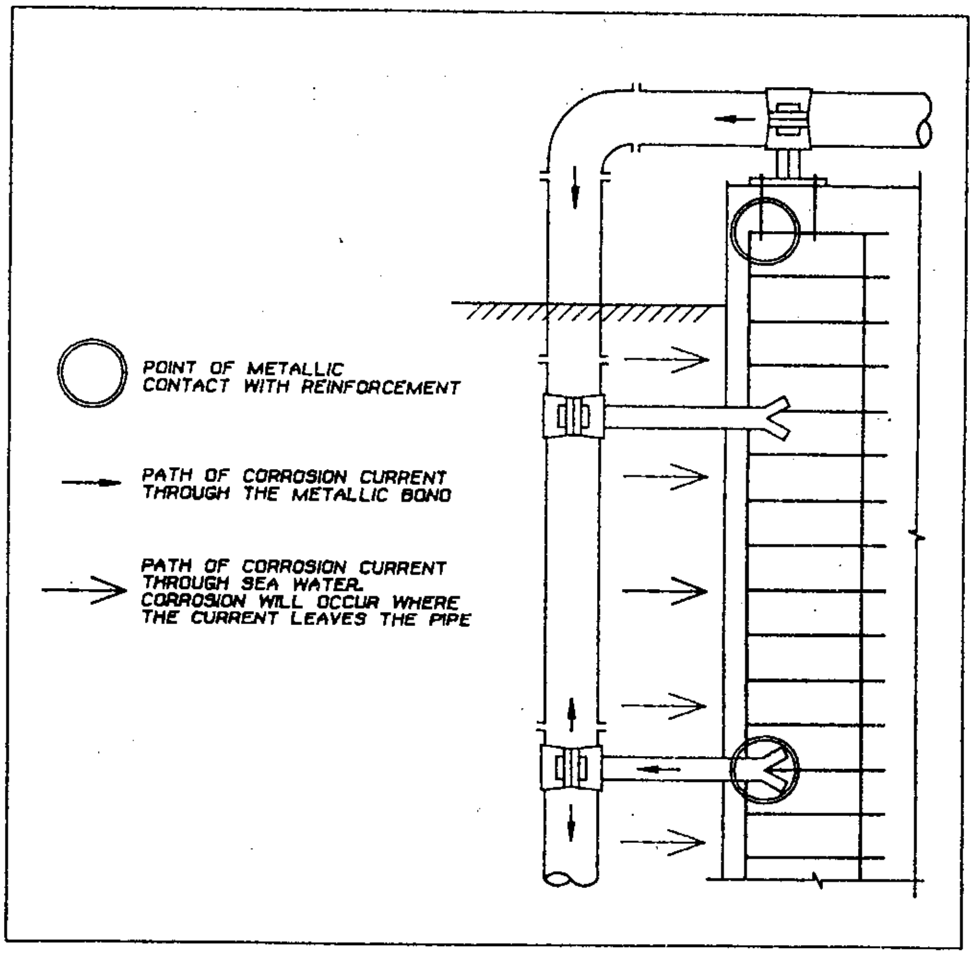
(d) Attack of Built-In Items

Various types of submerged steelwork are incorporated onto concrete platforms outside the concrete walls; for example, steel skirts, J bolts and riser supports. If this steel is in direct contact with internal reinforcement a galvanic cell is formed, with the reinforcement acting as a large, protected cathode and the built-in item as a small, active anode (see diagram below).

Any corrosion of the built-in item will lead to cracking of adjacent concrete and eventually to the introduction of a corrosion path to the main reinforcement.



Corrosion of Built-In Items

(2) PHYSICAL ATTACK

(a) Freeze/Thaw Damage

Repeated freeze and thaw cycles of moisture in the concrete surface in the splash zone causes high stresses in the porous surface of concrete due to water expansion on freezing with resultant local failure. Subsequent thaw will leave a more porous concrete where water can be taken into new areas and the cycle repeated until more general failure occurs.

Since high quality concrete is relatively impermeable this does not generally occur in the types of concrete used offshore.

(b) Cracking

It is generally accepted that all concrete structures will contain cracks. Cracking is mainly due to:

- overloading
- shrinkage
- thermal stresses

Unlike steel structures, the presence of cracks in concrete structures will not generally impair performance, as the concrete is primarily carrying compressive loads. Hence, a cracked concrete structure is not comparable to a cracked steel structure, where such problems, combined with an aggressive environment, can be cause for major concern.

Provided cracks do not exceed a certain width, they do not constitute a corrosion hazard to the embedded reinforcement. British Standard Code of Practice CP110 limits crack width to 0.004 times the depth of concrete cover to the steel.

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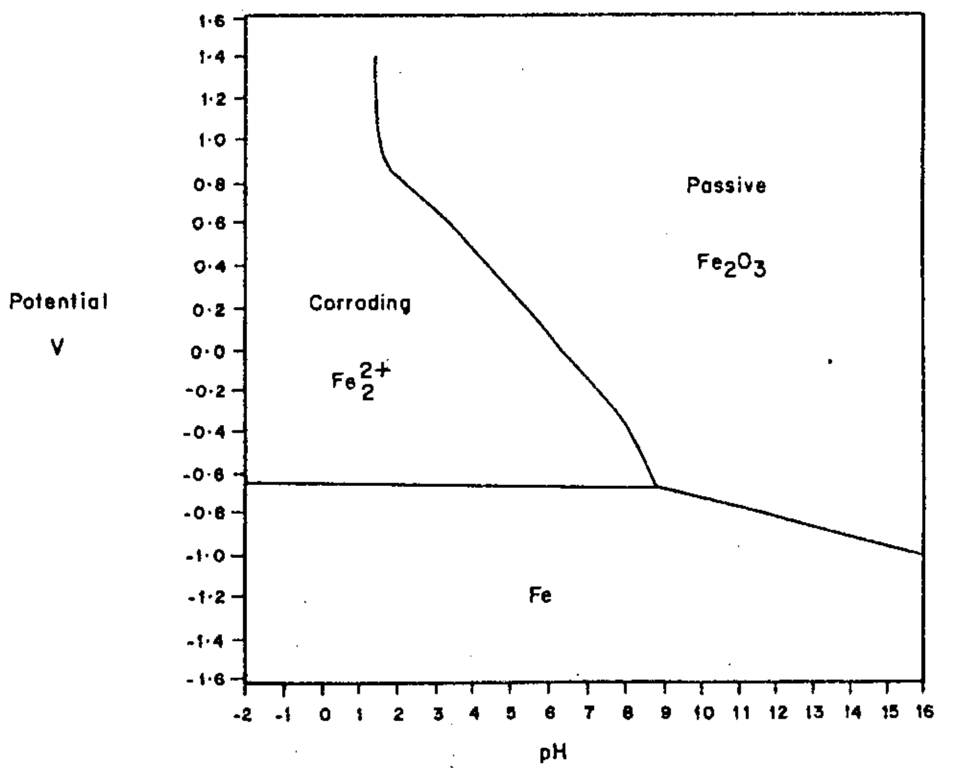
The ingress of chloride ions (from seawater) can destroy this passivation and if sufficient oxygen is available, corrosion of the embedded reinforcing steel can proceed. Corrosion is an expansive reaction, the corrosion products accumulating around the reinforcing bar resulting in cracking and spalling of the concrete cover. This allows penetration of additional deleterious materials and thereby accelerates corrosion. Early signs of such corrosion are rust staining and cracking following the line of the reinforcement.

The tidal zone is the area most at risk due to the high chloride concentrations caused by the evaporation of seawater from the surface. There is also a higher availability of oxygen in the splash zone region (air contains approximately 20% oxygen). The risk is magnified where inferior construction techniques may have resulted in porous concrete of reduced cover to the steel (75mm is the recommended minimum cover).

By contrast, in the submerged zone, concrete is less at risk as there is no possibility of chloride build-up and the oxygen content in sea water is low (approx 10 ppm).



Pourbaix Diagram

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(c) Crystallization Effects

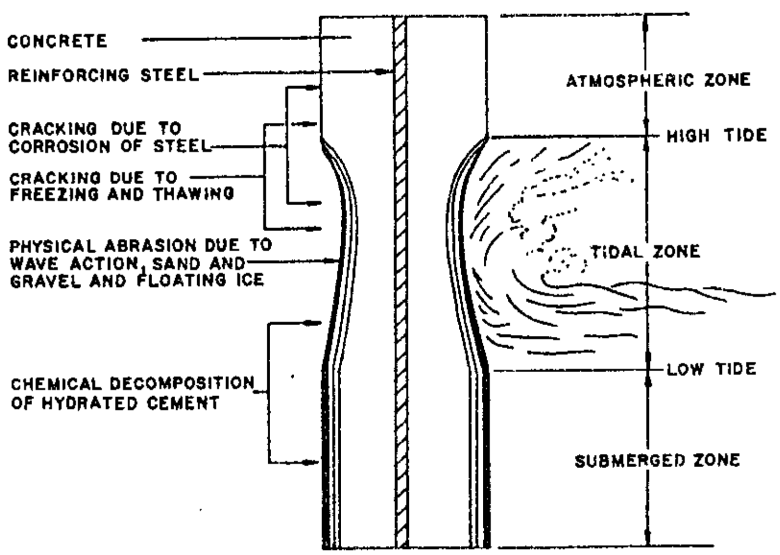
Crystallzation effects may be significant in the splash zone, resulting in the eventual partial, or total, disintegration of concrete. The mechanism of this failure is that dissolved salts in the sea water lodge in the pores of the concrete surface. On drying they crystalise, imparting considerable localised stresses to the concrete. Over a number of cycles of wetting and drying severe deterioration of the surface may occur, exposing fresh concrete to the deterioration mechanism.

(d) Abrasion and Cavitation

Abrasion and erosion effects by water carried solids may remove the concrete surface and hence reduce the thickness of concrete over the reinforcement. Cavitation due to the impact of air bubbles in fast moving water is similar in its effect to abrasion.

(e) Other

As previously discussed, accidental damage due to supply boat collision and dropped debris is a common occurrence. Foundation deterioration due to seabed scour is also a common cause for concern.



DETERIORATION OF A CONCRETE STRUCTURE IN SEA WATER

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2.2.4.2 DEFECTS COMMON TO CONCRETE

(a) Cracks

General - an incomplete separation into one or more parts. Cracks are classified by direction, width, depth (where measurement is possible) and type. The direction is usually described as longitudinal, transverse, vertical, diagonal or random. Suggested width ranges are: fine - generally less than 1mm; medium - between 1 and 2mm; wide - over 2mm. Theoretically any cracks less than 0.2mm wide should not allow direct access to the reinforcement, although all cracks should be reported.

Pattern Cracking - caused by differential volume change (eg shrinkage) of the surface or expansion of the concrete below the surface.

(b) Loss of Material

General - Loss of material can occur as a result of chemical attack, impact or other physical action, and can vary greatly in degree of significance. It will obviously be of greatest concern where either pre-stressing anchorage or ducts become exposed, or where there is total loss of cover to reinforcing steel, with consequent danger of corrosion leading to structural failure.

Further classification of loss of material follows in approximate order of significance.

Spalling - a spall is a fragment, usually in the shape of a flake, detached from the main mass by a blow, action of weather, pressure, or expansion from within the mass due, perhaps, to reinforcement corrosion.

Delamination - a sheet spall caused by exertion of internal pressure over a large area.

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Disintegration - this term covers the general deterioration of the mass into small fragments with considerable loss of material. While the results can be dramatic, the condition is uncommon and should not be found in good quality concrete. Disintegration may be an advanced stage of alkali-aggregate reaction.

Scaling - this is local or general flaking or peeling away of the surface layer, sometimes with loss of aggregate particles. This may be due to weathering or other reaction of the concrete with its environment. Assuming adequate cover to steel reinforcement, scaling will only be a problem if the condition is progressive. Again, the problem may be initiated by poor quality control of materials at the construction phase.

Popout - small portions of the concrete surface (10mm - 50mm diameter) break away due to internal pressure. They are similar to minor spalls, although "popouts" will usually be conical in shape and follow a random pattern over the surface. When caused by alkali/aggregate reaction, these can progress to become very debilitating to the structure although this condition is rare in the UK due to the quality of aggregate available.

Erosion - erosion is a type of deterioration caused by the abrasive action of fluids, or by solid particles suspended in fluids. This is a very long-term effect, unlikely to be a problem at an early stage in the life of offshore platforms.

(c) Stains and Surface Deposits

General - of these rust staining is obviously the most important, as it may be an early indicator of a future structural problem. Other stains and deposits are of little significance, except where they may obscure, or be mistaken for, rust staining.

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Rust Staining - throughout this document, stress has been placed on the importance of chemical passivation and physical protection of reinforcing steel and prestressing tendons against corrosion. In the absence of obvious evidence such as cracking, spalling or complete exposure of steel, rust staining of the concrete surface may be an early sign that the corrosion process has been initiated.

All such staining, when found <u>must</u> be reported and taken seriously, but assessment of its significance will depend on checking the location against design and construction records - not all embedded steelwork is structurally critical. In some precast units, especially, reinforcement may be included to cater for stresses anticipated during operations such as slinging and transportation, and become totally redundant thereafter.

Similarly mesh reinforcement included to minimise surface cracking may corrode and cause surface disruption, but in a massive concrete component under constant compressive load, the problem will be more cosmetic than structural. Other minor embedded items such as tying wires and shuttering nails, or even tools may give rise to spurious indications, but again may provide a corrosion path to structural steelwork which is critical.

Efflorescence - this is a deposit of salts, usually white, coming from within the concrete mass. This will usually only be found on "dry" faces, as the salts will disperse underwater.

Exudation - this is a liquid or viscous, gel-like material discharged through a pore or crack in the surface, probably due to alkaline aggregate reaction.

Incrustation - this is similar to efflorescence, but the deposits are lime leached from the cement which forms a crust on the surface of the concrete. Again, the symptoms will only be found on dry faces.

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SIMPLIFIED CLASSIFICATION OF CONCRETE DEFECTS

DEFECT TYPE	DIVER TO REPORT AS:	DESCRIPTION	CAUSE	DETAILS TO REPORT
GENERAL CRACKING	CRACKING	JAGGED SEPARATIONS WITH OR WITHOUT A GAP.	OVERLOAD, CORROSION OR SHRINKAGE.	DIRECTION, WIDTH, DEPTH, LENGTH.
PATTERN CRACKING	CRACKING	AS CRACKING BUT FORMED AS A PATTERN.	DIFFERENTIAL VOLUME CHANGE BETWEEN INTERNAL AND EXTERNAL CONCRETE.	SURFACE AREA, WIDTH, DEPTH.
EXUDATION	SURFACE DEPOSIT	VISCOUS, GEL-LIKE MATERIAL, ASSOCIATED WITH CRACKING	ALKALI AGGREGATE REACTION	SEVERITY, AREA, THICKNESS.
RUST STAINS	SURFACE DEPOSIT	BROWN IN COLOUR.	CORROSION OF REINFORCEMENT, TIE-WIRE OR SURFACE STEELWORK.	SEVERITY, AREA, THICKNESS.
INCRUSTATION	SURFACE DEPOSIT	WHITE CRUST ON CONCRETE SURFACE.	LEACHING OF LIME FROM CEMENT.	SEVERITY, AREA, THICKNESS.
POPOUT	CONCRETE LOSS	SHALLOW, CONICAL DEPRESSION.	DEVELOPMENT OF LOCAL INTERNAL PRESSURE, DUE FOR EXAMPLE TO EXPANSION OF AGGREGATE PARTICLE.	SURFACE AREA, DEPTH.
SPALL	CONCRETE LOSS	FRAGMENT DETACHED FROM A LARGER MASS.	EXTERNAL PRESSURE (FOR EXAMPLE ACCIDENTAL DAMAGE) OR INTERNAL PRESSURE (FOR EXAMPLE CORROSION OF STEELWORK).	AREA, DEPTH.
DELAMINATION	CONCRETE LOSS	SHEET SPALL.	INTERNAL PRESSURE OVER A LARGE AREA.	AREA, DEPTH.
HONEYCOMBING	CONSTRUCTION DEFECT	VOIDAGE BETWEEN COARSE AGGREGATE.	LACK OF VIBRATION.	AREA, DEPTH.

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3. RECORDING METHODS

3.1 INTRODUCTION

Underwater visual inspection is primarily carried out by the human eye, particularly in initial surveys to locate and identify areas of interest. However, it is difficult to quality assure the results of an inspection programme on the basis of human vision alone.

One major problem is that very often estimations are being made based on imprecise observations. No two inspectors can be relied upon to report the same defect to the same magnitude. Measurement underwater is often error prone, with low standards of accuracy. Furthermore, the eye cannot produce a permanent record. These problems highlight the need for effective and cost efficient recording methods.

The purpose of recording is to produce sufficient, reliable, and measurable data that documents condition and facilitates engineering assessments of integrity or deterioration.

The two permanent recording methods commonly used underwater are still photography and closed circuit television (CCTV). Each has its advantages and both are often used together.

Permanent recording satisfies a number of important functions. It allows the client and topside engineers to actually view the inspection site or anomaly under investigation. It is invaluable in clarifying confusing inspector to topside (or vice versa) communications. It allows further detailed analysis of anomalies. It is useful for comparative purposes in monitoring anomalies changing with time. It documents proof that the workscope has been carried out. In many instances, recordings are the only irrefutable and permanent record available to resolve ambiguities arising after completion of the contract.

Still Photography is a useful recording method for a number of reasons. A colour photograph gives a permanent, high quality (detail and resolution), visual record of the subject's condition. The results may be presented in transparency (slide) form or as prints.
Still Photography is used extensively in both general survey and close visual inspection. In general surveys, it may include anything from a general overview of an area (ie. a node) to a component (ie. riser clamp, anode etc). In close visual inspections, it is used for identifying and examining specific items under investigation (ie. welds, corrosion pits, etc).
A recent development in underwater photography is the increasing use of stereo cameras to provide three-dimensional images, or photogrammetric analysis, from which accurate measurements of specific anomalies may be obtained.

Closed Circuit Television has become an essential aid in most inspection operations, particularly general surveys. It can give better overall images than can be perceived by the diver, typically presenting twice his angle of view. It identifies particular features requiring more detailed inspection. CCTV has the unique advantage of providing 'real' time viewing, by topside personnel, of the actual inspection being carried out. It also presents the option of recording and editing of images on videotape.

Both recording methods have limitations. Still photography does not provide real-time viewing or a record of movement. Also, exposed film requires processing before success of results can be determined. CCTV lacks high definition, preventing close observation of fine details (ie. pitting). It also requires time consuming reviewing and editing, which may present a logistics problem. Suitable artificial light is normally required for optimum results in both techniques.

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Recording equipment is employed by divers in all modes of diving operations. It is also commonly deployed by ROVs, and manned or unmanned submersibles, particularly in pipeline surveys. The primary limitation in ROV deployment is restricted access in close-up (ie. weld) photography.

3.1.1 FACTORS AFFECTING LIGHT DISTRIBUTION

The four factors affecting distribution of light underwater are visibility, absorption, reflection, and refraction. These will now be discussed.

Visibility is reduced proportionally to the amount of suspended particles present in the water. Plant and animal plankton (much of it microscopic), as well as sediment, scatters and reflects light.

Absorption of light occurs increasingly with depth. The colour spectrum is absorbed progressively - red generally disappears by 3m, orange by 5m, and yellow at about 10m, only green or blue grey light is present to any significant degree.

Reflection of light occurs at the interface between air and water, and also underwater when suspended particles are present. Reflection either attenuates (reduces intensity of) light, or produces bright spots (commonly called backscatter).

Refraction occurs as light passes from one medium to another (ie. air/water). In principle, its velocity and direction changes.

Refraction has two effects - the image appears magnified, reducing the effective angle of the lens, and the focus is offset by approximately 25% (at increased distances). Many housings correct refraction at the glass interface. If not, presetting the focus to three quarter the distance between camera and subject is necessary.

3.1.2 LIGHTING

Underwater lighting is used primarily to provide illumination for close circuit TV cameras, photographic stills and for direct viewing by divers and ROV's.

Some applications require a "white light" for colour TV, photography and direct viewing, whereas black and white TV applications may benefit by use of a mercury vapour light.

The objective of underwater photography has been established - to produce a permanent, high quality record. In order to compensate for these factors and achieve this objective, the underwater inspector must introduce supplementary or artificial light.

Optimum lighting is critical for the success of both still photography and closed circuit television.

The presence of optimum lighting is not sufficient in itself to produce quality photographs or CCTV viewing. The placement of artificial lighting is also very important. There are two considerations in optimum light placement:

First of all, the inspector should photograph the subject from as close a distance as practicably possible. This reduces the volume of seawater between the subject and lens, therefore reducing the amount of absorption, and reflection or scattering by suspended particles. Photography at a distance less than one third of the available visibility is recommended.

Secondly, it is important to avoid backscatter, flare, and high contrast (too light or too dark). This is accomplished by angling the light source away from the lens to subject axis. This may have the affect of lighting only one side of the subject. In this case, the use of two light sources is recommended.

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In still photography, synchronised, electronic flash is the preferred solution. It is cost efficient and far less time consuming than the use of flash bulbs. As a result, flash guns are used almost exclusively.

In CCTV inspection, it is necessary to use flood lighting. Quartz iodine and mercury vapour lamps are the most widely used of the several types available. Care must be taken to turn off the power when the lamp leaves the water. These lamps are not adequate for still photography as they have significantly less power than the electronic flash.

3.2 STILL PHOTOGRAPHY

3.2.1 PRINCIPLES AND TERMINOLOGY

The underwater inspector has been introduced to the purpose of recording, the types and limitations of recording methods, and the problems encountered underwater, particularly that of lighting.

The purpose of this section is to discuss the principles of still photography, camera types, film choice, and applications so that the inspector may appreciate how components are matched to the photographic requirement.

The **camera** is a device used to reproduce an image by focusing light in a controlled manner onto a photosensitive surface. Film exposure to light is controlled by shutter speed, aperture control, and film speed. Focus and angle of view is determined by the lens.

To appreciate the relationship of these functions, a more detailed description of terminology is provided:

Shutter Speed controls the amount of time that the film is exposed to light. Typical speeds in seconds are 1, 1/2, 1/4, 1/8, 1/15, 1/30, 1/60, 1/125, 1/250, 1/500 and 1/1000. Each position admits two times the light (ie. 1/60s admits two times the light as 1/125s).

Aperture Control regulates the intensity of light admitted to the film by the 'opening up' or 'closing down' of an iris in the lens. Typical aperture settings are marked as: f/1.8, f/2, f/2.8, f/4, f/5.6, f/8, f/11, f/16 and f/22. These numbers represent a simple relationship between the focal length and diameter of the aperture. Thus the notation f/4.5 means that the focal length of the lens is 4.5 times its effective diameter. As with shutter speed, each aperture control setting admits twice the light (ie. f/5.6 admits two times the light of f/8 - a smaller 'f stop' number equals a larger opening). The smaller the f/number, the larger the lens diameter for a given focal length, and the greater the light gathering power or "speed" of the lens.

A direct relationship exists between shutter speed and aperture setting ie. the required time of exposure increases with the square of the f/number. The following examples will yield the same exposure:

1/250s at f/8
1/125s at f/11
1/60s at f/16
1/30s at f/22

Film Speed is a numerical representation (ASA designation) of film sensitivity to light. A more sensitive or 'faster' film requires less light for exposure. It has a higher ASA number, but produces a 'grainy' image. A less sensitive or 'slower' film produces a sharper image (fine grain), but requires more light for the same exposure as a higher film speed. This is accomplished by slowing the shutter speed or 'opening up' the aperture setting. Typical ASA values are 25, 50, 64, 100, 200, 400 and 1000.

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100 ASA film is 1 f stop slower than 200 ASA film, and 1 f stop faster than 50 ASA film

Thus, the exposure given in any situation is determined by light intensity, which is controlled by three factors:- shutter speed, aperture control, and film speed. The following combinations yield the same exposure:

1/250s at f/8 with ASA 400 film
1/125s at f/8 with ASA 200 film
1/60s at f/8 with ASA 100 film
1/30s at f/8 with ASA 50 film

Focus is defined as the point where an optical image is clearly defined. Focal length of the lens determines the angle of view. A short focal length produces wide angle viewing.

Depth of Field of a lens is the distance each side of this focus point in which subjects continue to appear focused. It is determined by the aperture opening and focal length of the lens. Smaller aperture openings (higher numerically, ie. f/16 - f/22), and wide angle lenses result in 'greater' depth of field, or a longer range of focus.

In underwater inspection photography, a wide angle lens is preferred as it produces optimum viewing and greater depth of field. Although a wide angle lens requires greater light intensity the result is a photographic record of high resolution and good definition.

3.2.2 PHOTOGRAPHIC EQUIPMENT

3.2.2.1 CAMERAS

The choice of camera is usually determined by the following:

- Type of inspection required
- Physical constraints of the worksite
- Picture quality
- Number of photographs required
- Cost

There are two formats used in underwater inspection, each with its own applications and techniques. These are the 35mm and 70mm systems, used in both mono and stereo modes.

The **35mm Format** provides a frame of 24mm x 36mm in which a wide range of standard film cassettes are available (film speed, colour, black and white, bulk film lengths). These 35mm systems are relatively inexpensive, small (allowing access to restrictive areas), produce sufficient quality for most photographic recording needs and are easily viewed as positive transparencies by slide projector. A 21mm lens would normally be used for stand-off work and a 50mm lens for close-up work.

The **70mm Format** provides a frame of 60mm x 60mm. This is approximately four times the area of the 35mm format. Consequently, a much higher quality photograph is obtained, which may be required in some detailed inspection applications. The drawbacks to the 70mm format are: few types of film are available (without special order), the cameras are more complicated, they are expensive, bulky (poor access in restrictive areas), need careful handling, and positive transparencies cannot be readily viewed by projector if required.

Mono Camera systems are the most widely used in photographic recording. They range from small, low cost, purpose-built water/pressure proof 35mm cameras (ie. Nikonos), to large, expensive 70mm cameras in water/pressure proof housings. Intermediate expense cameras include the 35mm SLR Olympus in Scoones housing, and the purpose-built 35mm Hydroscan Close-Up Camera.

Stereo Camera systems are not as widely used in underwater inspection programmes, but are becoming more popular. Stereo systems are more complex, involving the use of large, single housings or two camera housings installed on a jig. Adequate site access, good visibility, and correct lighting are essential in stereo photography.

Stereo systems are available in both 35mm and 70mm formats. Once again, the main difference between them is quality of results, size of camera, and cost.

Stereo photography provides a third, ie. "depth" dimension to viewing. This can be invaluable when assessing damage or a potential defect.

Photogrammetry is an extension of stereo photography which enables accurate measurements to be obtained from the resulting photographs. As it requires a great deal of precision and quality control, it is difficult and expensive. The principles of photogrammetry are discussed in detail under applications, section 3.2.3.4.

3.2.2.2 FILM

There are a wide variety of films available in still photography. The photographic requirements determine what characteristic the film should have. Film characteristics include sensitivity (slow, medium and fast), colour or black and white, and positive or negative transparency. Each are discussed below:

Film sensitivity is determined by its speed (discussed in photographic principles, section 3.2). Inspection photography requires the use of both slow and fast films.

Slow Films (ASA 25-64) have a fine grain structure which allows fine detail to be resolved by the film. This high resolution makes slow film ideal for close inspection work. However, it does require high light intensity for optimum performance.

Medium Films (ASA 100-200) do not have as fine a resolution as slow films, but the results are very acceptable for most photographic requirements, particularly "stand-off" shots. If in doubt use a medium film.

Fast Films (ASA 400-1000) have a coarse grain structure which restricts the resolution of fine detail. Since it is more sensitive to light, fast film is used in low light intensity applications. It is ideal for meeting general survey and MPI photographic requirements.

Colour Film is specified for nearly all still photography underwater. Colour photographs are preferred in most situations because more information may be obtained from them. There are two drawbacks to colour film use. These are narrow latitude and the precision required in processing. Latitude is the film's tolerance to over and under exposure, which is approximately only half an f-stop in colour. Often, a skilled photographic technician is required for on-site processing.

Black and White Film is more suitable than colour film in the following situations: when very high definition is required (as in photogrammetry); when colour correction is impossible due to light filtration in excessive stand off distances, or light source colour bias (ie. thallium iodide for green; quartz (yellow), etc); and when a wide latitude is required due to uncertain exposure.

Negative Film undoubtedly produces the highest quality prints. But processing offshore normally requires a dedicated photo technician and a well equipped darkroom.

Positive Film is more commonly used as colour transparencies (slides) are easily processed offshore in a basic darkroom using the "E6" process (photo technician not normally required unless large volumes of films are being processed). Furthermore, results can be available within one hour for viewing by the naked eye through a magnifying glass, or by projection onto a screen. Copy transparencies and positive prints by polaroid systems can also easily be produced offshore.

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3.2.3 TECHNIQUES/APPLICATIONS (INCLUDING PHOTOGRAMMETRY)

At this time there are four specific techniques in the use of still photography, each with different applications. These are stand-off, close-up, stereo/photogrammetric, and MPI photography.

In order to ensure quality results, there are a few main points relevant to all techniques that the inspection photographer should be aware of:

- every location must be suitably identified.
- ensure that the field of view is not obstructed by exhaust bubbles, umbilicals, soft lines, etc.
- care must be taken to ensure each shot is representative, centred, and at the right angle
- WHEN IN DOUBT, ALWAYS TAKE ANOTHER SHOT - FILM IS CHEAP COMPARED TO DIVE TIME

3.2.3.1 STAND-OFF PHOTOGRAPHY

Stand-Off is the standard technique term used in general inspection photography. Typical applications include photographs of anodes, clamps, nodes, marine growth, physical damage, debris, scour, inlet grills, concrete defects, etc. The camera to subject distance varies from 0.5m up to as much as 5m depending upon the photographic requirement, although a distance of 1m is most common.

Good subject composition in stand-off photography requires a degree of operator experience and skill as the field of view can normally only be estimated. This is due to the view finding restrictions of the diver's mask and underwater camera housing.

When accurate stand-off distance is required, the use of a magnet and cord attached to the subject may be used. Prior to firing, the magnet is tugged so that the field of view is not obstructed.

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"Idents" for Stand-Off Photography

Identifying the subject in stand-off photography is one area where problems occur. The "idents" should be large enough to be seen clearly without obscuring the subject. The "idents" should include the following:

Member/Component Identification; this should be unambiguous with each member/component clearly identified, ie. MB76 and MC81 not MB76/MC81.

Scale; an indication of size by providing a metric scale of clearly visible dimensions.

Subject; a specific "ident" showing the main subject material. This may take the form of arrows indicating a defect or a more specific subject such as Anode AN3.

Colour balance reference; a colour strip of the three primary colours red, yellow and blue is a valuable aid, especially when assessment of colour may contribute information such as deposit or marine growth sampling.

When photographing large areas for general inspection, size references should always be placed in the same place as the particular feature under investigation. Subsequent close-up pictures should be taken from left to right and top to bottom to produce a natural build-up of overlapping prints.

3.2.3.2 CLOSE UP PHOTOGRAPHY

Close-Up photography is the technique employed in close visual inspection. The most common application is weld photography, particularly after cleaning to a high standard of surface finish for MPI. Other applications include photographs of local corrosion, pitting, or damage (ie. burn marks); specific marine growth; missing or broken sub-components (ie. bolts, bond wires etc).

The 35mm format is arguably the best suited to close-up photography because, being smaller it is more able to access restricted areas. Fixed stand-off prods, typically 15cm long, are often used to ensure a fixed distance to the subject and to assist the inspector in referencing one shot to the next, thereby ensuring consistent results.

<u>"Idents" for Close-Up Photography</u>

This technique will be required for photography of defects, usually on welds. Identification in the photograph should include:

Member identification; each member included in the photography should be individually marked, ie. BM76 and NC79. They should <u>not</u> be marked as NC79/BM76. The appropriate ident should be on the actual component.

Scale; a scale marker should be included in the photograph.

Defect; the extent of the defect or remedial work should be marked with white arrows (or other suitable colour) at either end. It should also indicate the subject using the correct code, eg. CK for crack, GR for grinding. See Figure 1.

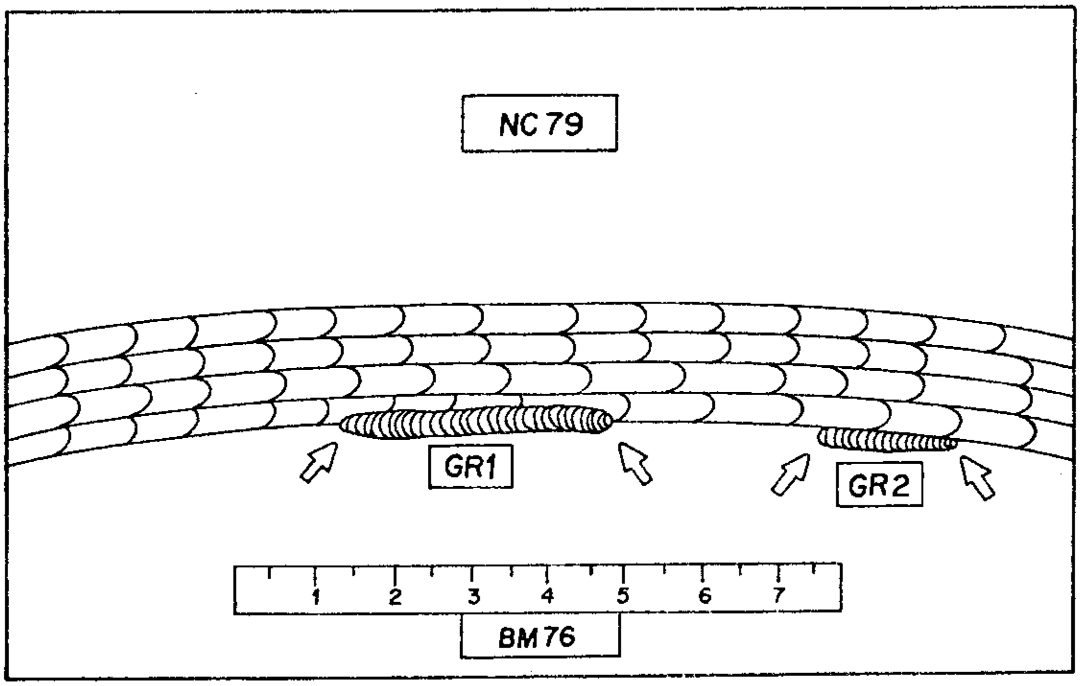

FIGURE 1

AN EXAMPLE OF I-DENT REQUIREMENTS FOR CLOSE-UP PHOTOGRAPHY

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Close-Up Weld Mosaic

It may be necessary to photograph part of a weld, ie. a long defect or it may be required to do a mosaic of the whole weld. In either case the essentials of mosaic photography are to provide a scale or other means to link the photographs together and to provide sufficient overlap, 30% if possible, so that no features are missed. Bearing this in mind, it can be seen that a failure of one photograph can invalidate the entire sequence. Mosaic photography requires care and patience for success. It is well worth over emphasising the problems and giving a comprehensive briefing before this is attempted. Identification in the photographs should include:

Member identification; every frame should contain identification for each member or component included in the photograph, eg. MB76 and NC79. Again, the appropriate "ident" should be on the actual component.

Clock positions; the approximate clock positions of 12, 3, 6 and 9 o'clock should be placed beside the weld. This can be carried out before photography begins.

Tape; the tape provides continuity between one frame and the next. It should therefore be included in every shot. Use a tape long enough to go around the whole weld, and if possible use a thin one so that no features are obscured. Obviously, welds differ especially from one platform to another, and their individual geometry can be quite complex. For these reasons, the following method is recommended.

Start the tape at 12 o'clock and run it clockwise around the weld. Use magnetic backed tape or alternatively use two or three 2" horseshoe magnets to secure the tape. By moving one magnet at a time, the tape is smoothed around the weld and photographs taken as you go. In this way the tape can be moved to accommodate complex geometries without losing continuity from the 12 o'clock start. Ensure that magnets do not lie between the prods. A typical sequence of photographs is shown in Figure 2.

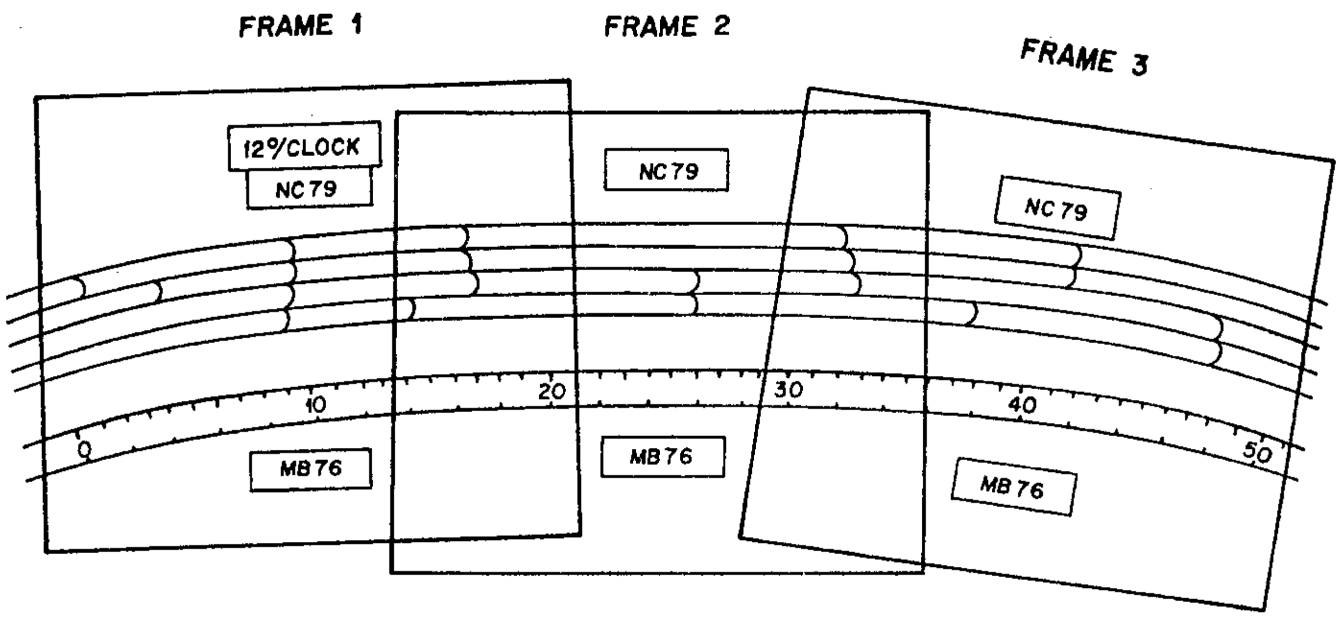

FIGURE 2

TYPICAL SEQUENCE OF PHOTOGRAPHS TO PROVIDE A CLOSE-UP WELD MOSIAC

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3.2.3.3 MPI PHOTOGRAPHY

MPI photography is a close-up technique which has been successfully carried out by a number of diving companies. Its purpose is to produce a photographic record of defect indications highlighted by MPI inks which are either visible or fluorescent in the presence of ultraviolet radiation.

This technique requires the inspector to be MPI qualified. The subject must be magnetised, a suitable ink applied (Magnaflux, Ardrox, Castrol and Miglow inks can all be used), and a satisfactory indication obtained before shooting. Identification and size reference labels must be correctly positioned, taking care to ensure that magnetising coils, tapes and magnets do not obstruct the camera or strobes.

Because the intensity of fluorescent indications is low, relatively long exposures were traditionally required. Exposure time has been reduced by using fast film, wide aperture setting, and positioning the lamp as close to the subject as possible.

An "exciter" filter on the lamp or strobe is required to eliminate any non-ultraviolet light. Depending upon the type of filter and ink, the resulting fluorescence may be blue, green, red, or yellow.

3.2.3.4 STEREO PHOTOGRAMMETRY

A stereo photograph is one that allows three dimensional viewing. It is produced by overlapping a pair of photographs taken of a subject with identical lenses of known separation.

Photogrammetry may be defined as the science of accurate measurement and analysis from photography, specifically from stereo photographs.

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Stereo photography may be obtained from almost any form of camera used underwater. In order for accurate photogrammetric measuring to be undertaken, however, the geometry of the system used must be known in order to reconstruct it during the photogrammetric analysis. Optimum camera to subject distance ratio ranges between 1-4 and 1-10.

Photogrammetric cameras are manufactured with a reseau plate. This holds the film flat and super imposes accurate register marks on the film to aid analysis. The principal point is defined as the intersection of the optic axis and the film plane. Both 35mm and 70mm formats are used, the choice determined again by camera access and degree of definition required.

A typical system would consist of a pair of cameras with a preset calibrated separation between the two. An alternative arrangement utilises a single camera with two lenses in one housing or a single lens whose position is altered automatically within the housing.

Once the photographs have been taken and processed, they are analysed and images are expressed in terms of X, Y and Z co-ordinates. Complex computer based data processing techniques are then employed to translate the image co-ordinates into true co-ordinates from which accurate measurements may be taken.

Photogrammetric analysis is worthwhile and valuable only to the extent that the required level of accuracy is achieved. It is particularly dependent upon maintaining the calibration of the equipment, the skill of the photographer and the final computer analysis. In addition, there are the following technical factors which govern potential accuracy: the quality of image produced, photographic scale, suitability of cameras and photogrammetric instruments used and camera to subject distance ratio.

Photogrammetry has been employed in a wide range of applications including:

- corrosion measurement (particularly pitting)
- corrosion monitoring
- weld profiling
- construction site surveys (ie. for clamp installation)
- physical damage surveys (tubular distortion and dent)
- scour and freespan measurement
- concrete defects (ie. spalling)
- anode wastage, volume analysis

A brief list of advantages when using underwater photogrammetry are summarised as follows:

- reduces time consuming, low accuracy, diver measurement tasks
- increases the amount of information obtained relative to other measurement techniques
- can be deployed by ROV or manned submersible
- results may be presented in a number of ways, including calculated dimensions, angles, areas, volumes and offsets, or plotted as contour maps, plans and cross sections.

NB: Photogrammetric camera arrays and lens systems are particularly susceptible to damage and disarrangement in the underwater environment. The specified lens separation <u>must</u> be maintained. Protect them adequately and ensure that they are not subjected to shock and physical abuse.

The underwater inspector has been introduced to four techniques used in still photography, and their applications in the inspection programme. Engineers rely heavily on photographic recordings in the analysis of inspection data. If the inspector's photographic technique is sloppy or inconsistent, valuable data is lost or obscured.

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Therefore, photographic recording tasks must be carefully planned to ensure the requirements are met. The inspector needs thorough pre-dive briefing. Once in the water, it is stressed that it is far better to take extra time to assure quality photographic results, than to have to return and re-photograph - a costly and time consuming exercise.

3.2.3.5 UNDERWATER PHOTOGRAPHY - TOPSIDE CAMERA PREPARATION

Assuming a phototechnician is unavailable, the following checks should be carried out by the Inspection Controller to ensure correct camera operation.

a) Open up and check seals, grease lightly.
b) Load film properly ensuring container is light-tight and that there is sufficient film for the job in hand. Wind on.
c) Check batteries - change if low.
d) Switch on flash and test.
e) Pre-set aperture and shutter speed according to conditions and stand off distance.
f) Angle flash for correct lighting conditions.

3.2.3.6 RECORD KEEPING IN STILL PHOTOGRAPHY

The photographic record consists of negative or positive transparencies from which prints may be produced. In order to consider this record valid and reliable, a suitable photographic log must be included. It is the Inspection Controller's responsibility to ensure that the film log is accurately and completely filled in.

Each log sheet should include the following information:

CLIENT	FILM REFERENCE NUMBER
LOCATION	EQUIPMENT USED (CAMERA AND LENS)
DATE	FILM TYPE
SUBJECT	INSPECTOR'S NAME

3.2.4 FILM PROCESSING

It is not uncommon for the inspection controller to develop the films used after a photographic survey.

E6 processing is a step-by-step process used extensively offshore because of its speed and simplicity. Care should be taken, however, as although it is quite difficult to ruin an exposed film entirely, the quality of the final slide, from which an enlarged print may be needed is important. The final quality can be influenced in many ways using processing and it is thus worth keeping the following points in mind.

Always keep a careful log of the number of films processed with the particular chemical batch, likewise the shelf-life of the batch as well. It is not worthwhile to process "just one more roll", mix a new chemical batch if it is necessary.

The temperature of the chemicals is critical; the developers need to be at 37.8°C ± 0.3°C, the more accurate you are the better the quality in the end.

Time is the other important variable. Remember that the times given are exact and include a 10 second drain off. Also remember that the last rolls processed in a chemical batch will need slightly more time in the first developer than the first rolls processed.

Full details of E6 processing are contained in every batch of bulk chemicals. Read the instructions carefully.

The basic requirements for E6 processing are listed as follows.

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E6 PROCESSING

Solution	Time (mins)	Temp (°C)	Agitation
1) First Developer	6	37.8±0.3	Every 30 secs
2) First Wash (x2)	2(2x1 min)	33-39	Every 30 secs
3) Reversal Bath	2	24-39	Initial only
4) Colour Developer	6	37.8±0.3	Every 30 secs
5) Conditioner	2	24-39	Initial only
6) Bleach	7	33-39	Every 30 secs
7) Fixer	4	33-39	Every 30 secs
8) Wash (x3)	6(3x2 min)	33-39	Every 30 secs
9) Stabiliser	1	33-39	Initial only
10) Dry in drying cabinet			

E6 Chemicals - Mixing From Bulk

E6 chemicals will normally be kept in bulk onboard a diving support vessel. To prepare a batch of fresh chemicals of 600ml per solution, the following procedure should be adhered to, and measurements made as accurately as possible.

Chemical/Water Solution

Mixing Instructions to Make 600ml of Solution

Chemical Amount		Water Amount	Total
1st Developer	150ml +	450ml	600ml
Reversal Bath	30ml +	570ml	600ml
Colour Developer			
Part 'A'	110ml) +	375ml	600ml
Part 'B'	115ml)		
Conditioner	100ml +	500ml	600ml
Bleach			
Part 'A'	285ml)+	200ml	600ml
Part 'B'	115ml)		
Fixer	60ml	540ml +	600ml
Stabiliser	32ml +	568ml	600ml

NB: Read the instructions on the bulk solutions carefully.

The basic requirements for E6 processing are as follows:

1	E6 Water Bath Unit
11	Chemical Storage Bottles
4	Measuring Cylinders (25ml to 1000ml)
1	Durst Portable Drying Cabinet
3	Darkroom Thermometers 0 - 70°c
1	Black Change Bag
1	Multi unit Developing Tank (with three spirals)
2	Darkroom Clocks
1	Light Box
2	Pairs Darkroom Scissors
1	Plastic Washing-Up Bowl
1	Gepe Slide Press
1	Slide Viewer
12	Film Holder Clips
2	Squeegee Tongs

Consumables

E6 First Developer
E6 Reversal Bath
E6 Colour Developer
E6 Conditioner
E6 Bleach
E6 Fixer
E6 Stabilizer
Photography Log Sheets
Processing Log Sheets
Viewpack Hanging Files
Gepe Plastic Slide Mounts
Slide Stickers, (blank)
Dusting Aerosols

3.2.5 **ACCEPTANCE**

It is ultimately the Client Representative's responsibility to accept or reject photographs. However, the Inspection Controller will be the first to see the completed photography work and it is likely that photographs will be rejected or recommended for acceptance at this stage. When considering and assessing photography, several points should be borne in mind.

Is the photograph important? If simply routine, say of anode depletion, then poor quality might be acceptable (with a recommendation that better technique be employed next time). If it is not routine, say of an important defect, then the best quality should be aimed for. This may mean a repeat dive, the controller is entitled to request this.

Location; if the spread or vessel has moved then a repeat dive might not be possible; this should be considered in terms of time and effort required to repeat the work. Restricted access; a poor photograph may be due to geometry and location and be the best result possible. Always consult the Client's Representative if in any doubt about acceptability and repetition of work.

3.3 CLOSED CIRCUIT TELEVISION

Underwater video has become an essential aid to the inspection process. By presenting 'real'-time images it assists topside personnel in orientation to the job site, clarifies ambiguous communications and identifies features to be inspected. When handled properly by the inspector, CCTV becomes an invaluable engineering aid.

Good results in video are dependent on the skill in deployment and operation of the video system. In order to aid the underwater inspector in achieving as high a standard as possible, this section introduces the principles and types of CCTV commonly used, problems encountered, handling methods, and narrative commentary procedures.

3.3.1 PRINCIPLES

Television applies the basic principle that the human brain is unable to differentiate a moving object from a rapid sequence of still photographs. It transmits moving images as 25 or more still pictures per second. This is the same basic principle that motion picture film projection relies upon.

CCTV equipment differs from commercial television in that the CCTV monitor does not need a sophisticated channel selecting receiver. Instead, the electrical signal is transmitted directly to the monitor by cable. It is called CCTV since it is a closed electrical loop or circuit.

The various components of a video system include camera, lighting and cable underwater; as well as monitors, recorders, screen typewriter and editing facilities topside. This makes CCTV one of the more sophisticated and sensitive of inspection tools. The basic operating principles of a video system are described below.

The camera focuses an image on to a photo electric screen, which is scanned by the camera tube's electron beam and transmitted as electrical impulses to the monitor. The significant difference between types of camera is the capability of colour or black and white.

Colour cameras are quickly becoming commonplace offshore although their development for underwater use is relatively recent. Their advantage is a gain in information due to excellent colour reproduction and detail, making it suitable for general survey inspection. However, the resolution of colour CCTV is less than black and white.

Black and White cameras have a wide range of sensitivities, are reliable, and produce high resolution. They are suitable for all inspection purposes, particularly for subjects requiring detail, or low contrast subjects (ie. areas of low visibility, or subjects with no colour content, such as bare metal welds).

In the monitor, the impulses or signals transmitted by the camera activate a cathode ray tube, which emits an electrical beam that forms a moving, visible image on the phosphorescent coated screen. The monitor has adjustments for brilliance, contrast and horizontal/vertical hold.

3.3.1.1 PICTURE QUALITY

Picture Quality is determined by camera tube sensitivity and the number of TV lines, or the line standard. The purpose of the camera tube is to convert light energy into electrical signals. A number of horizontal lines (625 UK or 525 USA) divide the monitor screen. Along each line are thousands of tiny cells that are excited by electron beam scanning from the rear of the cathode ray tube. This scanning occurs every 1/50 second (UK) or 1/60 second (US).

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Colour cameras are available as single or three tubed. The three "gun" camera produces greater detail and better overall results, but is proportionally larger and more difficult to handle in the water. Picture resolution is proportional to the number of TV lines, which range from 300-350 in colour systems. Solid state CCD (charge couple device) colour cameras are the latest development. These cameras can be used for general and close-up inspections and produce excellent results. The CCD sensor does not burn when pointed directly at a light source. Black and white camera tubes may be classified by their sensitivity to light. Vidicon tubes are most common because they produce the highest resolution, but they require more light. Silicon diode or silicon intensified target (S.I.T.) tubes are more sensitive to light (require less light), but resolution is reduced and they are bulkier. Black and white systems produce higher resolution as the number of TV lines range from 400-700.

3.3.1.2 VIDEO RECORDER

The video recorder records images displayed by the monitor as well as audio commentary. There are three formats available: VHS (½ inch tape), U-matic (3/4" inch tape) and reel to reel (½ inch tape).

Reel to reel have generally been superseded by U-matic tapes which are easier to use, more robust and produce better picture quality. However, given the constraints of offshore viewing, the visible loss of quality between U-matic and VHS is negligible. Furthermore, since VHS systems are cheaper, more compact, and the tapes easier to store, they have recently become the preferred CCTV system for offshore diving operations.

The video typewriter allows the Inspection Controller to type words of introduction, identification, and commentary supplements.

The video timer produces a time-date printout on the screen which correlates real time reference simultaneously with occurrences.

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3.3.1.3 LIGHTING

As with still photography, artificial lighting is critical for CCTV. A wide range of flood lighting is available with varying characteristics of efficiency and colour enhancement.

In black and white CCTV, the vapour discharge lamps - mercury vapour and thallium iodide - are preferred because of their high intensity light output. Since they emphasise the blue green spectrum, they are not appropriate for colour CCTV.

In colour CCTV, the incandescent lamps - quartz iodine and tungsten halogen are preferred because of their high output in the red spectrum, which compensates for red light preferential absorption in water.

Lighting is very important in detailed inspection. A light held too close to the subject causes 'flare'. Too much light can cause too high a contrast. Three specific light related problems the underwater inspector should be aware of are 'bloom', 'lag' and 'burn'.

Blooming occurs when a highly reflective subject appears as an unfocused ball of light, caused by the camera's inability to produce an accurate image in the presence of intense, reflected light. This effect may be reduced by installing an opaque diffuser over the flood light.

Lag produces a flare trail across the screen after the camera has picked up a highly reflective, moving object.

Burn is a type of scar on the target area (electronic camera eye) of the camera caused by pointing the camera at high intensity light. The burn which may be permanent or may persist for a long time, obscures subsequent images. Cameras should never be pointed at the sun, or any bright light. However, CCD cameras are not affected by this.

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The cable or tether is very important as it transmits image information from the camera to the monitor. Failure in this tether is the most frequent cause of equipment downtime in CCTV inspection. Therefore, special care should be taken not to damage its integrity both on deck and in the water. Pay particular attention to the electrical connection between camera lead and umbilical when handling cameras or looking for faults.

3.3.2 TECHNIQUES

The Inspection Controller may have only a video tape and some photographs to assess a situation or condition. Therefore, the video should contain sufficient information, produced in a logical and clear format.

To aid the underwater inspector in achieving this objective, he is introduced in this section to helmet mounted and hand held modes, applications, preparation and camera handling in CCTV.

3.3.2.1 HELMET-MOUNTED AND HAND-HELD MODES OF DEPLOYMENT

The procedures, operation, preparation, handling and reporting are similar in both modes of deployment. The difference is in the size of camera and quality of picture resolution produced.

Helmet-mounted cameras are smaller, lighter, and less sensitive than the hand held units. Therefore, they are used widely for general inspection and monitoring diver activity. This mode of deployment is much more convenient for the inspector as it allows the use of both hands. Furthermore, there is no tether to look after since the TV/power cable is secured to the diver's umbilical. Time is not wasted in moving and securing the camera, and the risk of TV cable damage is reduced. The disadvantages are diver fatigue in long duration dives due to the increased umbilical size and limited manoeuvrability in confined spaces due to the head mounting.

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The hand-held camera is deployed when high quality image reproduction is required. Therefore, it is used most often in detailed inspection. It is not very suitable in situations where the inspector needs to carry out tasks simultaneously, or when conditions (ie. heavy surge or current) require the use of both hands.

In both modes of deployment, it is important to ensure that the camera is correctly orientated in its clamp. Otherwise, a very disorientated image is transmitted, resulting in topside confusion in directing camera movement to the inspector (and vice-versa). This is accomplished by a simple and quick pre-dive check, taking care not to overheat the lamp.

3.3.2.2 APPLICATIONS

In general surveys, CCTV produces a visual guide to a structure's overall condition. The inspector begins with establishing shots (ie. a particular node, painted identification, etc) to positively locate the area under investigation. The route followed should be covered in a logical sequence. At each node, the camera should 'tilt' up and down and 'pan' right and left for a general view to locate any debris or potential anomalies. Overviews of anodes, marine growth, presence of scour/burial (or freespan in the case of pipelines), and physical damage should be included along the access path.

Components should be identified as they appear in the camera's view (not the inspector's view). Where damage or potential defects are found, an attempt should be made to establish their cause with full video coverage of associated areas. CCTV produces a reasonably detailed visual guide to a component or defect's specific condition. Although most CCTV coverage is concentrated on weld inspection selected anodes, riser clamps and flanges, etc are also covered.

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Close up CCTV should begin with an establishing shot of the general area, then move into the specific inspection starting point. It is important to conduct detailed CCTV at a slow pace as quick or jerky movements are extremely disorientating to topside observers. Correct lighting is much more critical than general survey CCTV. A marker or pointer with a small scale at the tip greatly assists in highlighting points of interest during close up CCTV.

In addition to general and close up CCTV, a third common application is inspection monitoring. This allows engineers to monitor the inspection procedure being conducted by a diver or vehicle. The camera is deployed by the inspector in the helmet-mounted mode, by a second diver with a hand-held unit, or by ROV.

The monitoring camera should show all the relevant operations relating to the inspection procedure, taking care to avoid interfering with inspection operations. As with all visual inspection techniques, the inspector should carry these basic tools - plastic metric ruler, non-stretch metric tape measure, pit gauge, hand wire brush/scraper and 'yellow paint stick' (welders wax marker).

3.3.2.3 PREPARATION

Preparation requires that the equipment is working correctly. Carry out a test recording with the camera on-deck to ensure that:

- the camera is correctly orientated in its mounting.
- the tape recorder, videowriter and time generator are working.
- the dubbing system is working.
- there is a tape in the recorder.

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Preparation also requires that the diver is aware of the specific purpose of the video and to ensure that the survey adequately provides the information required in the most concise manner possible. Surface preparation requires the diver to be properly briefed by the Inspection Controller and to be clear in his mind as to:

- the purpose of the video survey.
- the location to be surveyed.
- the direction of movement during the survey.
- camera stand-off during the survey.
- rate and detail in which the survey is to be executed.
- rigging necessary prior to video.
- surface directions employed.

Specific preparation at the site depends upon the inspection requirements and the standard of surface finish required. Cleaning should be completed before deploying CCTV whenever required.

In localised or detailed CCTV, the inspector should take sufficient time in rigging the area (particularly in adverse sea conditions) to ensure a flowing, uninterrupted survey. He should also establish identity and dimensions of the site prior to beginning the survey.

Finally, the inspector should rehearse a 'dry run' of the area to be surveyed. This ensures topside satisfaction that the area has been properly cleaned and identified, there is sufficient TV cable and that there are no obstructions (ie. rigging). The dry run also enables the Inspection Controller to prepare a script for his verbal commentary.

3.3.2.4 CAMERA HANDLING

Without correct camera handling, acceptable and informative results are impossible. Two approaches to camera handling and common terminology used are described below.

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In one approach, the inspector carries out his own survey of a particular subject without topside direction. In this case, the diver must be aware of the camera's angle of view, its focus range, and depth of field. He gains this knowledge with topside feedback during the 'dry run' and through general experience.

In the second approach, the inspector conducts the survey only as directed by topside. In this case, he acts merely as a 'robot', following instructions from the surface. It is important that these instructions are given in mutually understood and accepted standard terms.

The standard terms for views that may be requested are:

1. **Midwater shot** - provides background for typed heading.
2. **Establishing shot** - shows overall view of survey area.
3. **Long shot** - presents the whole of a specific subject.
4. **Mid shot** - shows approximately half the subject.
5. **Close up** - details the subject. Extreme close up is as close as possible without blurring focus.

The standard terms for camera handling are:

1. **Pan Left/Right** - move the camera slowly in a horizontal plane without changing its position.
2. **Tilt Up/Down** - move the camera slowly in a vertical plane without changing its position.
3. **Move In/Out** - move slowly away or towards the subject for the view requested (ie. long, mid, close-up shot)
4. **Move Up/Down or Left/Right** - move the camera slowly without changing the angle. May require the diver to change position.
5. **Rotate Left/Right** - move the camera slowly to change orientation of viewing.
6. **Hold/All Stop** - stop camera movements.

It is stressed that slow, purposeful movements of the camera are necessary to produce good CCTV coverage. Rapid movements leave a decaying image while a new one is being produced (the 'lag' effect), making for a lower quality picture. Suitable rigging greatly assists the diver inspector in handling the camera comfortably.

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If the diver is unable to continue surveying smoothly, he should hold at some distinctive point and instruct topside to "pause". He may then rerig, reposition the camera at the same distinctive point, and inform topside he is ready to continue.

3.3.2.5 NARRATIVE COMMENTARY/TOPSIDE SYSTEMS CONTROL

A video report is complete only when a clear and accurate commentary accompanies the tape. Fluent commentaries require close co-operation between the topside Inspection Controller and underwater inspector, careful preparation, standard terminology, and thorough knowledge of the area being surveyed.

The purpose of narrative commentary is to orientate the viewer to subject location and explain exactly what he is seeing at the outset. Baseline data required to describe the component's condition must be established by the Inspection Controller and be clearly understood by the inspector. This may include descriptions, measurements, and any other information required to base engineering evaluations upon.

The method of audio recording is determined by the client. Three common narrative recording techniques are:

1. Direct recording of all comments made during the operation, both topside and underwater.
2. Direct recording of all comments on one channel, with a dubbed narrative commentary on a second channel.
3. Dubbed, spontaneous commentary by the Inspection Controller as the dive proceeds, all other communications are independent.

When recording direct as in 1 and 2 above, the underwater inspector is responsible for producing a spontaneous, flowing, clear and descriptive narrative commentary. Careful observance of the following points ensures that this objective is realised:

- Take up as comfortable a position as possible and relax.
- Before making any statement, be certain of what is being reported.

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- Speak slightly more slowly and with more precision than in normal conversation.
- Use short sentences or phrases, pausing between each.
- Make descriptions clear, succinct, and definite (what is obvious on-site to the inspector is often ambiguous to topside reviewers.
- Use a systematic approach (ie. report in the same order) when presenting repetitive items.
- Do not make unnecessary, derogatory, or repetitive comments (unless it is a matter of safety).

The video tape recording begins with a typed introduction and identification superimposed over an establishing or midwater shot. The following information should be superimposed onto the video recording:

DATE (DD/MM/YY) - TIME (HH/MM/SS)
TITLE/HEADING
LOCATION
DIVE CO, DIVE NO, DIVER
TAPE NO.

For example:

20/08/87 - 23:10:15
SAMCO PETROLEUM (UK) LIMITED
RISER CLAMP SURVEY
TNSP NN1 -104m
TSOL, DIVE NO. 284, DIVER J JONES
TNSP/87/02

As a leader each new tape will have the main title superimposed onto the centre of available screen area. The main title will be on the screen for approximately 30 seconds, while the Inspection Controller providing the commentary gives a verbal description of the spread/task details.

Upon completion of the video survey, a single, concise, summary statement should be made if possible. It may include a remark of overall condition with reference to specific anomalies discovered. For example: "There are no visual defects on this weld other than slight, localised pitting at 9 o'clock."

Finally, the most effective method of improving narrative commentary technique is to review one's own recording whenever possible.

Topsides, during the dive, the Inspection Controller should ensure that the tape is recording continuously. This can be accomplished by playing back the recording during such time as the diver is re-rigging or performing some other non-video task. On completion of the dive the controller must re-play the video, making note of points of interest which may require further attention.

Recorded tape is normally stored in a box labelled with the following:

TAPE NUMBER, eg.	TNSP/87/02
TITLE	RISER CLAMP SURVEY
LOCATION	TNSP NN1 -104m
DIVE COMPANY/VEHICLE	TSOL
DIVE NUMBER	DIVE NO. 284
DATE	20/08/87

The above information will be labelled onto:

- the actual tape label.
- the front of the tape box.
- the spine of the tape box.

3.4 SIZE REFERENCING, IDENTIFICATION AND STRUCTURAL MARKING

Methods of marking a structure vary in sophistication depending on the purpose of the marking.

The most readily available and rapid technique of identification marking is the use of underwater crayons known as "paint sticks". These are suitable for marking out or highlighting areas to be recorded but should only be used as a last resort for identification in videos and photographs due to the messy and unprofessional appearance created.

For identification and size reference of general view videos and still photographs marker boards are normally used. The boards should contain the following subject information as a minimum:

i) scale
ii) platform identity
iii) date
iv) area identification (eg. node number)
v) depth (if area not well defined)
vi) colour chart (if applicable)

"Dymo" labels are most suitable for this purpose.

The boards may be fixed to steel structures by small magnets and by suction cups to concrete surfaces. Alternatively, tie cord may be used.

For close-up photography(eg. welds) the scale in the form of a tape measure, can be attached to magnetic strip tape and placed adjacent to the subject. "Dymo" labels containing subject details can similarly be fixed to magnetic tape and located. Clock positions should also be marked as appropriate and magnetic arrow markers used to identify any defects or anomalies found.

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Permanent structural marker systems may be encountered underwater. These generally comprise:

i) "SeaMark" type markers of cupronickel antifouling mesh set in brightly coloured fibreglass with contrasting coloured letters.

ii) Steel plates secured to the structure at standard locations with identifying numbers or letters cut through the plate (similar to a stencil).

iii) Numbers or letters formed by weld bead at fixed locations.

iv) Painted identification marks on the structure.

v) Aquasign Underwater Markers of non-stick brightly coloured and lettered antifouling silicone rubber.

3.5 RECORD KEEPING

A photographic and CCTV video record is an essential element in producing a good inspection report. The requirements for these records are specified by the client.

In general, records of documented results from inspection programmes are the only assurance the Operator has that the structure is safe and fit for purpose. Furthermore, records of this documentation are necessary to obtain or continue a certificate of fitness.

More specifically, records provide the necessary information for planning and monitoring the progress of underwater engineering in inspection and maintenance tasks.

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4. UNDERWATER VISUAL INSPECTION

4.1 INTRODUCTION

Visual inspection forms the basis of all underwater inspection programmes. Being the preferred method, visual inspection by divers and remotely operated vehicles or manned submersibles is still the most used of any inspection technique. The workscope of any of these techniques is determined by the requirements of the owner/operator, certifying authorities, insurance companies, and other legislative bodies.

The purpose of underwater visual inspection is to generate sufficient data to satisfy engineering assessments of integrity and deterioration. This is the information which must be routinely recorded to assess the condition of the "Structure's Inventory". Routine data would include the status of, for example, marine growth, corrosion, cathodic potential and wall thickness. The structure's inventory includes elements such as members and nodes; primary appurtenances such as risers, caissons; components such as clamps and flanges; and sub-components such as bolts, hinges and neoprene insulation.

Flowlines from riser tube-turns to burial points may fall into the category of primary appurtenances or may come under a separate pipeline inspection programme. Although pipelines are now often inspected by manned or unmanned submersibles, the methods and objectives of pipeline inspection are the same as structural inspections.

Underwater visual inspection is a difficult technique for acquiring quantitative data because the Inspector is often dealing with subjective values. Examples include the type, thickness and overall coverage of marine growth; the extent of blistering, flaking and disbonding of coatings; and the identification of type and extent of corrosion.

Therefore the Inspector must acquire a clear understanding, through standardised instruction and on-site briefing of the inspection procedures including all the methods and common terminology to be used during reporting. He may also be briefed with information concerning the history of the structure. Examples of this include previous damage, repairs, and variations from design specification. The two most commonly termed categories of underwater visual surveys are general visual inspection and close visual inspection.

4.1.1 GENERAL VISUAL INSPECTION

The primary objective of a general inspection is to document the structure's general condition, though it is only a guide to true condition. This procedure normally does not require cleaning. As the diver or ROV negotiates the structure in an efficient, logical sequence, reports are made on the structural integrity paying particular attention to major defects such as missing, buckled or dented members, gross cracks, and abrasions. A general visual survey may also include a report of anode condition, presence of scour and burial points, marine growth cover, and all debris, particularly metal debris in contact with the structure. Equipment normally required for this procedure includes CCTV and light, tape measure, wire brush, hand scraper and suitable marker.

4.1.2 CLOSE VISUAL INSPECTION

Close visual inspection is the detailed examination of a component or defect. Although this procedure is normally confined to physical damage, weld inspection, corrosion inspection and selected areas of marine growth, an inspection programme may require close visual inspection of selected anodes, clamps, flanges, previous repairs, etc. In addition to the basic general inspection tools, the use of a straight edge, calipers, pit gauge, still camera, cathodic protection/wall thickness meters, and NDT equipment for magnetic particle, ultrasonic and radiographic testing of welds may be required.

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Both general and close visual inspections often result in extending inspection to associated areas and identify sequential tasks to be carried out. For example, an apparent visible crack may require MPI, remedial grinding, followed by reinspection.

It is important to note that the primary item of equipment for any visual inspection is the naked eye, be it that of the on-site diver or an ROV Pilot/Observer Inspector viewing what is limited to the video screen. In either case the eye is extremely dependent on the adequate intensity and direction of light, a detail often taken for granted and overlooked.

4.1.3 GENERAL NOTE ON THE INSPECTION OF OFFSHORE STRUCTURES

The general philosophy of underwater visual inspection is the same for both steel and concrete structures ie. to discover and report defects. This is achieved by performing a general visual inspection augmented by a detailed inspection of critical areas.

The Department of Energy Guidelines (three editions - 1974, 1977 and 1984) state that the initial inspection schedule should take account of the nature of the deterioration to which structures are liable in the marine environment and the regions in which "defects are most prone to occur", and members or regions "which have been, or are likely to have been, highly stressed or subjected to severe fatigue loading". They also state that special attention should be given to areas of suspected damage or deterioration and to areas repaired following earlier surveys. The foregoing matters should all be taken into consideration before inspection schedules are drafted.

In all structures, the area of the splash zone requires special attention as it is an area particularly vulnerable to physical damage, excessive wave loading, marine growth and corrosion. It is the duty of the Diver/ROV Inspector to describe and report as accurately as possible any defects encountered (see Section 2).

Generally speaking, the purpose of an underwater inspection programme is to provide credible assurance to the Owner/Operator and the Certification Authority that any deterioration of the structure is within limits which will ensure safe operation of the installation throughout its service life. In order to achieve meaningful results, a well organised and efficiently co-ordinated inspection programme is required.

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4.2 CLEANING METHODS AND SURFACE FINISH

4.2.1 INTRODUCTION

Cleaning of marine fouling from offshore structures is performed for the following 3 main reasons:

- to prepare the surface for inspection and NDT
- to prepare the surface for repair and maintenance work
- to reduce static and dynamic loading

Cleaning is generally essential to the success of an inspection programme. It is frequently the most time consuming element and consequently the most expensive. It takes several times longer to clean a weld than it does to actually inspect it. The extent of cleaning is determined by the inspection requirements agreed with the client. Cleaning does not require a specific qualification, but divers must have sufficient knowledge and training to correctly and safely operate the cleaning system.

4.2.2 CLEANING METHODS

The method of cleaning is determined by the standard of surface finish desired, access to inspection site, company policy and safety considerations for the diver.

There are four methods of cleaning underwater structures, each with its own merits and limitations. These are hand cleaning, mechanical cleaning, water jetting and grit/sand entrained water blasting.

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4.2.2.1 HAND CLEANING

Hand cleaning is used for the localised removal of general marine growth where the removal of more tenancious hard growth such as tubeworm casts and barnacles, or protective coatings is not required. Scrapers and wire brushes are inexpensive, reasonably efficient and easy to deploy and use. The major disadvantage is diver fatigue when cleaning large areas. Care must be taken not to damage the surface, particularly weld caps, with scratches or gouges which could result in spurious defects being manifested during magnetic particle inspection.

4.2.2.2 MECHANICAL CLEANING

Where a surface finish of bare metal for NDT techniques is required, mechanical cleaning can be carried out using pneumatically or hydraulically powered tools.

Pneumatic tools are effective in shallow depths down to approximately 20 metres. Below this, they become progressively less efficient unless heavy duty high powered compressors are employed topside.

Hydraulic tools are extensively used and offer the same advantages as pneumatic tools along with the added benefit that there is no depth restriction to their efficiency. Hydraulic powered brushes are effective and are mainly used for cleaning small areas in preparation for MPI, UT etc.

Both pneumatic and hydraulic tools require careful handling as there is a risk of surface damage. In both cases, the surface finish is very reflective and adversely affects flash photography and CCTV.

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4.2.2.3 HIGH PRESSURE WATER JETTING

High pressure water jetting (10,000-20,000 psi) is the most extensively used cleaning method for the removal of general marine growth. It is also effective for intense cleaning where all but the most stubborn deposits and coatings will be removed. Leaving a polished finish, the problem of reflected light in photography is again encountered. In order for the diver to balance himself against the force of the jet, 50% of the power at the gun is used in 'retro-jet'. As a result, the need to maintain high water pressures places a heavy operational demand on equipment.

4.2.2.4 SAND ENTRAINED WATER BLASTING

Where clean matt metallic surface finishes are required, a variation of the high pressure water jetting method is used called sand blasting or sand-entrained water blasting.

There are two common methods of providing sand to the worksite. These are the dry sand and wet slurry delivery systems. Each has its own technical and logistic disadvantages. Both systems use an abrasive silica sand which increases the cleaning rate and is very effective in producing a grey matt surface finish. Both systems use a conventional high pressure water pump and simply modify the jetting gun to mix the sand at the nozzle end. In order to minimise the chance of removing metal, the working pressure range is reduced to 3,000-7,000 psi compared to a water only jetting range of 10,000 psi plus. This has the advantage of reducing operational wear and tear on equipment.

With the dry sand delivery system, sand is drawn down a large bore air hose normally limiting it to the air diving range. Productivity is diminished by hose blockage whenever air pressure fails and water backs up the hose, or internal damage caused by the abrasive sand itself.

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The wet slurry system, since it does not need air, can be used at greater depths. However, its cleaning rate is much less than dry grit because of reduced volume delivery and frictional losses down several hundred feet of hose. The most recently developed slurry systems utilise mechanical 'movers' in the delivery hose which have improved saturation range cleaning. Both systems require the mobilisation of large stocks of silica sand.

4.2.3 SAFETY ASPECTS

A major consideration in the operation of these high pressure water systems, particularly water jetting, is diver safety. The jetting gun is potentially a dangerous tool. All divers using this equipment must be trained in its use and must handle it with great care. The following precautions are recommended:

1. Only one diver should be working in an area where jetting is taking place.

2. Only the diver should ask for the high pressure water supply to be activated and only when he is ready to start jetting.

3. Under no circumstances should the diver try to maintain a locked open position on the trigger. When he experiences fatigue, he should stop jetting and rest.

4. A strong guard should be fitted around the trigger to prevent accidental operation and the retrojet guard should be long enough to prevent damage to the diver's equipment.

5. The wearing of a helmet instead of bandmask is recommended. Care should be taken to clean all equipment of abrasives after each dive, particularly life support functions such as diver's helmet demand regulator and free flow valve, and hot water or suite inflation valves.

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6. The diving supervisor should always be in direct contact with the technician who should be standing by the high pressure water pump while it is running.

4.2.4 SURFACE FINISH AND STANDARDS

Cleaning is performed in order to remove excessive marine growth or to prepare the surface for close visual and NDT inspection. To avoid time being wasted by cleaning to too high a standard or through having to return to a location for further cleaning, divers must be clearly briefed concerning the extent of cleaning required.

At present there are no cleaning standards which relate directly to the cleaning of subsea steel surfaces, prior to close visual inspection and NDT. However, the Swedish Classification Standard SIS 05 5900 (surface preparation, required on rolled steel prior to paint coating) is generally used to define the standard of subsea cleaning required for weldment inspection.

Thorough Blast Cleaning

Thorough removal of all protective coating, millscale, rust and foreign matter to the extent that only traces remain as stains. The surface to have an otherwise uniform matt metallic colour. This mode of cleaning is to produce a surface finish similar to Svensk Standard Sa 2.5 (referring specifically to blast cleaning) as defined by the appropriate Swedish Standard mentioned above. This is the standard most commonly applied to weldment inspection.

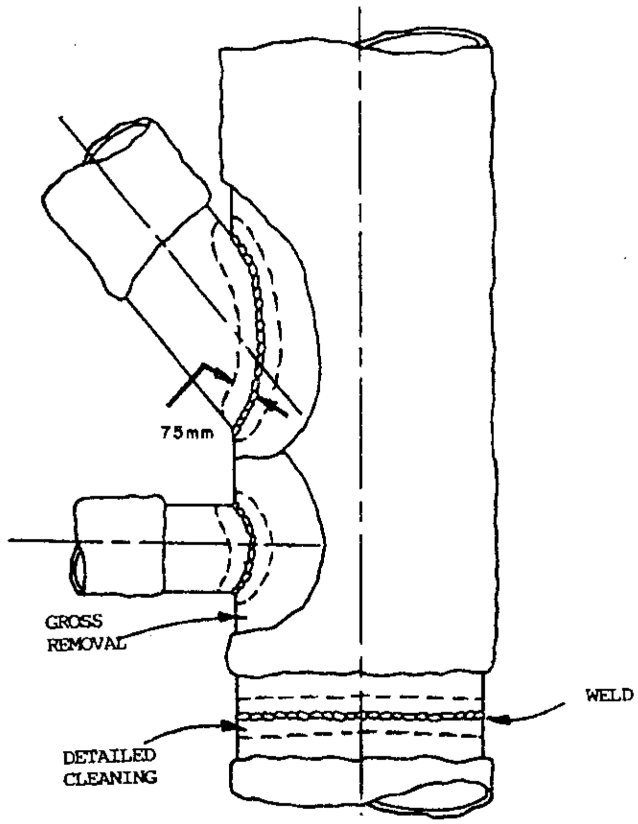
Thorough Wire Brushing

Thorough removal of all loose mill scale, rust and foreign matter, the surface to have a pronounced metallic sheen. This mode of cleaning is to produce a surface finish similar to Svensk Standard St3 (referring specifically to wire brushing).

4.2.5 **EXTENT OF CLEANING**

The extent of cleaning required will be primarily dependent upon the job of work to be done and should always agree with the client procedures.

For weld close visual inspection the entire weld cap including a strip of parent metal typically 75mm wide on either side of the cap is normally required to be cleaned to bright metal - Sa 2.5. The exact requirements, however, may vary from client to client.



4.3 VISUAL WELDMENT INSPECTION

4.3.1 INTRODUCTION

Nearly all steel components visually inspected underwater are joined together by fusion. The process of metallurgical bonding primarily used to fabricate offshore steel structures is called fusion welding, or more specifically electric arc welding.

Welds are never completely defect free. No matter how good the weld procedure and the welder may be, a fusion weld may be affected by one or more of the following factors:

- Metallurgical variation between electrode (weld metal) and parent metals.
- Residual tensile and compression stress around a completed weld (even after post heat treatment).
- Presence of possible defects due to faulty technique.
- Inherent material defects in manufacturing (ie. lamination).
- Inadequate structural design.

These factors should have been minimised, and serious defects identified and repaired during the construction phase. Most visual defects encountered by inspection personnel occur in-service as the result of loading or accidental damage. Other factors involved in the deterioration of welds prior to defects appearing, such as fatigue, and brittle or ductile fracture (which usually cannot be detected prior to failure), are discussed in the section Modes of Failure and Deterioration (Section 2).

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Weld inspection concentrates on non-redundant, fatigue sensitive welds, especially where the risk of failure cannot be tolerated. It nearly always involves detailed, close inspection procedures. Usually a high standard of surface finish is required through the use of water jetting, or sand entrained water blasting, particularly if MPI is to follow.

Weld inspection is the most critical and most time consuming (when cleaning is taken into account) part of an inspection programme.

4.3.2 WELDING PROCESSES

Although there are currently more than 35 different welding processes used in industry, it is not the intention of this document to go into detail on the various welding processes. However, an appreciation of two of the most common fusion processes is given here. These are:

1. Flux shielded arc welding; techniques include:
   - manual metal arc (MMA)
   - automatic metal arc
   - submerged arc

2. Gas shielded arc welding; techniques include:
   - metal inert gas (MIG)
   - tungsten inert gas (TIG)

Both processes use an electric arc to produce a very efficient heat source of approximately 6000°C. The core wire of the electrode melts and is transferred by the arc to fuse with the molten parent metal pool. Electrostatic attraction of the charged molten drops to the earthed workpiece facilitates positional welding techniques.

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The quality of a weld depends upon a number of factors, most significant of which are heat input and protection of the molten weld pool from atmospheric contamination, particularly oxidation, while the weld solidifies. The primary difference between these two processes is the type of protective shield utilised. As implied in their names, flux blankets the weld pool with dry chemicals (called slag when cooled), and the other shields the weld pool with inert gas, such as helium, argon, and sometimes carbon dioxide.

Most nodal welds visually inspected underwater are welded by the manual metal arc technique as it is cost effective and meets the required structural standards. Other welds in the early fabrication stage, such as circumferential leg and pipe butt welds and seam welds are welded by automatic metal or submerged metal arc techniques. Welds experiencing high pressure as in risers and pipelines, utilise TIG for at least root and hot passes.

Hyperbaric repairs nearly always use TIG for root and hot passes, and manual metal arc or automatic flux core wire feed techniques for filler passes.

4.3.2.1 FLUX SHIELDED ARC WELDING

Manual Metal Arc is the most widely used of all welding techniques in the construction of offshore structures. Commonly called "stick welding", it is a completely manual technique in which weld metal is deposited by melting the electrode and parent metal with an electric arc. The electrode, commonly called a "welding rod", is a solid core wire coated in flux. Flux produces a floating, protective slag that cleanses impurities from the molten metal pool, protects the pool from oxidation, stabilises the electric arc and assists in achieving the desired weld contour. An outstanding advantage of MMA is that alloying elements such as manganese, chromium, and molybdenum can be added to the flux to adjust the composition of the weld metal. This acts to improve the properties of low carbon and low alloy mild steel used in the construction of offshore structures.

Automatic or Mechanised Metal Arc is simply a logical extension of the finite length electrode used in manual arc where a solid core wire coated in flux is continuously fed. Its advantage is purely economic in certain production applications, because by using higher current with deeper penetration faster welding speeds can be achieved.

Submerged Arc Welding is another automated production welding technique. Instead of using continuous coated electrodes, the electrode wire and the arc are submerged under a layer of granular flux. It is often used in structural work requiring the welding of thick plate.

4.3.2.2 <u>GAS SHIELDED ARC WELDING</u>

Tungsten Inert Gas (TIG), or Tungsten Arc Gas-Shielded Welding (TAGS) as it is called in B.S. 499, uses inert gas instead of flux to shield the weld pool from atmospheric contamination. Pure argon is normally used, though the use of helium is common when the parent metal requires a higher heat input. In TIG, the tungsten electrode is not consumed. Instead, weld filler metal is applied separately by filler rod. The filler rod often contains alloying elements incorporated in the flux.

Metal Inert Gas (MIG), or Metal Arc Gas-shielded Welding (MAGS) as it is called in B.S. 499, has in common with TIG a gaseous shield. Carbon dioxide is more often used as it provides a more stable arc in low carbon steel and is less expensive. The technique differs from TIG in that the electrode is continuously fed automatically as it is consumed. A variation of the solid core wire is the flux core wire. This technique combines both forms of protection and is preferred when certain weld characteristics are required.

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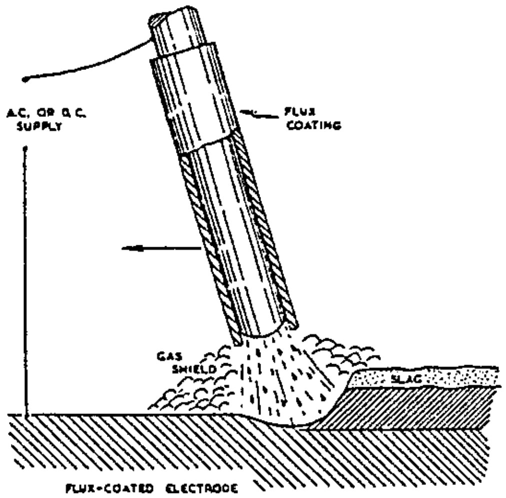
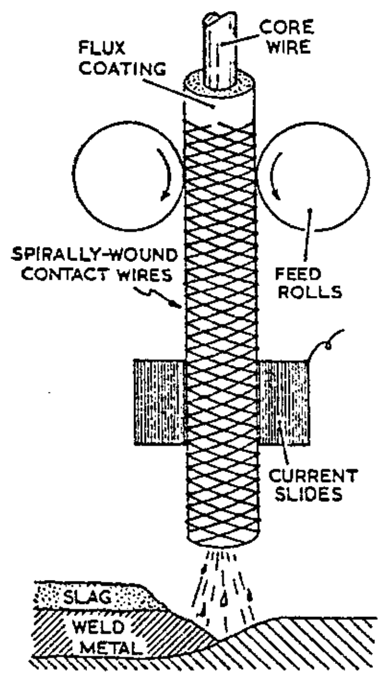
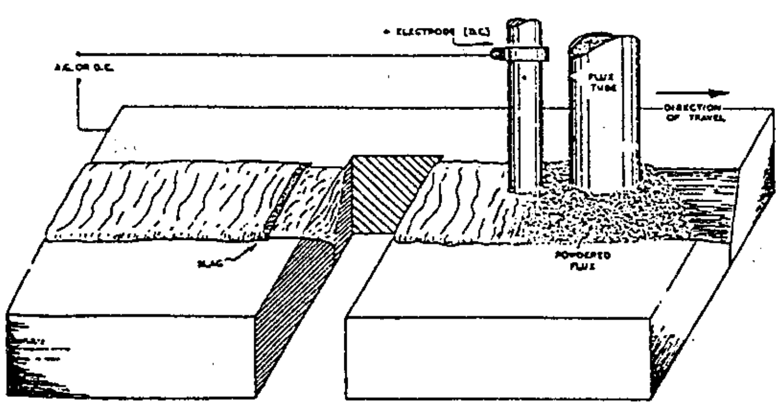
FLUX SHIELDED ARC WELDING



Manual Metal Arc

Automatic or Mechanised Metal Arc





Submerged Arc Welding

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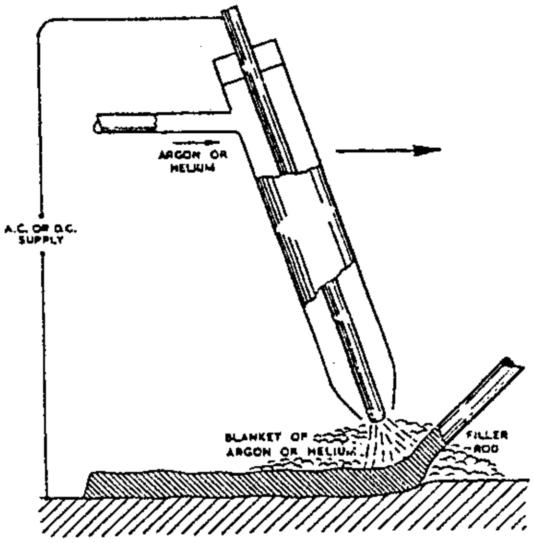
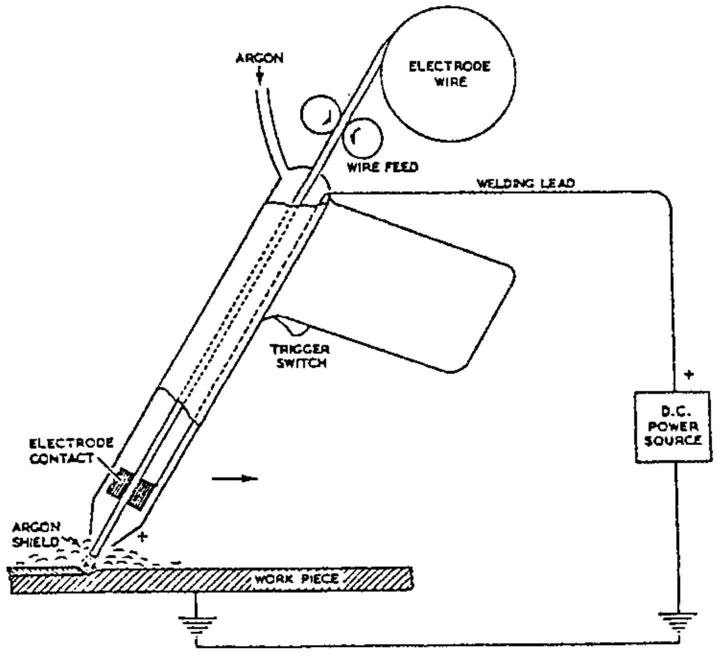
GAS SHIELDED ARC WELDING



Tungsten Inert Gas (TIG)

Metal Inert Gas (MIG)



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4.3.3 WELDMENT TERMINOLOGY

4.3.3.1 TYPE OF WELD JOINTS

There are a numerous amount of different joint types which can be used when welding two metals together. Only five types are discussed here, the butt, 'T', lap, corner and cruciform joint.

Butt Joint A connection between the ends or edges of two parts making an angle to one another of 135^o to 180^o inclusive in the region of the joint.

This type of joint is common offshore found in seam and circumferential leg welds.

T-Joint A connection between the end or edge of one part and the face of the other part, the parts making an angle to one another of more than 5^o up to and including 90^o in the region of the joint.

Lap Joint A connection between two overlapping parts making an angle to one another of 0^o - 5^o inclusive in the region of the joint.

Corner Joint A connection between the ends or edges of two parts making an angle to one another of more than 30^o but less than 135^o in the region of the joint.

Cruciform Joint A connection in which two flat plates or two bars are welded to another flat plate at right angles and on the same axis.

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4.3.3.2 **TYPES OF WELD**

Two types of weld are most common, the butt weld and fillet weld. Several types of joints can be used with each depending on the welding method, weld position etc. A butt weld is a tension resisting weld in which the bulk of the weld metal is contained within the planes or thickness of the joined parent metals. The bulk of a fillet weld is contained outwith the parent metal planes or thickness. Generally speaking, a fillet weld is never used in a fatigue situation since its tensile strength is significantly less than the parent metal. For this reason, most welds encountered by inspection personnel will be the butt type.

4.3.3.3 **FEATURES OF A WELD**

Fusion Face	The portion of a surface, or of an edge, which is to be fused on making the weld.
Fusion Zone	The depth to which the parent metal has been fused.
Heat Affected Zone (HAZ)	The part of the parent metal that is metallurgically affected by the heat of welding but not welded.
Weld Zone	The zone containing the weld metal and the heat affected zone.
Weld Junction	The boundary between the fusion zone and the heat affected zone.
Reinforcement	Weld metal deposited lying outside the plane (Excess Weld Metal) joining the toes.

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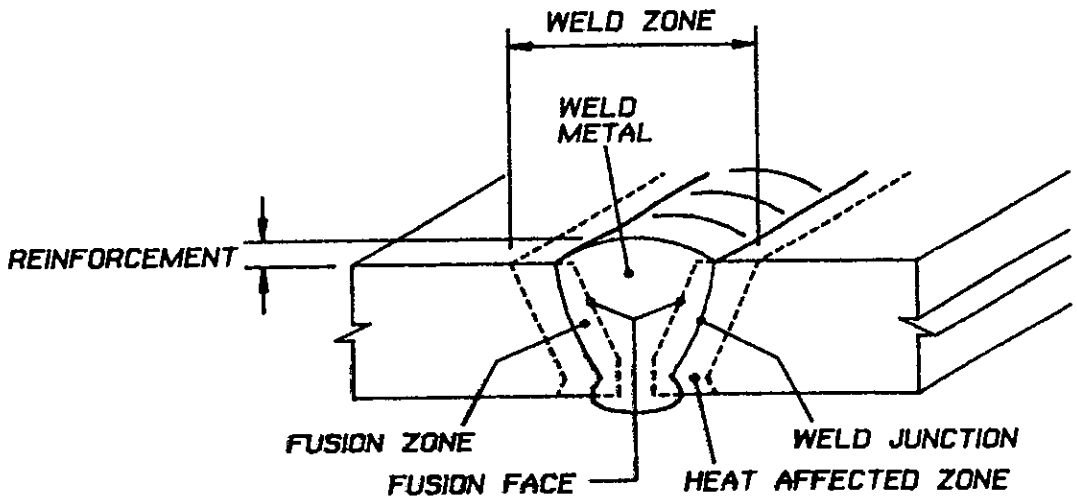
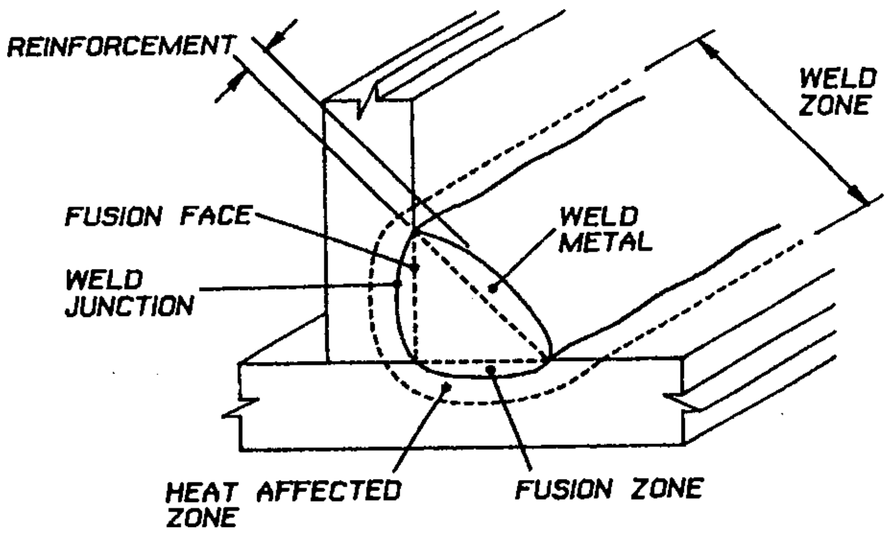

WELD ZONE
WELD
METAL
REINFORCEMENT
FUSION ZONE
WELD JUNCTION
FUSION FACE
HEAT AFFECTED ZONE


REINFORCEMENT
WELD
ZONE
FUSION FACE
WELD
METAL
WELD
JUNCTION
HEAT AFFECTED
ZONE
FUSION ZONE

Weld Face — The surface of the weld exposed on the side from which the weld has been made. Commonly called the 'cap'.

Toe of a Weld — The junction between the weld face and the parent metal or, the junction between runs.

Root of Weld — The zone on the side of the first run furthest from the welder (in a fillet weld, the apex of the angle formed by the two fusion faces).

Throat Thickness (Actual Throat Thickness) — The thickness of weld metal in a butt weld measured at its centre line

OR

The shortest distance from the root of the weld to the weld face of a fillet weld.

Design Throat Thickness (Effective Throat Thickness) — The minimum dimensions of throat thickness used for purposes of design, ignoring excess metal and penetration.

Leg Length — The size of a fillet weld is expressed by the leg length, the width of the fusion face ie the distance from the root of the joint to the toe of the weld.

Weld Width — The shortest distance between the outer toes of a weld.

Weld Preparation — A preparation for making a connection where the individual components, suitably prepared and assembled, are joined by welding.

Root Face — The portion of a fusion face at the root that is not bevelled or grooved.

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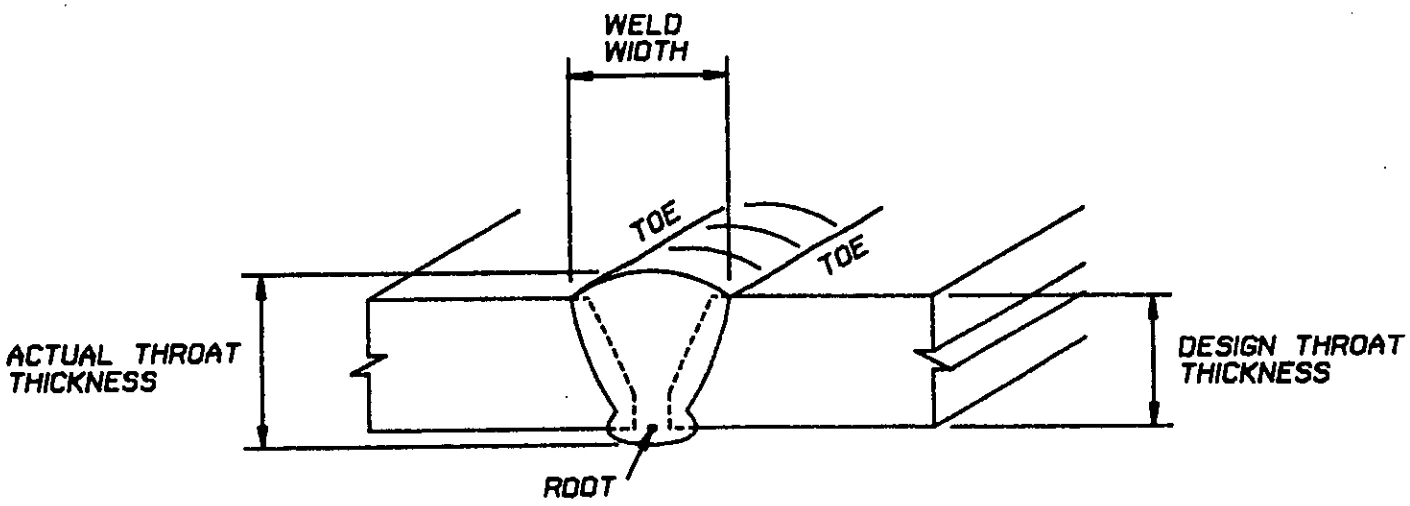
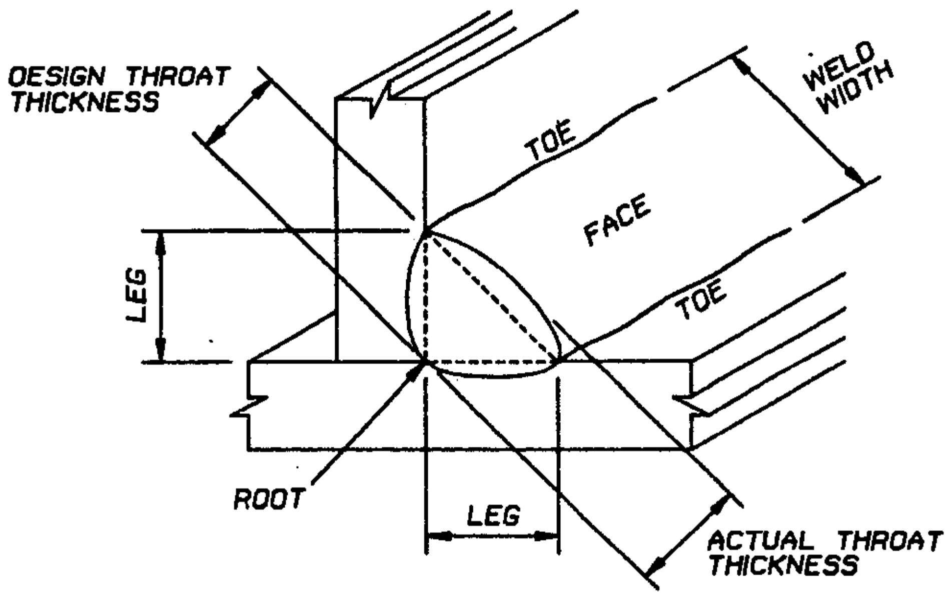

WELD WIDTH
TOE
TOE
ACTUAL THROAT THICKNESS
DESIGN THROAT THICKNESS
ROOT


DESIGN THROAT THICKNESS
WELD WIDTH
TOE
FACE
TOE
LEG
ROOT
LEG
ACTUAL THROAT THICKNESS

Contents

Root (of Preparation)

(i) In a butt joint preparation, the zone in the neighbourhood of, and including the gap.

(ii) In a square butt joint, the zone between the prepared edges adjacent to the backing strip.

(iii) In a fillet weld, the zone in the neighbourhood of the actual or projected intersection of the fusion faces.

Root Gap

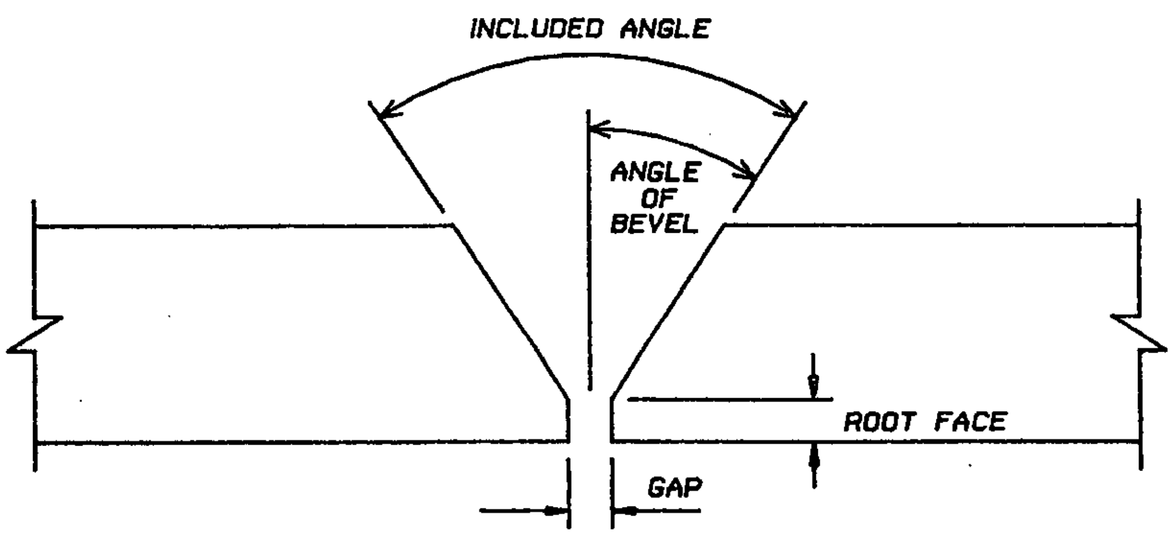
The minimum distance at any cross section between edges, ends, or surfaces to be joined.

Angle of Bevel (Angle of Preparation)

The angle at which an edge or an end of a component is prepared (cut) for making a weld.

Included Angle

The angle between the planes of the fusion faces of parts to be welded.



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4.3.4 **WELD DEFECT IDENTIFICATION AND LOCATION**

The more common general weld defects likely to be found in underwater visual inspection are cracks, physical damage, undercut, overlap, and significant corrosion and surface defects predominantly caused by in-service wear and tear but which may also be associated with faulty technique and inherent material/design weakness.

Defects occur most often where there are abrupt changes in configuration, crevices and weld toes in particular, and in the acute angle crotches between structural members.

It is stressed that what is of paramount importance is for inspection personnel to clearly describe with standard terminology visibly identifiable weld defects.

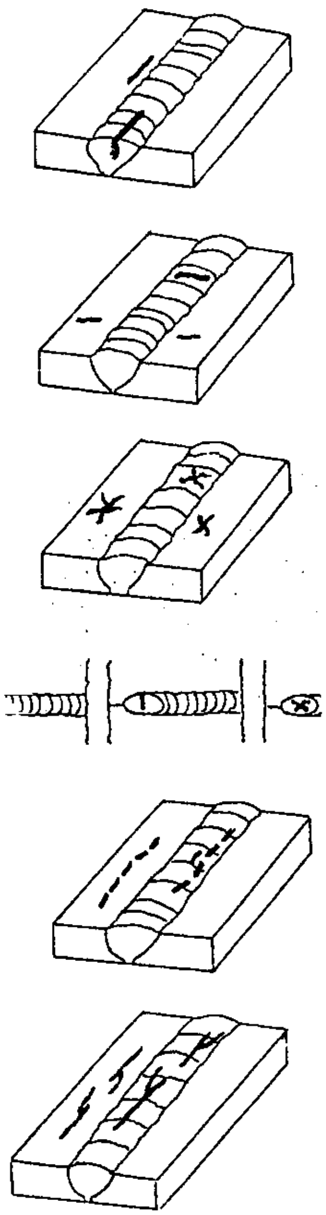
The International Institute of Welding (IIW) and British Standard 499 both group visible defects into six categories, although some non-visible internal weld defects are included for NDT reference. The following definitions originate from BS 499 and IIW.

The six categories of defects are:

1. Cracks
2. Cavities
3. Solid Inclusions
4. Lack of Fusion and Penetration
5. Imperfect Shape
6. Miscellaneous defects not included in groups 1-5.

4.3.4.1. CRACKS

A crack is defined as a linear discontinuity produced by fracture or local rupture. Cracks are the most serious of defects found in underwater inspection. They warrant thorough investigation as a visually detected crack is usually already at an advanced stage. Most cracks detected underwater are longitudinal, located along a weld toe or branching into the heat affected zone.



TYPE	DESCRIPTION	LOCATION
LONGITUDINAL	Parallel to the weld axis	Weld metal Weld junction Parent metal HAZ
TRANSVERSE	Transverse to the weld axis	Weld metal HAZ Parent metal
RADIATING	Radiating from a common point called 'star' cracks	Weld metal HAZ
CRATER	May be longitudinal, transverse, or radiating	End of crater of bead pass
GROUP OF DISCONNECTED		Weld metal HAZ Parent metal
BRANCHING	A group of connected cracks originating from a common crack	Weld metal HAZ Parent metal

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The most common cracking faults are as follows:

(a) <u>**Solidification Cracking**</u>

Often referred to as hot cracking or centre line cracking, weld metal cracks of this type may be longitudinal, transverse, crater or hairline. The most usual type is a longitudinal crack through the centreline. The main factors controlling susceptibility are:

Restraint
Weld shape
Material composition

Restraint produces residual stresses the exact value of which varies according to the arrangement and bulk of the surrounding material. The imposition of excessive transverse strains may result in cracking.

Weld Shape - welds with a large depth-to-width ratio (greater then 2:1) are susceptible to centre line cracking. This is most likely to occur when using a deep penetration process such as high current CO_2 process and submerged arc.

Material Composition - non-metallic impurities may produce low melting point constituents between the solidifying crystals of metal which under contraction stresses may rupture to form cracks. The most common element producing this effect is sulphur, S, which forms low melting FeS films on the grain boundaries. The problem is aggravated by increase in carbon content.

(b) <u>Heat Affected Zone Hydrogen Induced Cracking</u>

Often referred to as heat affected zone cracking, hydrogen cracking, cold cracking or toe cracking.

Such cracks frequently occur in or near the HAZ in the region of ambient temperature.

If the cooling rate associated with welding is too rapid, excessive hardening may occur in the heat affected zone. This alone may create problems but in addition if hydrogen is present above a certain critical value, the hardened zone may crack spontaneously under the influence of residual stress after the weld has cooled to near ambient temperature. Often, the cracks form 1-4 days after completion of the welding. Important factors are:

- the diffusion of hydrogen from the weld metal into the hardened heat affected zones. The hydrogen may come from moisture in or on the welding consumables or on the joint faces. The greater the amounts of hydrogen absorbed the greater the likelihood of cracking occurring.

- the magnitude and distribution of residual stresses caused by the welding operation. The higher the residual stress the greater the likelihood of cracking occurring. The probability of cracking increases with increase in section thickness.

- the presence of a susceptible microstructure. In general, the harder the microstructure the more susceptible to cracking it will be. Both hardenability and susceptibility are increased by increase in carbon content.

(c) <u>Lamellar Tearing</u>

Cracking can occur in either the parent plate or heat affected zone and generally propagation occurs parallel to the plate surface. Cracks of this sort display a characteristic step formation.

In certain types of joint, when the restraint is high and stresses build up during the welding process, lamellar tearing becomes likely in susceptible plate material. Susceptibility depends on the presence of non-metallic inclusions distributed parallel to the plate surface. These inclusions reduce the through - thickness ductility of the steel. The susceptibility of steel to this type of defect increases with increase in plate thickness due to the higher level of restraining forces involved.

4.3.4.2 CAVITIES

A cavity is a void, pocket, or pore formed by gas entrapped during the solidification of molten metal. Weld face indications of this defect are usually repaired at the construction stage. Underwater inspectors should be careful not to confuse porosity (a group of gas pores essentially spherical in form) with corrosion pitting.

Blowhole

A large cavity in the weld (generally over 1.5mm in diameter) formed due to gas being trapped.

Typical causes - moisture or contamination on parent or filler metal.

Wormhole

Elongated or tubular cavities formed by entrapped gas during the solidification of the weld metal. The elongated pores often appear as a 'herring bone' array on a radiograph.

Typical causes - gas may come from surface contamination or from crevices formed by the joint geometry.

Gas Pore

A cavity, generally under 1.5mm in diameter, formed by entrapped gas during the solidification of molten metal.

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Uniform Porosity

Porosity (a group of gas pores) distributed in a substantially uniform manner throughout a weld.

Typical causes - damp fluxes, air entrainment in gas shield, hydrocarbon contamination of parent metal or filler.

Restart Porosity (Localised Porosity)

Porosity confined to a small area of weld, usually occurring in manual or automatic arc welding at the start of a weld run.

Typical causes - unstable arc conditions at weld start coupled with poor manipulative technique.

Surface Porosity

Gas pores which break the surface of a weld.

Typical cause - excessive contamination from grease, dampness, or atmosphere entrainment. Occasionally caused by excessive sulphur in consumable or parent metal.

Crater Pipe

A depression due to shrinkage at the end of a run where the source of heat was removed.

Typical cause - incorrect manipulative technique or current decay to allow for crater shrinkage.

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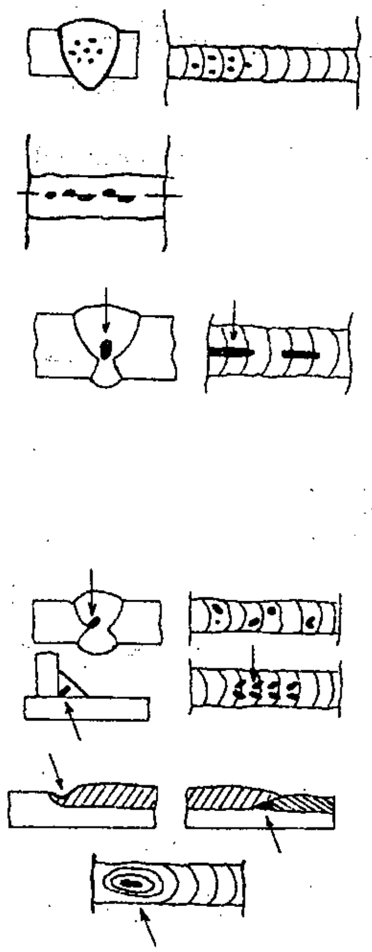


TYPE	DESCRIPTION	LOCATION
BLOWHOLE	Over 1.5mm in diameter	Weld metal
LOCALISED POROSITY	Cluster of gas pores	Weld metal
LINEAR POROSITY	Line of gas pores parallel to weld	Weld metal
ELONGATED CAVITY	Large non-spherical cavity parallel to weld axis	Weld metal
SHRINKAGE CAVITY	Cavity due to shrinkage during solidification	Weld metal
WORM HOLE	Tubular cavity caused by release of gas	Weld metal
CRATER PIPE	Depression at end of bead run due to heat loss shrinkage	Weld metal

4.3.4.3. SOLID INCLUSIONS

Defined as foreign matter entrapped in the weld metal during welding. This type of defect is normally more irregular in shape than a gas pore.

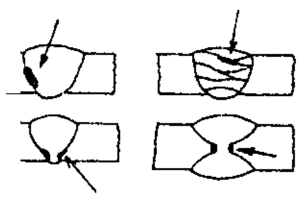
The principle non-metallic inclusions are slag, flux and oxides. Metallic inclusions include tungsten from TIG electrodes and copper from the MIG contact tube or nozzle.

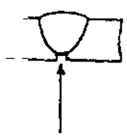
Typical causes - unclean parent metal or filler, slag not cleaned from preceding runs, loss of slag control because of poor manipulative technique.

TYPE	DESCRIPTION	LOCATION
INCLUSIONS	May be linear or isolated depending upon the circumstances of formation	Weld metal

4.3.4.4 LACK OF FUSION AND PENETRATION

Lack of fusion in a weld occurs between weld metal and parent metal, or between parent metal, or between weld metal and weld metal. More specifically it may occur in the side wall of a weld, or between multi-runs of a weld, or at the root of a joint. Lack of penetration is a more severe lack of root fusion where weld metal fails to extend into the root of a joint at all. Both defects are due to faulty technique (heat input too low, too rapid travel with electrode) poor preparation of the joint in the case of lack of root fusion. These are not visible defects in a completed weld, although overlap, sometimes called cold lap (imperfect shape), is visible when excessive weld metal in the cap fails to fuse with the parent metal.





TYPE	DESCRIPTION	LOCATION
LACK OF FUSION	Failure of Union in: - weld metal to weld metal - parent metal to weld metal - parent metal to parent metal	Side wall between runs root
LACK OF PENETRATION	Failure of weld metal to extend into root	Root of joint

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4.3.4.5 IMPERFECT SHAPE

This group of defects is defined as imperfect shape of the external surfaces of the weld or defective joint geometry. External surfaces of the weld include the root as well as the weld face or cap. Two of these defects, undercut and excess weld metal are often detected underwater, although the more serious cases are usually repaired before installation of the structure. In poor visibility conditions, the underwater inspector should be careful not to confuse slage inclusion in the weld toe with the more serious undercut defect.

Undercut

A groove or hollow melted into the parent metal surface or fusion face at the toe of a weld, and left unfilled by weld metal.

Typical cause - poor welding technique (travel speed too slow, excessive weaving), too high a welding current.

Overlap

An imperfection at the toe or root of a weld caused by metal flowing on to the surface of the parent metal without fusion to it.

Typical cause - poor manipulative technique, inadequate heat input at toes (current and voltage too low).

Excess Weld Metal

Also referred to as excessive reinforcement. As the title infers this is due to excessive thickness at the throat of the weld due to the deposition of too much weld metal.

Typical cause - inadequate weld preparation, excess arc energy producing surplus weld metal, incorrect selection of electrode size (too large).

Excessive Penetration

Excessive weld metal protruding through the root of a joint welded from one side only.

Typical cause - unsuitable edge preparation, weld energy input too high, electrode travel too slow.

Root Concavity

A shallow groove which may occur at the root of a butt weld caused by contraction (shrinkage) of the weld.

Typical cause - incorrect root preparation, weld energy too low, poor technique.

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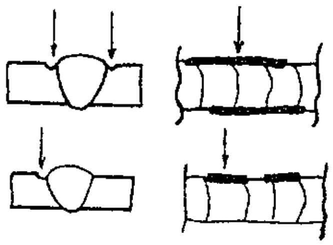
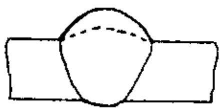
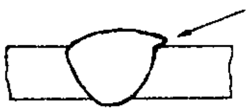
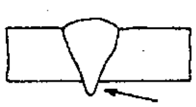
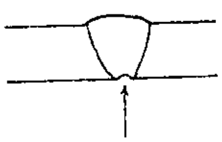
	TYPE	DESCRIPTION	LOCATION
	UNDERCUT	Irregular groove at the toe of a weld run. May be continuous or intermittent	Toe of weld face runs, usually in weld metal to parent.
	EXCESS WELD METAL	Also called excessive convexity - an excess of weld metal or reinforcement	Face of a fillet or butt weld.
	OVERLAP	Also called cold lap Weld metal flow onto parent without fusing to it	Weld face toe
	EXCESS PENETRATION	Excess metal protruding at the root	Root
	ROOT CONCAVITY	Also called shrinkage groove. A shallow groove caused by contraction of the weld	Root

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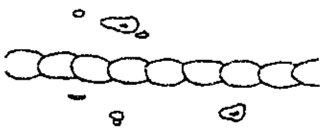
4.3.4.6 MISCELLANEOUS FAULTS

TYPE	DESCRIPTION	LOCATION
 STRAY FLASH	Also called arc strike, results from accidental arc strike away from the weld	Parent metal
 EXCESSIVE DRESSING	Removal of weld metal below surface of parent metal also called under-flushing	Weld face
GRINDING MARK	Local damage due to incorrect grinding	Weld face parent metal
CHIPPING MARK	Identation due to improper use of chipping tool, chisel, hammer blow	Weld face parent metal
SPATTER	Globules of weld metal expelled during welding adheres to surface, may cause surface pitting	Weld face parent metal
 TORN	Surface irregularity due to temporary attachment breakoff	Parent metal

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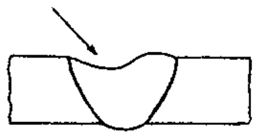

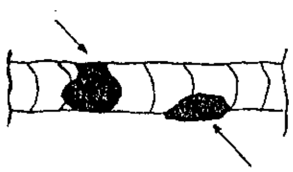

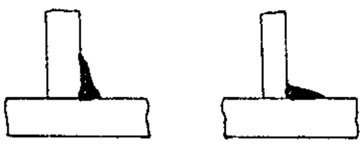

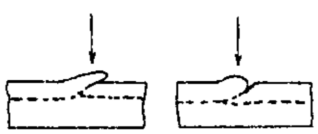

TYPE	DESCRIPTION	LOCATION
INCOMPLETELY FILLED GROOVE	Longitudinal or continuous channel due to insufficient weld metal deposition or collapse due to gravity	Weld face
BURN THROUGH	Localised collapse in weld run due to excessive penetration	Weld face
UNEQUAL LEG LENGTH	Asymmetrical fillet weld, variation of leg length	Weld face
MISALIGNMENT	Non parallel surface planes, or parallel misalignment of surface planes	
POOR RESTART	Local surface irregularity at weld restart	Weld face

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A large number of weld defects have been listed in order to introduce the underwater inspector to the more common flaws and to build a standard vocabulary of welding terminology. What is most important in weld defect identification is that the defect is correctly and accurately assessed and described. Many factors may obscure the inspection site such as lack of proper lighting, restricted access etc. If there is any doubt with specific identification, the underwater inspector need only clearly describe the defect leaving specific identification to the Inspection Controller or client engineer.

A NOTE ON INTERNAL DEFECTS:

CSWIP candidates should be familiar with the Welding Institute classification of internal weld or material defects as planar and volumetric:

PLANAR defects are essentially flat, located in one plane, and have little volume but a large surface area. These include cracks, lack of fusion, laminations and lamellar tearing.

VOLUMETRIC defects have a comparatively small surface area but a large volume. These include undercut, lack of penetration, cavities, porosity, solid inclusions, burn through, shrinking and blow holes.

4.3.5 DIMENSIONAL MEASUREMENT OF A WELD

The accurate measurement of the various parameters and features of a weld is a very important aspect of weld visual inspection. It is absolutely essential when sizing visible weld defects or the physical dimensions of the weld itself to be as accurate and as precise as possible.

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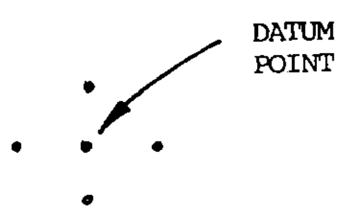
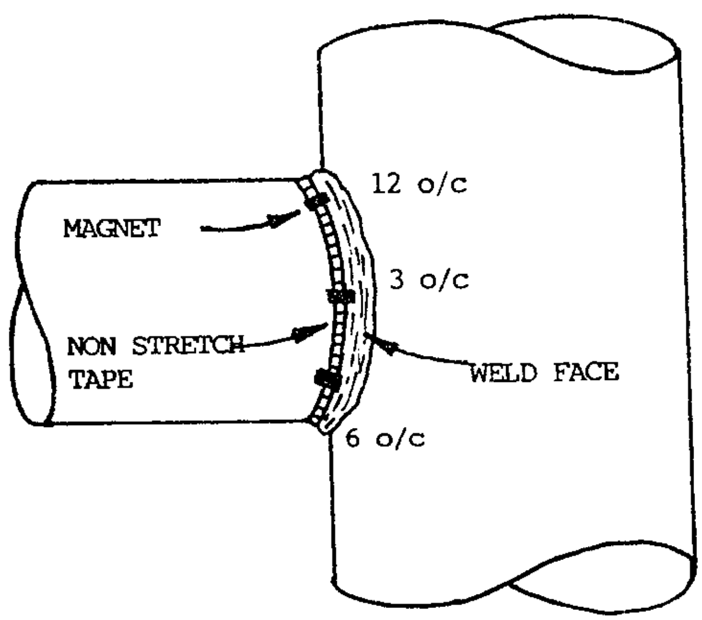
4.3.5.1 **WELD DATUM POINT**

Before any reliable weld measurements can be taken, a local weld datum point must firstly be established. The standard method is to centre punch a datum mark at the 12 O'clock position on the minor brace (member side). Datum marks normally consist of either three punch marks in a straight line perpendicular to the axis of the weld or, five punch marks arranged in a diamond shape pattern.

All position references are then taken with respect to this datum point. Linear measurements are taken from a scaled magnetic tape which is positioned around the member side of the node at a distance of 25mm from the member side toe of the weld, with the tape zero set at the 12 O'clock position and the tape running clockwise.





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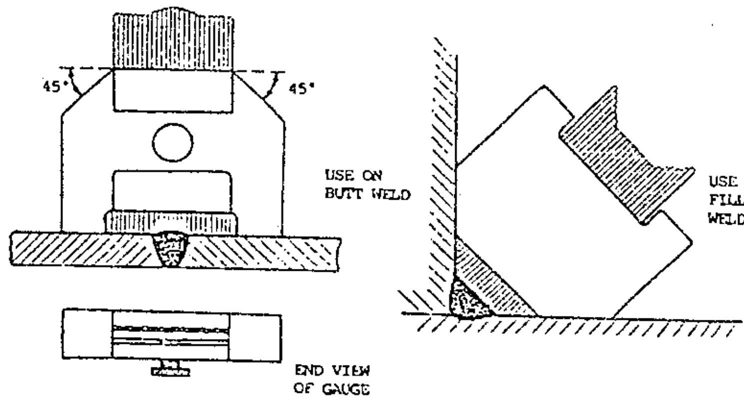
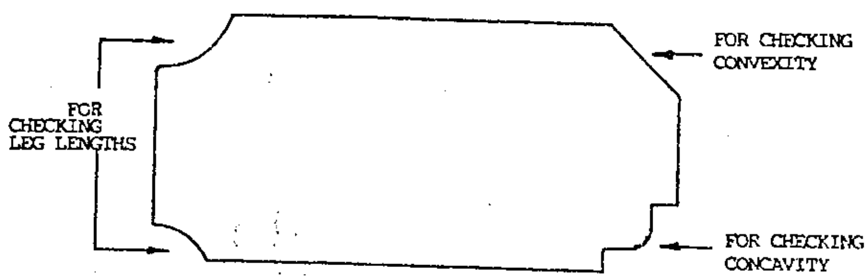
4.3.5.2 WELD DIMENSION CHECKS

Checks of the weld face contour include height of excess (reinforcing) weld metal and the general surface appearance of the weld itself. The profile (contour) gauge is a useful instrument which can be used for this purpose. Moulding compounds such as Epophen or Aquaprint may also be used to obtain a permanent record of an impression of the weld surface.

Weld face width measurement includes checks for leg length, and convexity or concavity. This is accomplished through the use of a fillet weld gauge.





EXAMPLE OF FILLET WELD GAUGE

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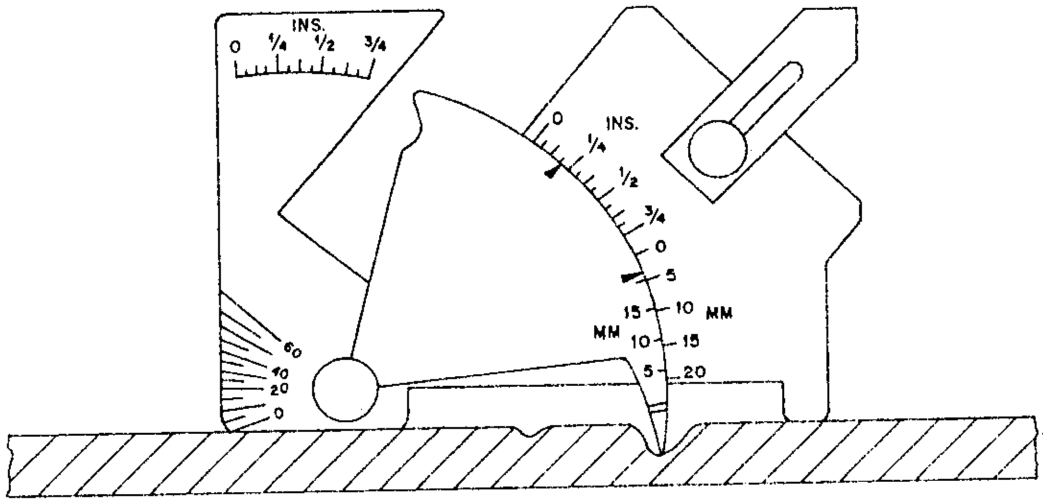
The most common gauges used to measure pit depth are those supplied by the Welding Institute and the Thorpe pipe pit gauge, shown below.

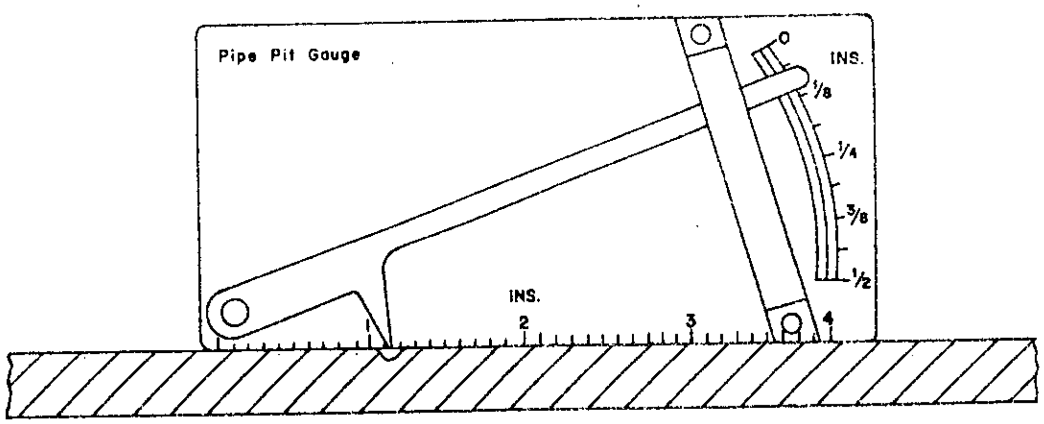
The Welding Institute gauges are favoured because they read in mm, though since they were not designed to read pit depth they are inconvenient to use.

The Thorpe gauge is easy to use, but reads only in inches.

Accurate measurement of welding defects is an important aspect of underwater inspection and is discussed in the section; 'Weld Close Visual Inspection'.



SKETCH SHOWING WELDING INSTITUTE GAUGE MK II



SKETCH OF THORPE PIPE PIT GAUGE

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4.3.6 WELD CLOSE VISUAL INSPECTION (CVI)

Weld inspection normally constitutes a large proportion of an underwater diving inspection programme and is, therefore, of particular importance to the Inspection Controller. Disregarding repairs or remedial work, it is safe to say that weld inspection is the single most crucial aspect of a steel platforms annual workscope.

The precise method of inspection will be dictated by the specific inspection procedure issued by the operator. However, certain aspects of weld inspection are common and rely on the good judgement of the Inspection Controller to concentrate the inspection on the pertinent points of interest rather than reporting the routine physical features of the weld. What is important is to distinguish between potentially serious in-service defects and non-serious fabrication features. Service defects will consist of mainly corrosion, physical damage and, potentially the most serious of all, cracks. Fabrication defects such as poor profile, spatter, arc strikes etc are common but in general should not pose a serious breach to the weld integrity since they have been present since the weld construction and have passed quality checks as being within safe acceptance limits.

The following points should be observed whilst performing weld CVI:

- Entire length of the weld cap, including a strip of parent metal approximately 75mm wide on either side of the cap requires to be cleaned to bright metal finish (Sa 2.5).

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- Datum mark has to be established at the 12 o/c position on the minor member. An approved magnetic tape should then be attached clockwise around the minor member circumference parallel to the weld and at a clear distance of 25mm from the toe. Tape zero should coincide with the punched datum mark at 12o/c. It is useful then to mark the 12, 3, 6, 9 O'Clock positions on the weld and record the appropriate tape positions.

- Visual inspection should then proceed in a logical sequence commencing at the 12 o'clock position on the upper HAZ, proceeding clockwise to the three o'clock position paying particular attention to the toes. This inspection sequence should then be repeated for the remaining three quadrants.

- It is important to keep good communication with the diver at all times reporting precisely and accurately all pertinent defects. Where a defect is found, the following information should be reported:

Type	- accurate assessment/description of defect.
Location	- relative position, HAZ/CAP/TOE and its start position measured from the 12o/c datum mark (mm).
Dimensions	- overall length of defect stating whether it is intermittent or continuous. Where necessary, report depth and width (mm).
Orientation	- for a cracklike defect indicate the orientation of the plane of the defect to the axis of the weld eg. transverse/ longitudinal.
Branching	- State whether defect is branching giving location, length and orientation.

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- Where corrosion is found a full description should be given reporting the following:

Location	-	outer HAZ, outer toe, weld cap, inner toe, inner HAZ giving its start/stop position (mm from 12o/c)
Type	-	general/local
% Coverage	-	estimate the percentage of element affected.
Depth	-	the maximum and average depth of pitting should be recorded using a Welding Institute Pit Gauge or similar.

Depending on the specific weld inspection procedures and the results of the close visual inspection further inspection may be necessary, principally close-up photography and MPI.

4.4 MARINE GROWTH

Marine growth or marine fouling are the common names for marine organisms that attach themselves to submerged surfaces. Since the principle role of the inspection diver is to locate, identify and report defects, the extent to which marine growth conceals structural surface features, components and sub-components from visual inspection is naturally a significant consideration. Removal of marine growth is often the most time consuming and expensive task of an inspection programme.

From the engineering point of view, knowledge of types and dimensional checking of marine growth is necessary to analyse the projected loadings and possible deterioration or failure of offshore structures. The inspection diver and ROV/observer are primarily relied upon for accurate reporting of type, thickness and percentage of overall cover. This information provides the necessary baseline data for an engineering assessment to be made.

4.4.1 TYPES AND DISTRIBUTION

The successive development of marine growth begins with the chance settling of larvae (animals) and spores (plants or algaes) on a structure. Their further development into mature colonies is determined by a number of environmental factors. These include geographical location, time of year, nutrient and oxygen concentration, light levels, depth, temperature and salinity of water. Exposure to currents and wave action, the presence of anti-fouling and corrosion protection systems also play a part.

There are basically two forms of marine growth to be considered from an engineering point of view. These are soft growth, where density is approximately equal to seawater, and hard growth, where density is approximately 1.4 times greater than that of seawater.

The following are the most commonly found soft fouling on offshore structures:

ALGAE	These are plants, often called slime; includes short red and green seaweeds.
SEAWEEDS	Many types of this plant exist, usually brown in colour of which kelp produces the longest fronds.
HYDROIDS	Often mistaken for seaweed, these are animals with a feathery appearance.
SEA SQUIRTS	These are soft bodied animals that usually grow in large colonies.
ANEMONES	These are soft, cylindrical bodied animals with a radial pattern of tentacles; grows in solitary and in colonies.
SPONGE	These are soft animals and will be represented by several different species varying in size and shape.
DEAD MANS FINGERS	Colonial soft coral (animal). Vary in length from 1 to 20 cm and grow in the form of fleshy, finger shaped main bodies. Likewise colour will vary from white, yellow, pink to orange.
BRYOZOA	These tentacled animals resemble moss in appearance and do not grow very tall.

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Hard marine growth is composed of calciferous and shelled organisms. The following are the most commonly found hard fouling on offshore structures:

BARNACLES Grow in dense colonies to a water depth of 15-20 metres and bond strongly to the structure's surface. Larger horse barnacles extend well into the saturation diving range.

MUSSELS This hard shelled mollusc firmly attaches itself to the structure by means of threadlike roots. Grow most densely on the upper surfaces of horizontal members in the 0-20M water depth range.

TUBEWORM CASTS These form distinctive calciferous white patterns on flat surfaces and are most stubborn to remove. Size may vary from a few mm up to 100mm long.

Species are either very densely populated at shallow depth or sparsely populated over the whole depth of the structure. Kelps, algae and mussels dominate the upper regions of the structure.

4.4.2 EFFECTS OF MARINE GROWTH, REASONS FOR REMOVAL

The rate of growth of marine fouling on offshore installations has proved to be greater than anticipated and in some instances has significantly exceeded structural design allowances, especially in tidal locations. The resulting effects are of concern to offshore installation operators and engineers. Therefore, it is important for inspection personnel to be aware of the many ways in which marine growth can affect a structure if it is not removed:

- Obscures important features of the structure and makes visual and NDT inspection difficult or impossible.

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- Increases mass without changing stiffness, increases static load and drag forces, and distorts natural frequency.

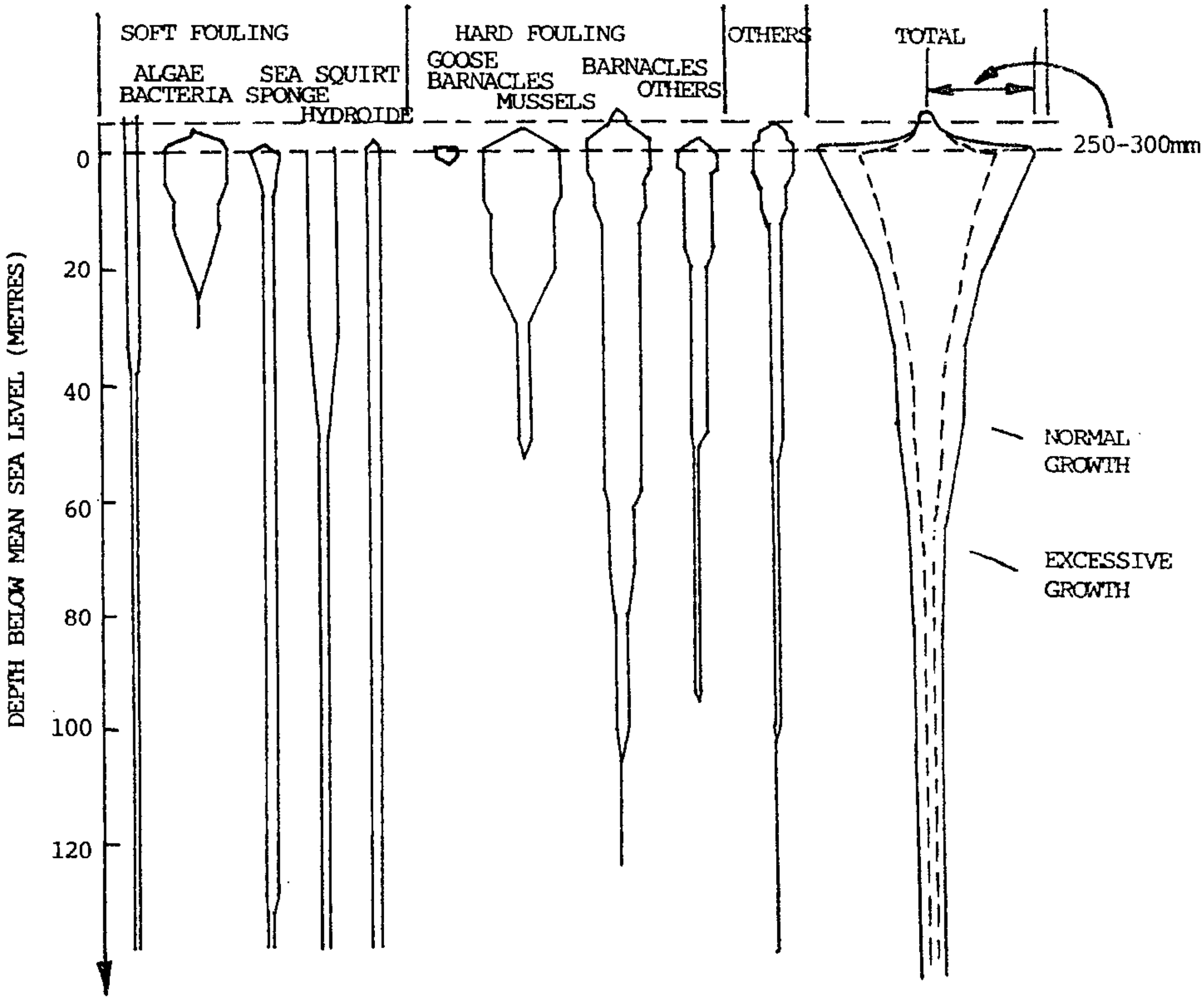
- Increases the "slam effect" in the splash zone which can lead to premature fatigue and stress related cracking (particulary in conductor guide frames).

- Reduces efficiency of systems such as service inlets and outlets, and heat exchangers.

- Accelerates internal corrosion on seawater processing and control equipment used to supply water for fire fighting, cooling, washing down and sanitary requirements.

- May affect the rate at which the structure corrodes.

Removal of marine growth is the only solution presently available which reduces and controls the magnitude of these effects although antifouling cladding is currently under development/test.



SOFT FOULING
HARD FOULING
OTHERS
TOTAL
ALGAE
BACTERIA
SEA SQUIRT
SPONGE
HYDROIDE
GOOSE
BARNACLES
MUSSELS
BARNACLES
OTHERS
250-300mm
DEPTH BELOW MEAN SEA LEVEL (METRES)
0
20
40
60
80
100
120
NORMAL
GROWTH
EXCESSIVE
GROWTH

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5. CORROSION AND CORROSION PROTECTION SYSTEMS

5.1 INTRODUCTION

Corrosion can be defined as the deterioration of a metal due to an electrochemical reaction with its environment. Before explaining the various methods developed to control and monitor corrosion, it is first necessary to explain the significance of corrosion, and the principles and reactions involved.

5.2 CORROSION AND ITS SIGNIFICANCE

Reduction in metal thickness by the actions of corrosion can have serious engineering implications, leading to a reduction in usable life of a structural component. For example:

- Severe pitting in a pressurised system, eg. risers and pipelines, can result in total or partial loss of pressure.
- In a stressed structure such as an oil production platform, the combination of corrosion, stress and fatigue can be debilitating to the point where structural failure can and does occur.

For these reasons development continues in the control and monitoring of corrosion protection systems.

5.3 BASIC CHEMISTRY OF CORROSION

Corrosion in the presence of sea water is an electrochemical process. This means that electrical current flows during the chemical reaction. In order for current to flow, there must be a driving force or a voltage, normally referred to as a potential difference, and a complete electrical circuit.

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5.3.1 VOLTAGE SOURCE

The source of voltage in the corrosion process is the energy stored in the metal by the refining process. Different metals require different amounts of energy for refining and therefore have different tendencies to corrode.

The magnitude of the driving voltage generated by a metal when it is placed in a water solution, is called the potential of the metal. It is related to the energy that is released when the metal corrodes. Potential values are a function of both the metal and the chemical and physical characteristics of the water.

5.3.2 ELECTRODE POTENTIALS

When a salt such as zinc sulphate is dissolved in water it partially splits up (partially dissociates) into zinc ions having a positive charge and sulphate ions negatively charged, expressed thus:

$$ZnSO_4 \longrightarrow Zn_{(++)} + SO_{4(--)}$$

In this case two units of charge (electrons) are involved, and the charged particles are given the name of ions. If we immerse a piece of zinc in such a solution, the zinc sulphate, containing a definite concentration of ions, we find there is only one electric potential (voltage) at which equilibrium can exist between the metal and the solution. For by dissolving, the zinc tends to form zinc ions until an equilibrium condition is reached between the liquid and the metal. This removal of ions, each with two units of positive charge, leaves the zinc electrode with an excess negative charge, which is characteristic of the metal. The greater the negative potential the greater is the tendency of a metal to dissolve.

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If a suitable scale is chosen the single electrode potential can be expressed in volts. This is frequently done by connecting the zinc electrode to a "hydrogen" electrode, consisting of platinum immersed in a solution of hydrogen ions at unit activity saturated with hydrogen gas a 1 atmosphere pressure.; its potential being taken as zero. In this way metals can be arranged in the order shown in the following table according to their potentials giving a list known as the electro-chemical series.

<u>**Electro-Chemical Series**</u>

Metal	Electrode Potentials (Volts) on normal hydrogen scale
Platinum	+1.20
Silver	+0.80
Copper	+0.35
Hydrogen	0.00
Lead	-0.13
Tin	-0.14
Iron (ferrous)	-0.44
Zinc	-0.77
Aluminium	-1.67
Magnesium	-2.38
Sodium	-2.72

The further two metals are separated from one another in this series, the more powerful is the electric current produced by their contact in the presence of an electrolyte (ie. a solution having good electrical conductivity).

5.3.3 THE ELECTRICAL CIRCUIT

The electrical circuit of the corrosion process consists of three parts:

(1) Anode

The anode is that portion of the metal surface corroding. It is the point at which metal dissolves, or goes into solution. When metal dissolves, the metal atom loses electrons and goes into solution as an ion. Since atoms contain equal numbers of protons (positively charged particles) and electrons (negatively charged particles), the loss of electrons leaves an excess of positive charges, and the resulting ion is positively charged. The chemical reaction for iron is:

$Fe \rightarrow Fe^{2+} + 2e^-$ Iron atom → Iron ion + 2 electrons

This loss of electrons is called oxidation. The iron ion goes into solution and the two electrons are left behind in the metal.

(2) Cathode

The cathode is that portion of the metal surface which does not dissolve, but which is the site of another chemical reaction(s) necessary to the corrosion process. The electrons left behind by the solution of iron at the anode travel through the metal to the cathodic surface area where they are consumed by reaction with ions present in the water. This consumption of electrons is called a reduction reaction.

A typical reaction in an acidic solution is:

$2H^+ + 2e^- \rightarrow H_2$

Hydrogen Ions + Electrons → Hydrogen Gas

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Or, if oxygen is present, two other reactions are also possible:

$$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$$

(Acid solutions)

$$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$$

(Neutral and Alkaline solutions)

Thus, the reactions at the anode produces electrons and the reaction(s) at the cathode consume the electrons. This is the essential feature of an electrochemical reaction. Electrons are generated by a chemical reaction at one point, and travel to another point where they are consumed by another reaction.

Electrical current flow is the passage of electrons from one point to another. Convention says that the electrical current flows in the opposite direction to actual electron travel. Thus, as electrons flow from the anode to the cathode, electrical current flows in the opposite direction, from the cathode to the anode. Do not forget that this current flow is within the metal. Thus, it is assumed that the path between the anode and cathode through metal is an electronic conductor.

(3) **Electrolyte**

In order to support the reactions previously listed and to complete the electrical circuit, the metal surface (both the anode and the cathode) must be covered with an electrically conductive solution. Such a solution is called an electrolyte.

Water is an electrolyte which increases in electrical conductivity as the amount of dissolved salts or ions increase in concentration. The electrolyte conducts current from the anode to the cathode. The current then flows back to the anode through the metal, completing the circuit. This combination of anode, cathode and electrolyte is called a corrosion cell. A schematic of the corrosion process is shown below (Fig 1).

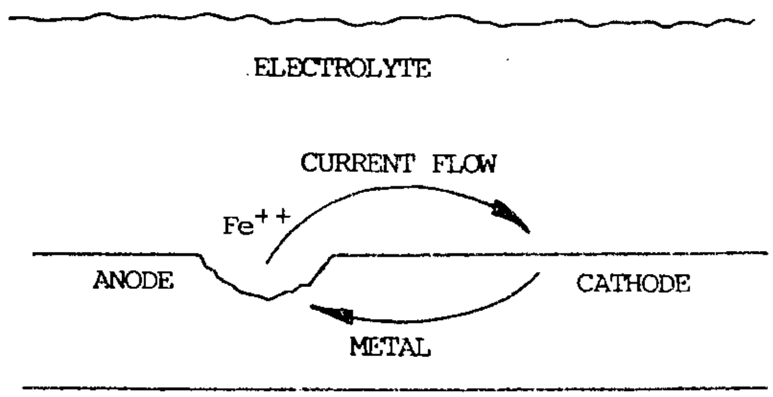

Fig. 1

This sketch is merely an illustration. Metal atoms do not necessarily dissolve at a single point on a metal surface, nor are cathode areas restricted to one area on the surface. In the case of localised corrosion, such as pitting, these processes are limited to localised areas. However, in the case of general corrosion the reactions occur randomly over the metal surface.

At this point one of the key questions in the study of corrosion arises: Why do certain areas of the metal surface act as anodes? The answer is not a simple one. However, in most cases the reason centers on inhomogeneities in the metal surface, in the electrolyte, or both. The type of corrosion which occurs usually gives a clue as to the major cause, and will be explored in more detail in later sections.

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5.3.4 THE NATURE OF METALS

Commercial metals are not homogeneous, but contain inclusions, precipitates, and perhaps several different phases. When the metal is placed in an electrolyte, potential differences exist between these phases, resulting in corrosion cells on the metal surface.

For example, steel is an alloy of iron and carbon. Pure iron is a relatively weak, ductile material. When it is alloyed with small amounts of carbon (usually 0.2 to 1.0 percent), a much stronger material is created. However, as a result of reacting part of the iron with carbon, we now have a metal composed of two materials: pure iron and iron carbide (Fe_3C), the product of the iron-carbon reaction. The iron carbide is distributed within the iron as tiny microscopic islands.

The iron carbide has a lower tendency to corrode than does pure iron. The Fe_3C and the pure iron are in intimate contact (allowing electron flow), so when the steel is placed in water (an electrolyte), the electrical circuit is complete and current flows through thousands of tiny microcells on the steel surface. If it were possible to look through a microscope and concentrate on two adjacent grains of Fe and Fe_3C on the surface of a piece of steel immersed in water, it might look like the sketch below:

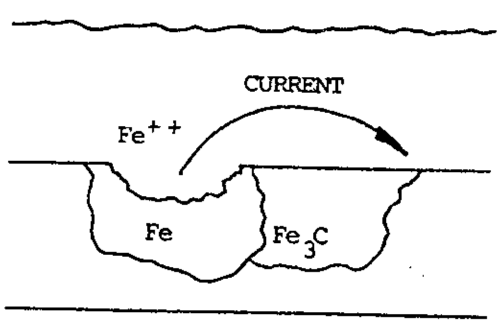

Fig. 2

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Other inhomogeneities in metals are also responsible for corrosion cells. In solid solution alloys, there may be potential differences arising from concentration differences from point to point. This can be pronounced in castings and welds.

Intergranular attack is caused or accelerated by potential differences between the grains and grain boundaries. Local heating can result in changes of the nature of phases or their compositions creating differences in potential.

Thus, metals are inherently inhomogeneous materials, and potential differences on the metal surface are a natural result. These differences are one of the primary causes of corrosion.

5.3.5 THE EFFECT OF ELECTROLYTE COMPOSITION

5.3.5.1 CONDUCTIVITY

The metal surface must be covered by an electrically conductive solution, to conduct the electrical current from the anode to the cathode of the corrosion cell. Hence, the more conductive the electrolyte, the easier current can flow, and if nothing else slows down the corrosion reaction, the faster corrosion will occur. The less conductive the electrolyte, the greater the resistance to current flow and the slower the reaction. It is important to realise that the amount of metal which dissolves is directly proportional to the amount of current which flows between the anode and the cathode. One ampere of current flowing for one year represents a loss of 20 pounds of iron.

For example, distilled water is not very conductive and is not very corrosive. In contrast, salt water is quite conductive and can be very corrosive. Bear in mind that at this point we are talking only about the effect of conductivity. The presence of dissolved gases and the pH of the electrolyte may make a low conductivity electrolyte fairly corrosive. Conversely, a very salty water may be virtually non-corrosive if it contains no dissolved gases and has an alkaline pH.

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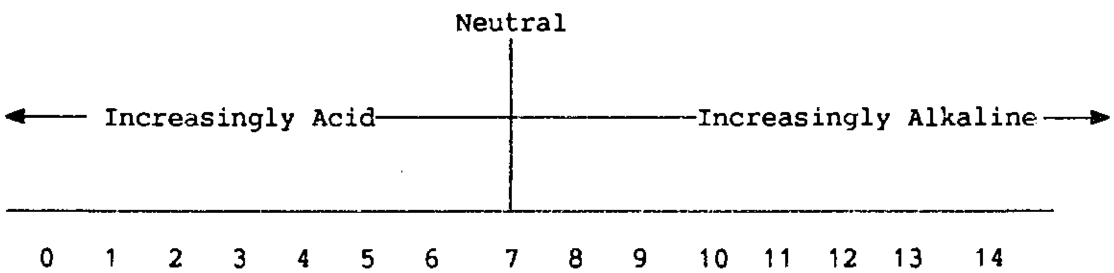
The importance of conductivity is its effect on the ease of transporting current from the anode to the cathode. The more conductive the electrolyte, the less driving force is necessary to make the corrosion reaction proceed if all other conditions remain constant.

5.3.5.2 pH

The pH of a water is a measure of the degree of acidity or alkalinity of a water. It is commonly expressed as a number between 0 and 14 and is the negative logarithm of the hydrogen ion concentration.

$$pH = -\log(H^+)$$

The greater the concentration of hydrogen ions, the more acid the solution and the lower the pH value. Just as a thermometer measures heat intensity, the magnitude of the pH indicates the intensity of the acidity or alkalinity.



The midpoint of the pH scale is 7; a solution with this pH is neutral. Numbers below 7 denote acidity; those above alkalinity. Since pH is a logarithmic function, solutions having a pH of 6.0, 5.0, and 4.0 are 10, 100 and 1000 times more acid than one with a pH of 7.0. Just remember that hydrogen ions (H^+) make a solution acid and therefore force the pH toward zero. Hydroxyl ions (OH^-) make a solution basic or alkaline and push the pH upward.

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The corrosion rate of steel usually increases as the pH of the water decreases (becomes more acidic), although extremely high pH solutions can also be corrosive. The general variation of the corrosion rate of steel with pH value is shown below (Fig 3).

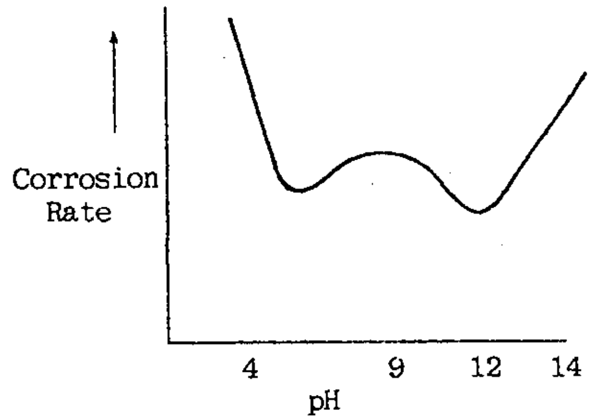

Fig. 3

The actual variation of corrosion rate with pH is obviously dependent on the composition of the water or electrolyte. In many oilfield waters protective scales such as iron hydroxide or carbonate scales may form on the steel surface and prevent or slow down further corrosion.

5.3.6 DISSOLVED GASES

Oxygen, carbon dioxide, or hydrogen sulphide dissolved in water drastically increases its corrosivity. In fact, dissolved gases are the primary cause of most corrosion problems. If they could be excluded and the water maintained at a neutral pH or higher, most oilfield waters would have very few corrosion problems.

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5.3.6.1 DISSOLVED OXYGEN

Of the three dissolved gases mentioned, oxygen is by far the worst of the group. It can cause severe corrosion at very low concentrations (less than 100 ppm), and if either or both of the other two gases are present, it drastically increases their corrosivity.

The solubility of oxygen in water is a function of pressure, temperature, and the chloride content. Oxygen is less soluble in salt water than in fresh water.

Mechanism of Oxygen Corrosion

Anode Reaction $Fe \rightarrow Fe^{++} + 2e^-$

Cathode Reaction $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

or, combining the two:

$$4Fe + 6H_2O + 3O_2 \rightarrow 4Fe(OH)_3$$

Iron, Water, Oxygen → Ferric Hydroxide

Oxygen accelerates corrosion drastically under most circumstances. It does this in two ways. First, it acts as a "depolariser". This means that it will easily combine with electrons at the cathode and allow the corrosion reaction to proceed at a rate limited primarily by the rate oxygen can diffuse to the cathode. Without oxygen, the energy it takes to evolve hydrogen gas from the cathode is a major bottleneck in the corrosion reaction and keeps it slowed down. When oxygen is present, it consumes electrons at the cathode surface and allows the reaction to speed up.

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Concentration cells, or differential aeration cells, can cause preferential attack or pitting. Any time there is a difference in the oxygen content of water in two areas of a system, attack will take place preferentially in the area exposed to the lowest oxygen concentration. Typical examples are water-air interfaces, and crevices.

5.3.6.2 DISSOLVED CARBON DIOXIDE

When carbon dioxide dissolves in water it forms carbonic acid, decreases the pH of the water and increases its corrosivity. It is not as corrosive as oxygen, but usually results in pitting.

CO_2	+	H_2O	--->	H_2CO_3
Carbon Dioxide	+	Water	--->	Carbonic Acid
Fe	+	H_2CO_3	--->	$FeCO_3$
Iron	+	Carbonic Acid	--->	Iron carbonate Corrosion product

5.3.6.3 DISSOLVED HYDROGEN SULPHIDE

Hydrogen sulphide is very soluble in water, and when dissolved, behaves as a weak acid, and usually causes pitting.

The combination of H_2S and CO_2 is more aggressive than H_2S alone and is frequently found in oilfield environments. Once again, the presence of even minute quantities of oxygen can be disastrous.

The general corrosion reaction can be simply, though not completely, stated as follows:

H_2S	+	Fe	+	H_2O	--->	Fe_xS_y	+	2H
Hydrogen Sulphide	+	Iron	+	Water	--->	Iron Sulphide	+	Hydrogen

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Though iron is used in this example, other metals react in essentially the same manner to produce metallic sulphides. The iron sulphide produced by this reaction generally adheres to the steel surfaces as a black powder or scale. The scale tends to cause a local acceleration of corrosion because the iron sulphide is cathodic to the steel and usually results in deep pitting.

It should be pointed out that hydrogen sulphide can also be generated by micro-organisms. In oil and gas production, the primary source of problems is Desulfovibrio Desulfuricans, commonly known as sulphate reducing bacteria. These bacteria utilise hydrogen produced by the corrosion reaction and reduce any sulphate present in the water to H_2S. Both hydrogen utilisation and H_2S formation cause increased corrosion rates.

5.4 FORMS OF CORROSION COMMONLY FOUND ON OFFSHORE STRUCTURES

5.4.1 GALVANIC CORROSION

When two dissimilar metals are in electrical contact in an electrolyte, the most electronegative (active) metal will become anodic to the other and will corrode to a greater degree than if it were exposed alone.

5.4.2 CONCENTRATION CELL CORROSION

Theoretically there are many causes of pitting in metals and alloys. All centre around localised differences in the metal or in the electrolyte in contact with the metal. Localised differences in electrolyte composition are generally referred to as concentration cells. Depending on the particular situation, concentration cells may be referred to as differential aeration cells, metal-ion cells, deposit attack or crevice corrosion, to name a few.

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5.4.3 CREVICE CORROSION

Crevices promote the formation of concentration cells. This is especially serious in oxygenated systems where the oxygen in the crevice may be consumed more rapidly than fresh oxygen can diffuse into the crevice. This causes the pH in the crevice to decrease, resulting in a more acidic environment, which accelerates corrosion (Fig 4).

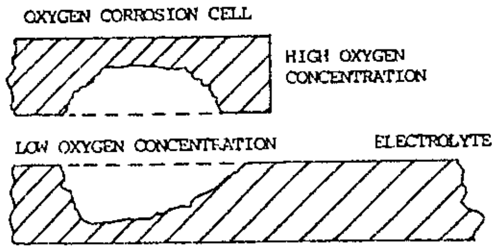

Fig. 4

Low O_2 decreases pH thus increasing corrosion rate

In a chemical system, variations in the concentration of dissolved chemicals represents a non-equilibrium state, and diffusion or other processes attempt to restore the balance. As an example, within a crevice some metal will dissolve and go into a solution as metallic ions. Remote from the crevice, the relative amounts in solution will result in a lower concentration outside the crevice than within. The metal just outside the crevice will try and reduce this inbalance and will begin to go into solution at a more rapid rate, ie. the metal outside the crevice will be anodic to the metal within the crevice. If the solution is in motion, the metallic ions will be carried away as it dissolves, preventing equilibrium and enhancing the corrosive attack. Rivet lap joints are typical areas in which metal ion concentrations may form, as shown. Since a crevice is often formed it is sometimes referred to as crevice corrosion.

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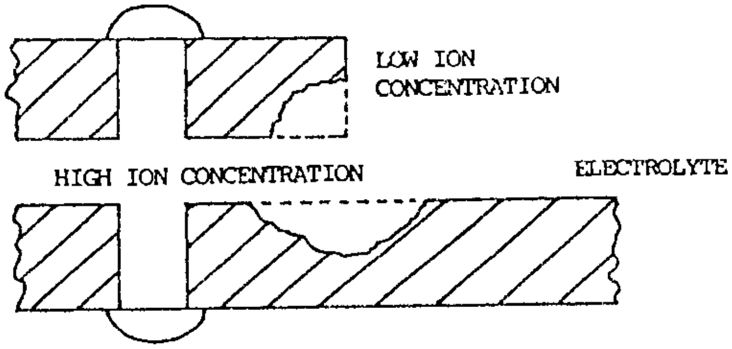


Fig. 5

Metal Ion Concentration Cell

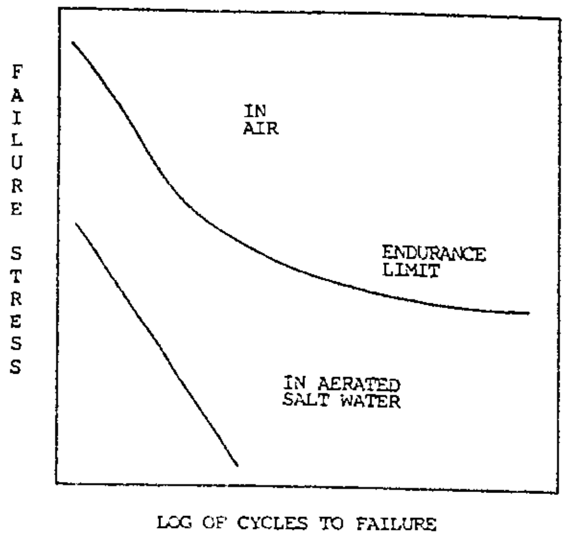
5.4.4 **CORROSION FATIGUE**

Metal fatigue is the cause of many costly failures in offshore structures. Most of these failures occur in corrosive media such as salt water and are therefore more correctly described as corrosion fatigue failures.

Fatigue of Metals in Air

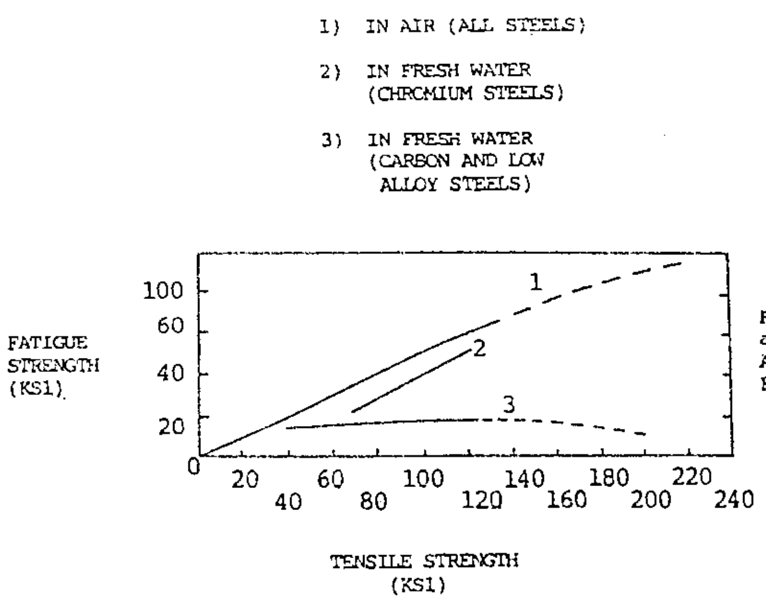
When ferrous metals are repeatedly stressed in a cyclic manner in air, they will fail at stresses far below the yield or tensile strength. There is, however, a limiting stress below which the material may be cyclically stressed indefinitely without failure. This stress is called the endurance limit and is always lower than the yield and tensile strengths. The performance of materials subjected to cyclic stressing is normally described by plotting the stress at failure against the logarithm of the number of cycles to failure for a series of stress levels. This type of plot is known as an S-N curve (Fig. 6).

The endurance limit for ferrous metals is usually 40% to 60% of the tensile strength, depending on the micro-structure and heat treatment (Fig. 7).



Typical S-N Curves for Steel in Air and in Aerated Salt Water.

Fig. 6



Relationship Between Fatigue Strength and Tensile Strength for Carbon, Low Alloy and Cromium Steels in Air and in Fresh Water.

Fig. 7

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Fatigue cracks usually start at the metal surface and the fatigue performance of any item is drastically affected by surface conditions. Notches or metal inhomogeneities such as inclusions or porosity act as stress raisers and the actual stress at the root of a notch may be many times the nominal applied stress.

Fatigue performance is also influenced by the stress history to which the part in question has been subjected. Prior cyclic stressing at a high stress reduces the fatigue life of a part subsequently cycled at a lower stress, when both stresses are above the endurance limit. Little or no fatigue damage may result from cyclic pre-stressing at low stresses. In fact, the fatigue performance is sometimes increased by a procedure known as coaxing, where the specimen is subjected to a series of stress cycles at successively increasing stress levels starting at some stress below the endurance limit.

<u>Corrosion Fatigue - The Effect of a Corrosive Environment on Fatigue Life</u>

The fatigue life of a metal is substantially reduced when the metal is cyclically stressed in a corrosive environment. The simultaneous occurrence of cyclic stress and corrosion is called corrosion fatigue. The presence of the corrosive media augments the fatigue mechanism and hastens failure. The critical characteristic of corrosion fatigue is that the metal no longer exhibits an endurance limit. Corrosion fatigue performance is normally characterised by the "fatigue limit" which is an arbitrarily defined quantity.
The corrosion fatigue limit is commonly defined as the maximum value of stress at which failure no longer occurs after 10^6 cycles.

In corrosion fatigue the corrosivity of the environment is extremely important. The presence of dissolved gases such as H_2S, CO_2 or oxygen causes a pronounced increase in corrosivity resulting in decreased corrosion fatigue life (Fig. 8). A pitting or localised attack is most damaging from the standpoint of corrosion fatigue, but even slight general corrosion will substantially reduce fatigue life.

The corrosion fatigue performance of carbon and low alloy steels is independent of strength. This has been shown both for aerated fresh water (Fig. 7) and for brine containing H_2S, CO_2, air, or some combination. Hence, heat treatment and alloying are most important as related to corrosion resistance rather than to physical properties. Stress history and surface conditions are just as important in corrosion fatigue as in air fatigue performance. Notches also remain critical. It must be realised that the frequency of the applied stress and therefore the time available for corrosion damage is extremely important in the corrosion fatigue behaviour of materials. Tests which are run at high cycle speeds may show little deviation from air fatigue performance over a wide portion of the S-N curve.

In contrast the same test repeated at a very slow cycle speed will show a significantly smaller number of cycles to failure for any given stress. Therefore, cycle speed must be considered as a major variable in corrosion fatigue performance.

CORROSION FATIGUE OF STEEL IN BRINE

DISSOLVED GAS	% DECREASE FROM AIR ENDURANCE LIMIT
H_2S	20%
CO_2	41%
CO_2+AIR	41%
H_2S+AIR	48%
H_2S+CO_2	62%
AIR	65%

Effect of Dissolved Gas Composition on Corrosion Fatigue Performance of Steel in Salt Water.

Fig. 8

5.4.5 STRESS CORROSION CRACKING

Stress corrosion cracking is an interaction between chemical and mechanical forces that results in a failure that otherwise would not occur. It is caused by the "synergistic" action of a corrosive and applied tensile stress; that is, the combined effect of the two is greater than the sum of the single effects. In the absence of stress, the particular alloy would not corrode, and in the absence of the corrodent, the alloy could easily support the stress. The result of the combined effect is a brittle failure of a normally ductile metal.

The stress leading to stress corrosion cracking is always a tensile stress. It can be either applied or residual. Frequently, residual stresses are more dangerous because they may not be considered in evaluating the overall stresses. When a metal suffers stress corrosion cracking, metal loss from corrosion is generally very low, although pitting is frequently observed. In many cases, pitting precedes cracking, with stress corrosion cracks developing from the base of the pits. The cracking may be either intergranular or transgranular but is always in the direction perpendicular to the highest stresses. Sometimes crack growth will relieve stresses and change the direction of the highest stresses. The cracks will not be straight, but will continue at right angles to the highest stresses.

5.4.6 INTERGRANULAR CORROSION

As the name implies, intergranular corrosion is preferential attack of a metal's grain boundaries (See Fig 9). (Intergranular corrosion is often confused with stress corrosion cracking. However, intergranular corrosion can occur in the absence of stress; stress corrosion cracking occurs only while the metal is under stress). Intergranular corrosion has been experienced in many alloys including austenitic stainless steels, copper alloys, aluminium alloys, and nickel alloys.

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In most cases, cracking results from a metallurgical structure that causes the grain boundaries to be more susceptible to attack than the grains themselves. Proper heat treatment generally can eliminate the grain boundary constituents which render the alloy resistant to intergranular attack.

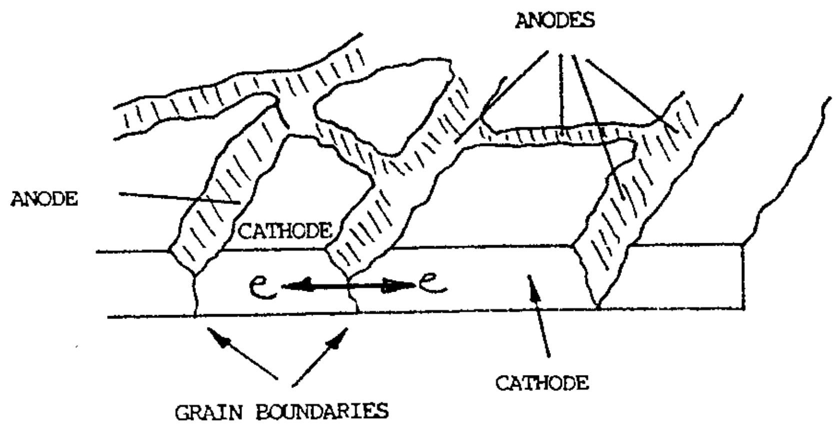

Fig. 9

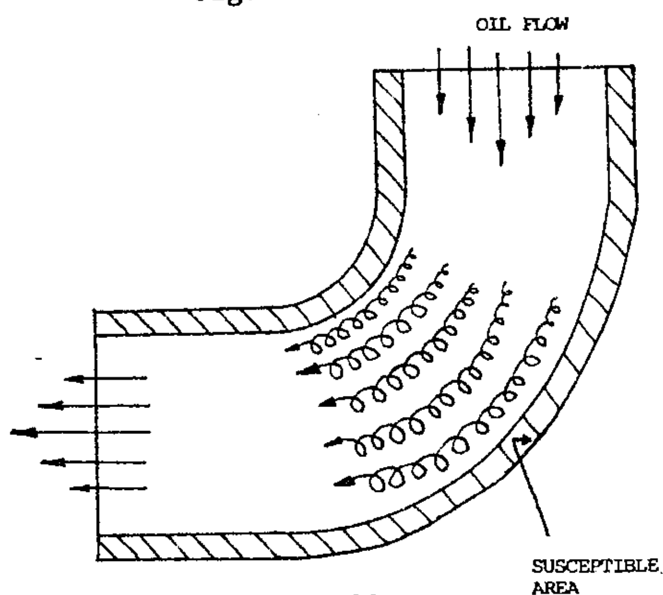

Fig. 10

The turbulence, the abrasives and corrosiveness of the crude oil flow can lead to a thinning of the pipe wall

5.4.7 EROSION CORROSION AND IMPINGEMENT

Since most metals owe their corrosion resistance to the formation and maintenance of a protective corrosion scale, removal of this scale at local areas can lead to accelerated attack. High velocity flow or turbulence will frequently erode away the protective scale and expose fresh metal to be corroded. This combination of erosion of the scale and corrosion of the underlying metal is termed erosion-corrosion. Carbon and low-alloy steels are particularly susceptible in environments which form scales that are easily removed, such as iron carbonate. The attack normally occurs only at certain areas, such as changes of sections or connections where there is turbulence from flow or at bends and elbows (See Fig 10).

A phenomenon similar to erosion-corrosion but even more localised, is known as impingement. This occurs when a stream impinges upon a metal's surface and breaks down protective films at very small areas. The resulting attack is in the form of pits that are characteristically elongated and undercut on the down-stream end. Impingement often results from turbulence surrounding small particles adhering to a metal's surface.

5.4.8 FRETTING CORROSION

FRETTING corrosion is similar to erosion in that wall thickness is reduced - but from the outside in this case. The wearing away of metal occurs when two surfaces rub against each other. Corrosion is accelerated when any corrosion film formed is worn away exposing fresh metal to seawater (See Fig 11).

The most common locations for fretting corrosion are in areas where debris is in contact with the structure, ie. wire rope abrasions, and areas of relative movement, ie. clamp/riser fretting.

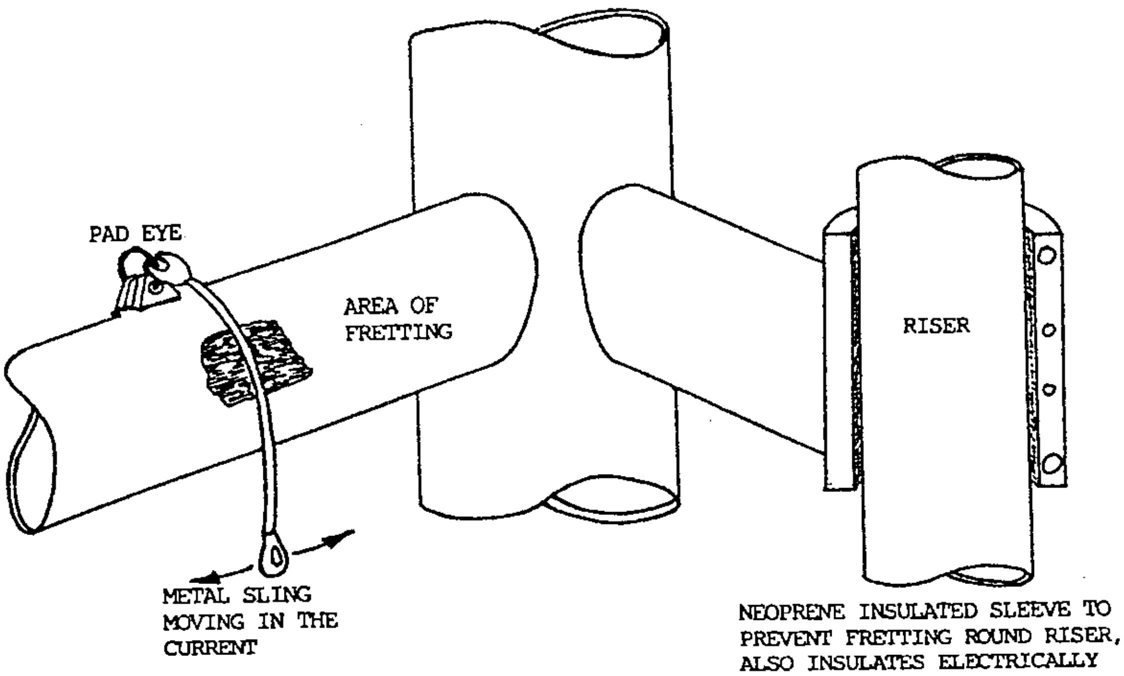

Fig. 11

5.4.9 BIOLOGICAL CORROSION

BIOLOGICAL corrosion is generally less significant in open sea conditions than those mechanisms already discussed.

Marine growth may affect the rate at which the structure corrodes. This effect is currently under study as some evidence indicates marine fouling may inhibit general corrosion. But specific types of corrosion in the presence of marine growth are detected in open water structures.

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For example, underneath areas of heavy marine fouling oxygen concentration may be produced (particularly under shell fish) causing oxygen concentration cell reactions. Fretting corrosion is sometimes detected where hard shelled organisms move about. Also, when marine organisms die, bacteria are produced which can result in direct chemical attack on metal or concrete. The underwater inspector is often instructed to remove a small area of marine growth to assess the surface condition of coating or bare metal if present. The presence of black deposits may indicate biological corrosion as described above.

Note: Black deposits of iron oxide are also very common and only detailed analysis can confirm the presence of the more corrosive sulphide content in the deposit.

5.4.10 GENERAL AND PITTING CORROSION

Pitting occurs when the metal undergoing corrosion suffers metal loss at localised areas rather than over the entire surface and the entire driving force of the corrosion reaction is concentrated at these localised areas. The corrosion rate at the areas undergoing attack will be many times greater than the average corrosion rate over the entire surface. The pits that result may be large and shallow or narrow and deep. A measure of pitting severity is the ratio of the deepest metal penetration at the local areas to the average metal penetration calculated by the overall weight loss. It is obvious that pitting can be much more damaging than general corrosion because the pitted area can become penetrated in a relatively short time. Strict dimensional checks rather than estimates, are necessary in order to obtain qualitative data. Divers pit gauge measurements can only be considered to be estimates. True dimensional checks utilise permanent recording methods such as casting and stereo photographs for photogrammetric analysis.

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Fig. 12

Uniform corrosion occurs as the metal surface corrodes and thins relatively evenly (see fig 13). It may be described as general corrosion when the entire member corrodes evenly, or localised when general corrosion takes place in patches (fig 12).

Fig. 13

Corrosion deposits generally appear black, red/brown or orange (note: some marine growth resembles rust). After reporting the percentage and colour of deposit, an affected area should be thoroughly wire brushed to determine the severity of attack and particularly whether any pits are present. Further deterioration is monitored and useful lifespan predicted by regular wall thickness measurements.

A note on two factors affecting the rate of corrosion:

1. <u>TEMPERATURE</u> differences and cycling increase corrosion rates. Therefore hot risers and cooling water caisson exits may corrode more rapidly than the rest of the structure.

2. <u>INCREASED WATER FLOW RATE</u> generally increases the corrosion rate. Pipes carrying seawater at different velocities and structures in fast moving tides and currents may corrode more quickly than expected.

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5.5 CORROSION PROTECTION

The theory of corrosion protection can be complex and can appear to be contradictory. Conventional current and electron flow direction are opposites in the USA and Europe. As a result, a confusing picture of cathodic protection can be presented, depending on the books and papers that are read.

From the outset, it would be best to state the conventions that this section will follow:-

1. The anode is +Ve and in comparison to the metal it is trying to protect is the more electronegative or base metal in the galvanic series.
2. The cathode is -Ve and is the least electronegative or more noble metal.
3. Electron flow passes from the anode to the cathode through the metal.
4. Current flow is opposite to electron flow, ie. from -Ve to +Ve, through the metal.

So, what is cathodic protection and how does it work?

Oil production platforms, pipelines, ship's hulls, etc. are constructed, generally, from ferritic steels. As has been explained, steel, when placed in an electrolyte, will begin to corrode. It will corrode because of a chemical reaction with the electrolyte and because portions of the steel are more electronegative than others. This imbalance in potential, combined with the chemical reaction generates a combined electrochemical reaction that results in depletion of the anodic areas.

The electrons flowing into the cathode from the anode have the effect of saturating this section with negatively charged electrons. This prevents the iron atoms in the cathode from splitting into ions and electrons, therefore no depletion takes place.

The purpose of cathodic protection is to prevent any depletion of the steel taking place; in effect to make it one giant cathode.

All that is needed is to introduce a metal that is more electronegative than steel into the system. Exactly the same reaction takes place, but this time all of the steel is injected with electrons and is therefore protected.

5.5.1 METHODS OF CORROSION PROTECTION EMPLOYED ON OFFSHORE STRUCTURES

There are two means of supplying the necessary cathodic protection current which are sufficiently different to merit separate discussion:

1. Galvanic (sacrificial) anodes, coupled directly to the structure to be protected, and
2. Impressed current anodes, which are relatively inert and require an external D.C. power source to force current to flow.

5.5.2 SACRIFICIAL ANODES

The galvanic reaction that exists between two dissimilar metals in electrical contact surrounded by an electrolyte must be understood. Referring to figure 14, two metals, zinc and steel, are in electrical contact sitting in seawater.

Because zinc has the greater electronegative potential, it will dissolve into solution at a greater rate than the iron. The electrons generated by the reaction are free to migrate through the metal towards the iron which, as a result, becomes increasingly negative. Zinc ions are conducted away from the zinc by the electrolyte thus allowing the reaction to continue.

By raising the electronegative potential of the steel to the point where it no longer corrodes, the zinc sacrifices itself into solution.

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The two elements predominantly used in the composition of sacrificial anodes offshore are zinc and aluminium. Occasionally magnesium is used but it has a relatively short life in seawater. Zinc anodes have been the most popular choice for a long time and have an excellent service record. They are less subject to environmental problems and passivation. Aluminium alloy anodes are now widely used as they are more economical in terms of current output and are lighter than zinc anodes, thereby reducing the weight loading on the structure. Their disadvantage is susceptibility to passivation and marine fouling.

Anode distribution is dictated by current distribution requirements. Three critical areas typically require a greater number of anodes in order to achieve an even current distribution - nodes, the splash zone, and conductor framings (also called 'conductor guide frames', or 'horizontal frames').

Sacrificial anodes are fixed to the structure in a variety of ways. Electrical continuity - a metallic path-is usually assured through contact bolts, welding or earthing (grounding) cable.

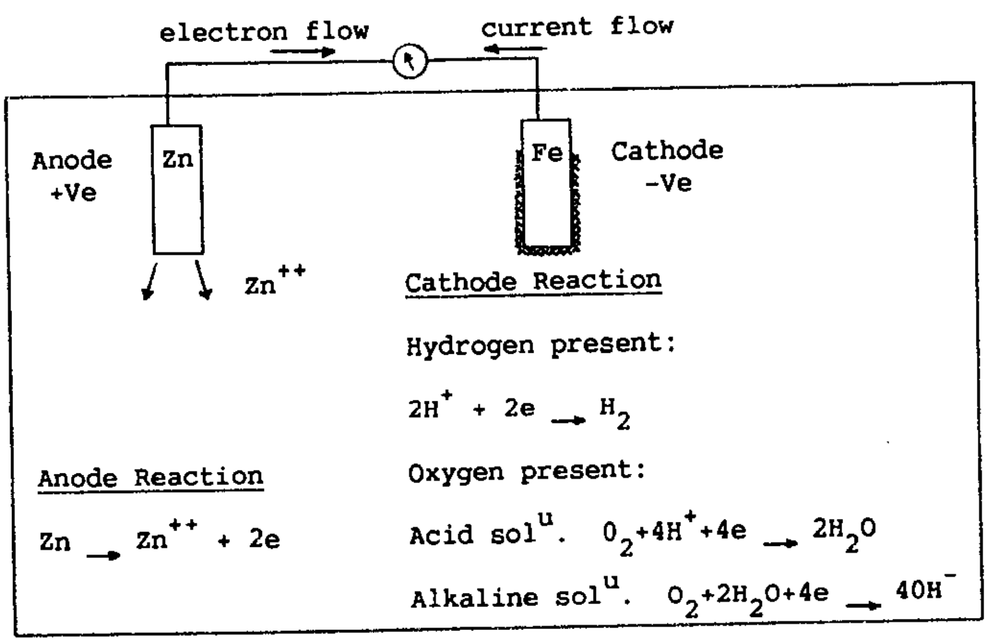

Fig. 14

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5.5.2.1 ADVANTAGES/DISADVANTAGES OF SACRIFICIAL ANODE SYSTEMS

Advantages:

1. No external power supply required
2. Simple installation
3. No danger of over protection (and possible hydrogen embrittlement)
4. No running costs once installed
5. Low maintenance costs
6. Active from day of submersion
7. Highly reliable

Disadvantages:

1. Output decreases with time
2. Weight loading and initial cost high due to large number of anodes required.

As with all parts of the structure's inventory, sufficient data must be generated to satisfy engineering assessments of integrity and deterioration. Therefore, a sample of selected sacrificial anodes is generally part of a structure's visual inspection programme.

In order to assess a sacrificial anode's effectiveness, the underwater inspector provides the necessary data to answer these two primary questions:

1. Is the anode active?
2. What is the extent of wastage?

These are answered by meeting the following typical inspection requirements for sacrificial anodes:

1. Report the approximate percentage wastage - girth measurement may be required. Often slight (0-25%), moderate (25-75%) or severe wastage (greater than 75%) will suffice.

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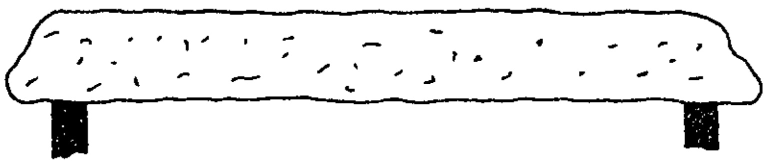
2. Describe surface condition (ie. extent of pitting) and presence of deposits (a crumbly, white deposit indicates an active anode).

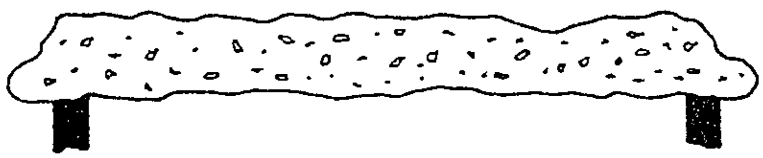
3. Check for electrical continuity through the integrity of contact bolts and earthing leads if present.

4. Describe the type, thickness and percentage cover of any marine growth.

5. CP readings around anodes and photographs of anodes are generally a standard requirement.



ANODE SLIGHTLY PITTED, ROUNDED EDGES



ANODE MODERATELY PITTED 50% MISSING

ANODE SEVERELY PITTED FRAME VISIBLE

Fig. 15

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5.5.3 IMPRESSED CURRENT CATHODIC PROTECTION

Impressed current cathodic protection is based on the same principle as sacrificial anode cathodic protection in that it relies on establishing the structure as a cathode in any corrosion reaction. As in sacrificial anode cathodic protection it is also accomplished by introducing a current greater and in opposition to the discharging current of corroding steel in seawater.

Since the current is applied from an external source, however, impressed current anode electrodes are composed of elements with a very low corrosion rate, such as platinised niobium/titanium and lead/silver alloys.

Two methods of impressed current anode distribution are commonly encountered in offshore structures. One system places large anodes (typically 6-12)concentrically around the outside of the structure. One such anode with an output of up to 500 amps could cover an area which would require approximately 100 sacrificial anodes. An alternative system utilises a series of smaller anodes within the structure at points selected to ensure an even current distribution. An operating power of up to 50 amps is typical for this type of impressed current anode.

DC Source

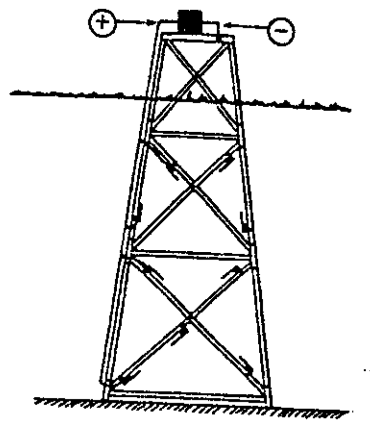

Fig. 16

DC Source

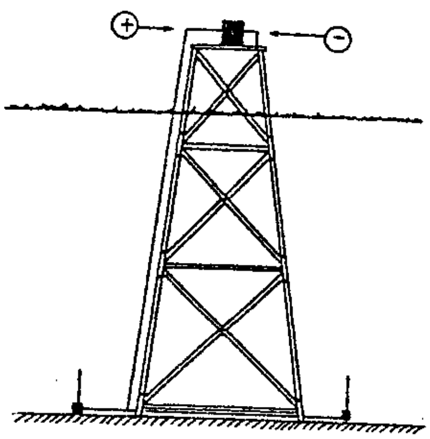

Fig. 17

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5.5.3.1 ADVANTAGES/DISADVANTAGES OF IMPRESSED CURRENT SYSTEMS

Advantages:

1. Fewer anodes required
2. Variable current output to compensate for changes over time (ie. loss of coating, or severe wastage of sacrificial anodes in hybrid system)
3. Reduced weight loading
4. Operational factors monitored remotely
5. Less expensive for a large structure

Disadvantages:

1. Subject to power supply failure and subsequent loss of protection
2. Requires continuous monitoring and regular electrical maintenance
3. Liable to over protection which could possibly cause hydrogen embrittlement
4. Problems with cables and conduits, particularly in bad weather
5. Wrong power source connection would result in serious corrosion of the structure itself
6. Hazardous to divers
7. After structure installation, structure can be unprotected until such time as the system is operational

5.5.3.2 TYPICAL INSPECTION REQUIREMENTS

Typical inspection requirements for impressed current anodes would include:-

1) A description of the anode surface condition paying particular attention to:
   - The presence and type of any deposits.
   - The presence and extent of any corrosion.

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2) A check on the integrity and electrical continuity of supply cables and cable to anode connections.

3) A description of the type, thickness and percentage cover of any marine growth.

4) Local CP reading and photographs. These would normally be taken by an ROV.

Occasionally impressed current anodes are associated with dielectric shields to channel current distribution towards particular areas. The condition of these shields needs to be reported mainly with respect to the presence of any physical damage or excessive marine growth.

5.5.3.3 <u>POLARISATION EFFECTS OF SACRIFICIAL ANODE AND IMPRESSED CURRENT CATHODIC PROTECTION SYSTEMS</u>

In addition to distributing current as evenly as possible throughout the structure, a secondary effect of sacrificial anode or impressed current cathodic protection is the formation of a "calcareous deposit" consisting mainly of calcium carbonate and magnesium hydroxide. At optimum current densities, the deposit is thin, hard, almost completely calcareous, and adheres to the structure very well. Besides promoting a more even current distribution it physically protects the steel surface and provides some temporary protection if the current fails. At high current densities the deposit is more soluble due to a higher percentage of magnesium hydroxide. This results in a porous, chalky, soft, and often spongy deposit that does not provide temporary protection during current failure. Calcareous deposits are naturally white but can be influenced by other deposits and may appear as grey, yellow/brown or a combination of both.

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5.6 COATINGS

The fundamental purpose of protective coatings underwater is to insulate the structure from the electrolyte, seawater. In doing so, the electrochemical circuit required for the corrosion reaction to take place is broken.

A coating also reduces the effective current required from additional cathodic protection systems, thereby reducing the number of sacrificial anodes or the size of an impressed current system required. The role of coatings is particularly important on structures where the sacrificial anode or impressed current cathodic protection system is weak or inadequate.

The underwater inspector typically encounters three types of protective coatings - paint, metal (monel) and concrete. Each has its own applications, associated defects, and typical inspection requirements.

5.6.1 PAINT COATING

'Paint' coatings consist of various epoxy resins, plastics and urethanes of various thicknesses (sometimes applied in the form of tapes). Of these, a coal tar epoxy is most commonly used on offshore structures. Should small breaks occur in the paint coating, the exposed metal area may become highly anodic and rapid pitting corrosion be initiated. Therefore, the condition of bare metal areas or blisters in coatings often requires a close inspection procedure.

5.6.2 MONEL SHEATHING

Metal (Monel) Sheathing has a high resistance to seawater corrosion (It is more noble to steel in seawater). It is often used in splash zones where cathodic protection is least effective. Monel wrapping or cladding is most commonly encountered on hot production risers. Monel sheathing can be bonded by mechanical means or adhesive, but most often by welding.

Since a galvanic corrosion cell (two dissimilar metals) is set up where the monel sheathing ends, protective coating is normally applied around the joint to exclude the electrolyte (seawater). Sacrificial anodes are also frequently installed closeby to afford additional protection.

5.6.3 CONCRETE COATING

Coatings are mainly encountered on offshore pipelines, and are often applied over a bitumen coating. A concrete coating provides corrosion protection by isolating the encased steel from seawater and physical damage protection from falling debris or dragging anchor wires and fish trawls. Concrete also acts as ballast (often called weight coating) to overcome buoyancy in the line. As with other protective coatings, damage to the concrete and underlying bitumen may result in severe localised corrosion.

5.7 CORROSION MONITORING PRACTICE UNDERWATER

5.7.1 REFERENCE HALF CELL

A direct measurement of corrosion rate for localised areas of a steel surface is not possible. However, the tendency or potential to corrode can be obtained by using a reference half-cell.

The principle of this tool is as follows:-

It has been shown that when two dissimilar metals are connected and bridged by an electrolyte, a corrosion cell is formed and an electrical circuit is completed. An electrical potential is generated and a potential meter (reading volts) placed in the circuit, will measure this potential between the anode and cathode of the cell and provide a measure of the tendency to corrode. For underwater inspection purposes, the steel acts as one half of the cell and the other half is the reference half-cell.

Normally, the silver/silver chloride half-cell is used underwater. The silver/silver chloride half-cell consists of silver immersed in a solution of silver chloride which is in contact with the seawater via a porous plug.

During inspection a lead or point of contact is earthed to the structure. If the steel is corroding, ferrous (+ve) ions will be in solution leaving behind electrons in the steel.

When the half-cell is placed into this area of positive ions, the distribution of the ions inside the porous pot are polarised in such a way that silver ions migrate to the silver rod in the middle and chloride ions migrate towards the porous membrane. This creates an overall positive charge in the immediate vicinity of the silver rod.

Since the half-cell is connected to the structure a galvanic cell is again set up and the silver rod becomes the cathode. The area of corroding steel is the anode. Since the cathode is also the negative pole and the anode is the positive pole, a voltmeter is connected in parallel to measure the potential difference between them. The potential of the steel surface with respect to the half-cell is always quoted as a negative value.

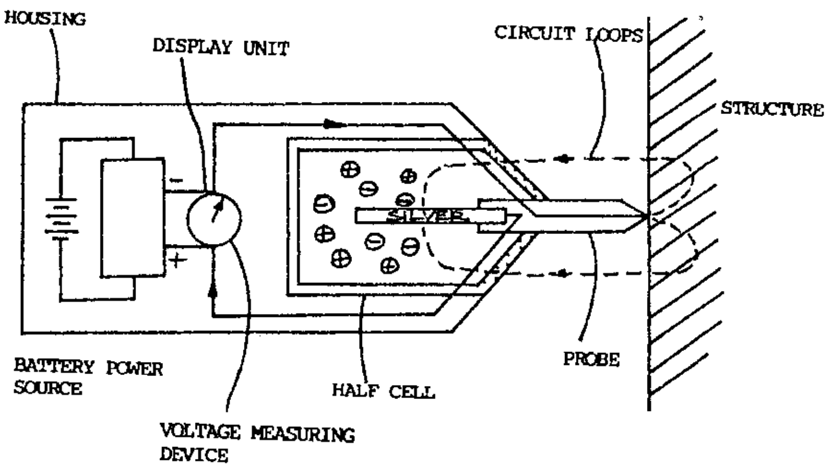
The expected range of potentials in seawater of the most common metals used in marine installations are shown below:

Metal	Measured with reference to the silver/silver chloride half-cell in mV
Unprotected iron and steel	-500 to -650
Cathodically protected iron and steel	-800 to -900
Zinc	-1000 to -1050

5.7.2 PRACTICAL USE OF PORTABLE DIVER HELD CORROSION METER

The object of the underwater inspection and NDT technician is to obtain reliable and valid data. If the corrosion meter is not used correctly the operator error will invalidate the readings.

The bathycorrometer is one form of corrosion meter and works on a similar principle to the half-cell except that instead of an earthing lead and a remote multimeter, there is a probe which is attached to the instrument which must come into contact with the steel surface. The voltmeter (digital) is housed in the instrument and instead of a porous pot, there is a diaphragm. The bathycorrometer contains a silver/silver chloride half-cell with a silver rod and silver (+) and chloride(-) ions in solution inside the half-cell.



Simple schematic of a bathycorrometer:

Fig. 18

When the probe touches the steel surface, a circuit is set up such that ferrous ions outside the instrument alter the distribution of ions inside the pot as in the half-cell. The relative potential of the steel surface with respect to the half-cell is measured by the voltmeter and the diver/inspector can read the voltage (again minus) on the digital readout.

To ensure the accuracy of all corrosion potential measuring devices, standard readings should be made to check that the instrument is in calibration. On site probably the most convenient readings can be taken against:

standard calomel electrode	0 to -10mV
freely corroding mild steel	-500 to -650mV
pure zinc	-1000 to -1050mV

Measured in seawater against a silver/silver chloride reference electrode. These checks should be made both before and after a dive when a CP meter is used.

During inspection a potential of between -800mV and -900mV is required to ensure protection of mild steel in seawater. A potential less negative than this would mean that the structure was not completely protected at the point in question. If the potential was more negative than -1100mV the structure could be overprotected.

5.7.2.1 <u>SETTING UP PROCEDURE</u>

Ensure CP meter is fully charged.
Immerse unit in seawater for one hour prior to use.
Calibrate using known test samples.

5.7.2.2 <u>OPERATION</u>

Identify location for inspection.
Clean away marine growth and clean area for inspection.
Apply CP meter to surface of structure and ensure a good contact is made between the end of the probe and the metal. Continuous hard pressure is necessary.

<u>NOTE</u>: See section 7.6.10.2 for a detailed description of the use and calibration of ROV deployed CP measurement equipment.

Ignore the initial more negative reading (5 seconds) and wait for reading to settle.

Take several readings in same location.

Repeat any unusual readings.

Report.

Move to next location.

5.7.2.3 MAINTENANCE

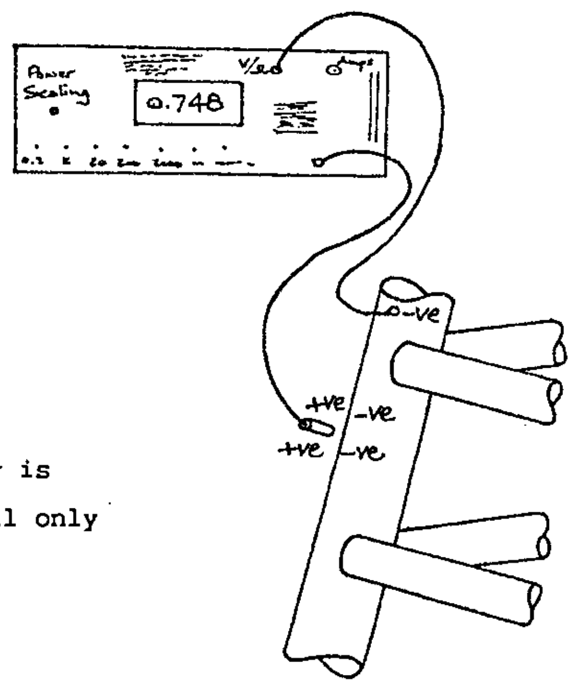
After use the unit should be rinsed gently with fresh water and towel dried before re-charging. Alternatively the unit can be re-charged while soaking in water so long as the plug connection is dry and out of the water. Soak in fresh water to avoid algae build-up on the semi-porous cell. The advantage of this method is that the unit does not require lengthy immersion in seawater prior to use. It can simply be disconnected, transferred to seawater for about 5 minutes, calibrated and sent to the work site.

A good examples of a direct contact unit is the Roxby Bathycorrometer Mk.V.

5.7.3 SURFACE READOUT

When direct readout underwater is inappropriate or where rapid surveys are required without needing to make an individual contact point, a surface unit attached to a wandering reference half cell is used.

VOLTMETER



NB: +VE side of the voltmeter is connected to the half cell only if the cell is Ag/AgCl

Figure 19

The most critical step in applying a wandering reference half-cell to measure potentials is a good electrical contact with the structure (ie. earth). Where necessary, paint should be scraped away to give a bright steel contact point. The contact wire should then be connected to the negative terminal of the instrument. This negative connection must be made to the surface section of the electrically continuous part of the platform being investigated. If the structure is a riser then care should be taken to identify any insulation joints, and connect accordingly. On concrete or hybrid structures the location must be compatible with the equipotential network of continuity bonds.

The reference half cell should be connected to the positive terminal and the cell manoeuvered into the correct position. This should be as close to the structure as possible without touching it. No cleaning or removal of marine growth is necessary.

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The cathode potential reading will be given directly on the surface readout. To ensure a stable reading the reference half cell should be moved a few centimetres across the metal surface.

Erratic readings are usually caused by poor surface connections or faulty insulation in the half-cell connection wire. Although radio signals can also cause problems.

5.7.4 PERMANENT MONITORING SYSTEMS

A number of offshore structures now incorporate permanent fixed cathodic protection monitoring systems. These systems are available in varying degrees of complexity but generally involve the use of either zinc reference electrodes, or monitored anodes, or a combination of the two.

Briefly, the zinc reference electrode consists of a block of high purity zinc insulated from but mounted close to the area to be monitored. A lead from the zinc block is taken through conduit to the recording instrument above water, and this in turn is 'earthed' to the structure.

Reference Electrode

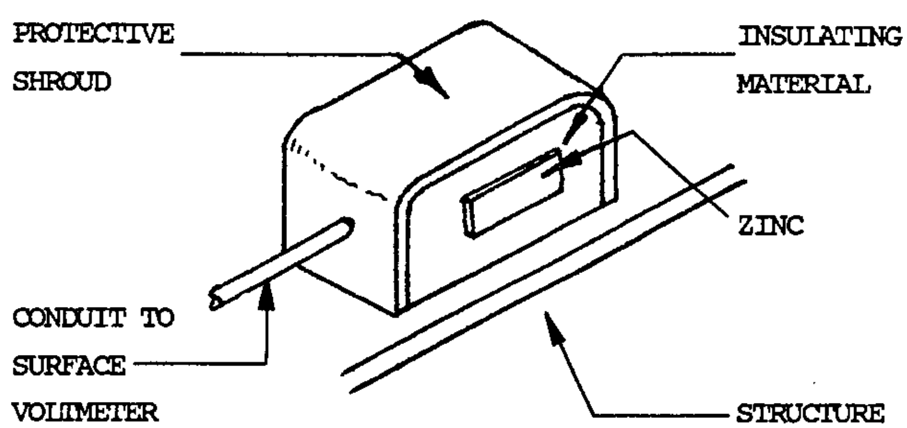

Fig 20

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A monitored anode is basically a modified sacrificial anode. The main visible difference being that the monitored anode will have a conduit running to one of the mounting posts. Another difference which may or may not be visible is that the anode material will be insulated from the steel structure apart from electrical continuity via the conduit to a surface mounted ameter. The object being to measure the current flowing between the anode and the structure.

MONITORED ANODE

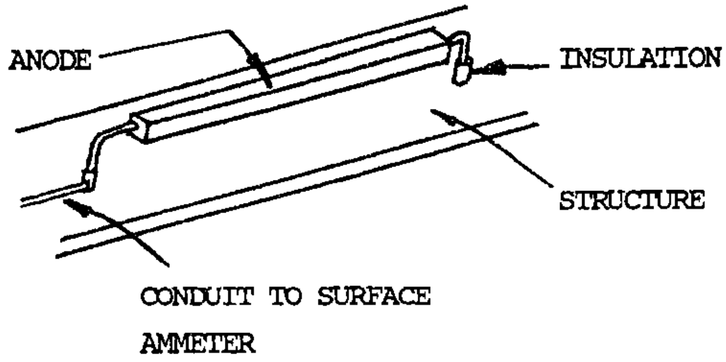

Fig. 21

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5.8 SUMMARY

Corrosion in an offshore sub-sea environment is an electrochemical process that involves the oxidation and reduction of metal atoms. The electrons and metal ions generated when two metals of dissimilar electropotentials are in electrical contact in an electrolyte form the basis of the corrosion process.

The magnitude of electropotential difference, the efficiency of the electrical contact and the composition of the electrolyte combine to produce a corrosion regime that can range between very active and passive.

The purpose of the cathodic protection system is to increase the electronegative potential of the structure to the point where it will no longer corrode. By introducing a metal of greater electronegative potential in one case and a source of electrons in the other, the development of sacrificial anodes and impressed current system achieve the desired effect.

Anodes of zinc and aluminium sacrifice their metal ions into the electrolyte whilst injecting the structure with electrons, whilst impressed current systems utilise an external power source to the same end.

As a means of monitoring the effectiveness of a cathodic protection system, instruments have been developed that can determine the electropotential of the structure. These instruments can be either diver or ROV operated or can be of a more permanent, fixed, nature.

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6. NDT TECHNIQUES

6.1 INTRODUCTION

In every engineering structure and component the possibility of including into it a defect that will later increase in size and impair the efficiency, or produce total failure of the structure or the component is a real danger.

With an offshore structure, its life can be divided into four distinct stages. These are listed below together with possible defects that may occur at that stage.

Stage	Possible Defects
(i) Manufacture of Material, eg. steel	Cracks, segregation, shrinkage, impurities, porosity.
(ii) Fabrication	Machining defects, residual stress, heat treatment defects, welding defects, fitting stresses, sharp edges.
(iii) Installation	Micro cracking due to high loading, residual stresses due to deformation of material, damage due to bad handling.
(iv) In-service	Deterioration due to fatigue, corrosion, erosion, wear, stress corrosion, corrosion fatigue, embrittlement, accidental damage.

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Ideally, the structure or component will be inspected at each stage so that when the structure comes into service a complete profile history of defects is available. However, defects at any stage may pass undetected, so underwater inspection at stage four must be capable of detecting all the above possible defects. To this end, advanced inspection techniques such as magnetic particle inspection and 'A'-scan ultrasonics have been developed for underwater use.

Investigation using advanced inspection techniques often relies upon the information already gained by the diver-inspector visually.

Because of the scope of visual inspection, its importance should not be underestimated. It is of vital importance that a diver inspector is capable of performing an accurate visual inspection. This initial report may well be backed up with either photographs or video tapes or both, but the crucial point is that the diver is inspecting the part visually. He can see the object in stereoscopic vision and in its true colour. No advanced inspection techniques would be employed until visual inspection had taken place.

In the following sections the various NDT methods available for use underwater will be discussed. Special attention is paid to MPI and Ultrasonics since these are by far the most widely used techniques.

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6.2 MAGNETIC PARTICLE INSPECTION

Magnetic particle inspection is used to detect surface or near surface discontinuities in materials that can be highly magnetised. This section describes the fundamentals of above and below water MPI. It is recommended that further reading includes BS6072: 1982 Magnetic Particle Flaw Detection upon which this section is based.

6.2.1 BASIC PRINCIPLES OF MAGNETISM

A magnetic field is a region in which magnetic influences can be detected and is represented by lines of force or flux. If there is a break in the magnetic circuit eg. by a crack at the surface, then the flux will leak into the air. The point at which leakage occurs possesses all the properties of a miniature permanent magnet ie. a north and south pole. Magnetic particles will then be attracted to this region and so reveal the crack. Sub-surface defects may also cause flux leakage and can be revealed if they are not too far beneath the surface. It is this phenomenon which is utilised during MPI.

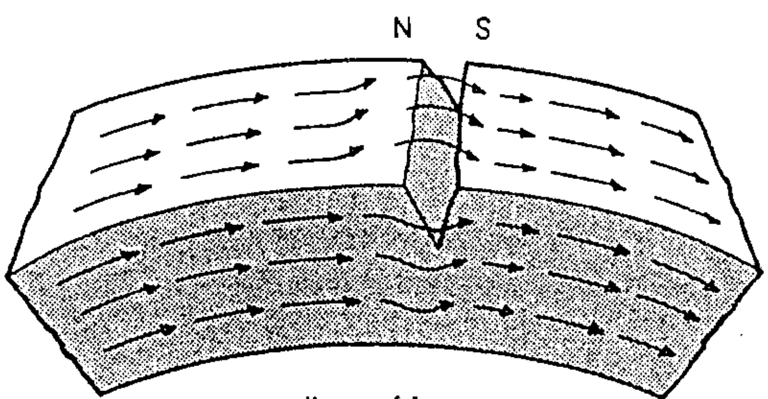

Figure 1a

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6.2.1.1 TYPES OF MAGNETISM

Magnetic properties are determined mostly by the electronic structure in the individual atoms as well as the way the atoms are arranged as molecules or a crystal structure. There are three types of magnetism.

(a) **Diamagnetism** - this type of magnetism is exhibited by materials that are repelled by a strong magnetic field. This externally applied magnetic field induces a "like" magnetic field within the material; hence repulsion occurs ie. the induced magnetic effect is in the opposite direction to the induction applied. All materials have diamagnetism, but in the majority, stronger magnetic effects swamp it out. Materials which <u>only</u> have diamagnetism are copper, gold, water and mercury.

(b) **Paramagnetism** - is exhibited by materials which are weakly attracted by strong magnetic forces. Generally this effect will hide (swamp out) the diamagnetism in any material. Most metals exhibit paramagnetism eg. platinum, palladium, as does Oxygen.

(c) **Ferromagnetism** - is exhibited by materials such as iron, steel and cobalt which can be strongly magnetised and which show good magnetic properties. The atoms in these materials are grouped together in domains. These domains have a magnetic moment created by the combined effect of electron spin and the motion of electrons around the nucleus of an atom.
Each magnetic domain has a North and South pole. When the material is unmagnetised the domains are randomly distributed and their magnetic effects cancel each other out. If, however, an external magnetic field is applied the domains align causing one end of the material to act as a North pole and the other to act as a South pole (see figure 1b).

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6.2.1.2 MAGNETIC POLES

When a material is magnetised, and is suspended or pivoted as in a compass, the material will rotate until it aligns itself with the Earth's magnetic field. The part of the material pointing towards the Earth's North pole is termed the 'North seeking pole' of the magnet, abbreviated to the 'North pole' of the magnet. Likewise the opposite end of the material is termed the South pole.

The force associated with magnetism appears to be concentrated at the magnetic poles of the material (Figure 2).

If two similar poles were brought together they will tend to repel each other whilst opposite poles attract.

Consequent poles exist when more than two poles are present in a magnetised object simultaneously.

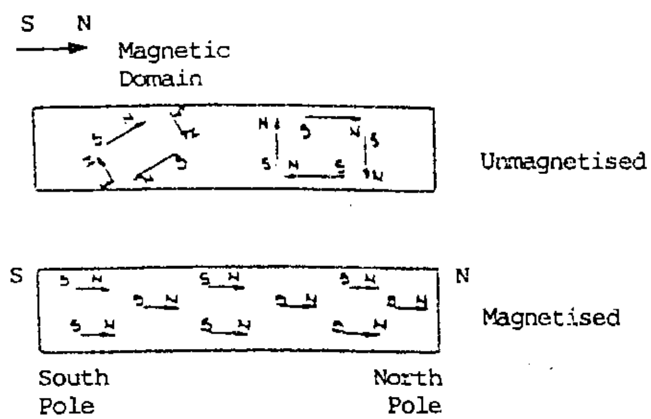

Figure 1b

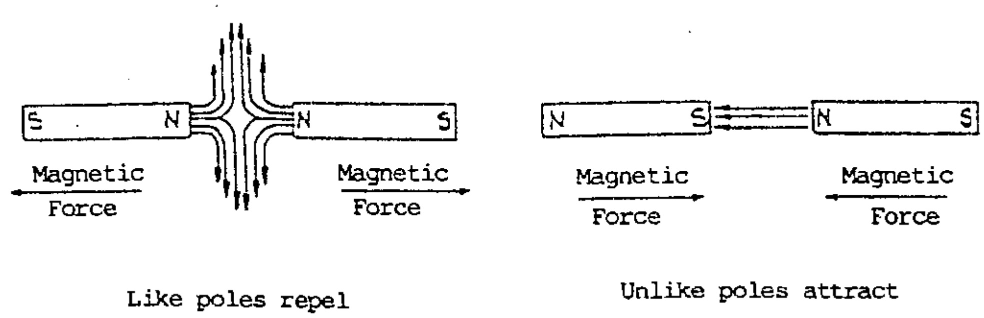

Figure 2

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6.2.1.3 MAGNETIC FIELDS

The area surrounding a magnet in which a magnetic force exists is termed the magnetic field. The concept of a magnetic field flowing along lines of force is convenient when studying magnetism.

In a permanent magnet the lines of force travel from the South pole to North pole internally and North to South externally ie. a longitudinal magnetic field is produced. Similarly, when an electric current flows through a conductor a circular magnetic field is induced around the conductor (refer to figure 3).

The lines of force or 'flux' lines arrange themselves in characteristic patterns. They seek the path of lowest resistance and are most concentrated at the poles in the case of a magnet or at the surface in the case of a conductor. Magnetic force is said to be a vector quantity ie. the force produced has a magnitude <u>and</u> direction.

If a current carrying conductor is wound into a coil the resultant magnetic field will be as shown in Figure 4 with each end of the coil acting as a magnetic pole in a bar magnet. The strength of the magnetic field will be approximately proportional to the current flowing and the number of turns in the coil, if the coil diameter exceeds its length.

6.2.1.4 FLUX LEAKAGE

If the bar magnet as shown in Figure 3 were to be formed into a circle and the ends fused together there would be no free poles and a continuous closed magnetic circuit would result. In this case no external magnetic force would exist (see figure 5A).
If a break were to occur in the ring, such as a crack on its outer surface, as shown in Figure 5B, then magnetic poles would be created either side of the break.

Some lines of force would then 'jump' across the break and an external field would be created. This external field is caused by flux leakage.

If a discontinuity lies below the surface of the material it is unlikely that any external flux leakage will occur unless the defect is very close (usually less than 3mm) to the surface.

The whole basis of magnetic particle inspection relies on detecting this flux leakage.

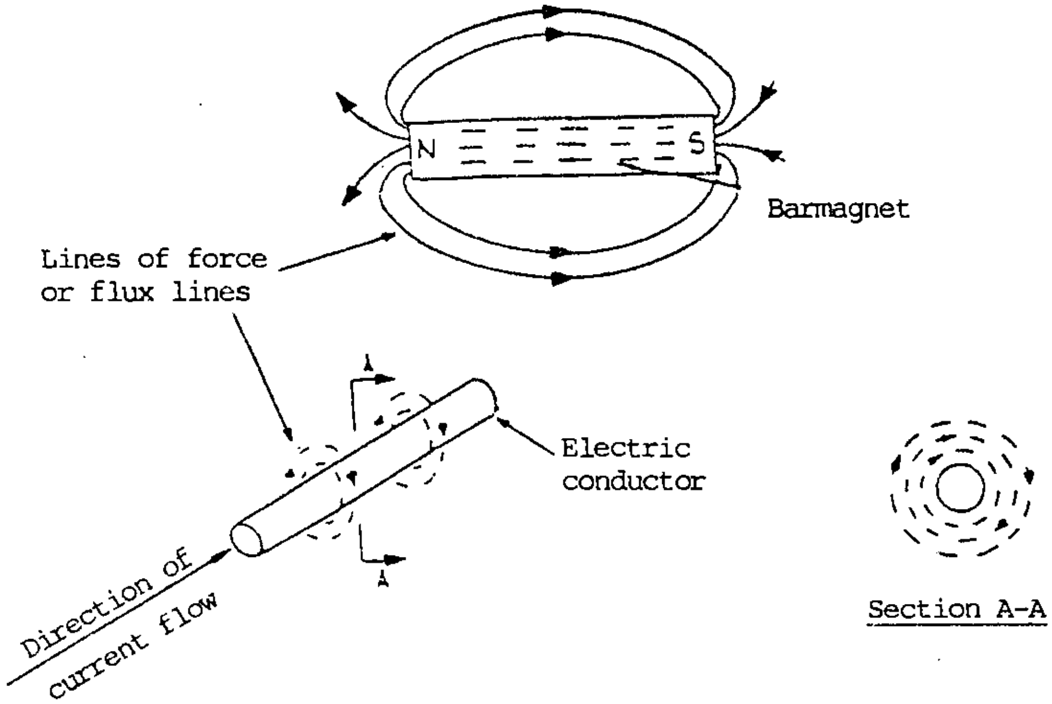
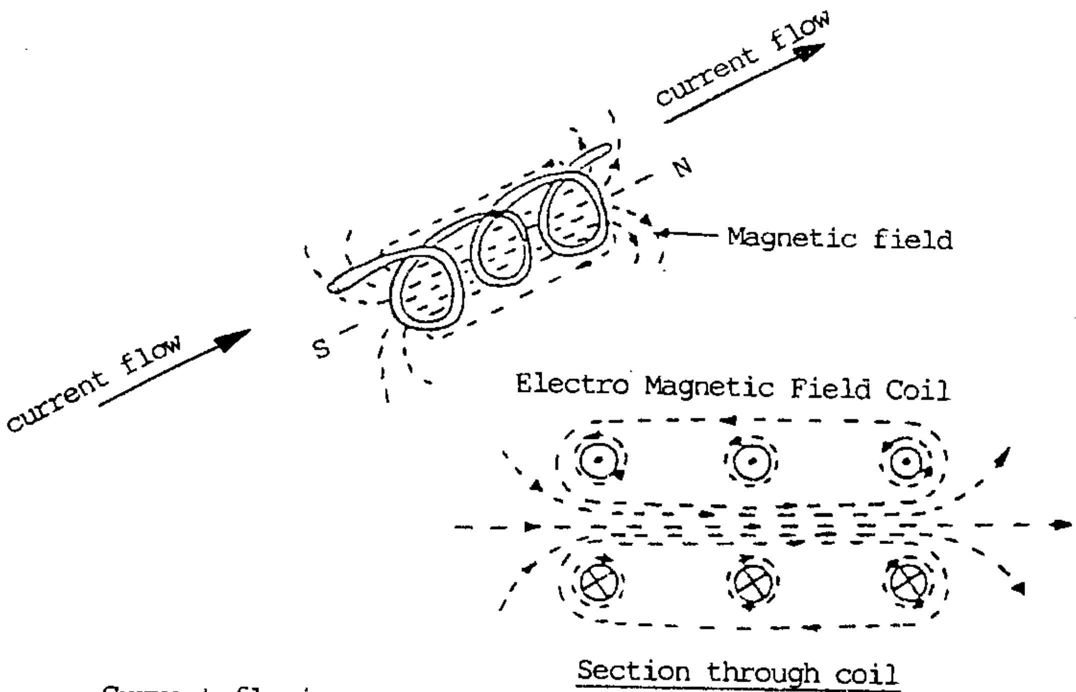


Fig. 3



⊙ Current flowing towards you

⊗ Current flowing away from you

Fig. 4

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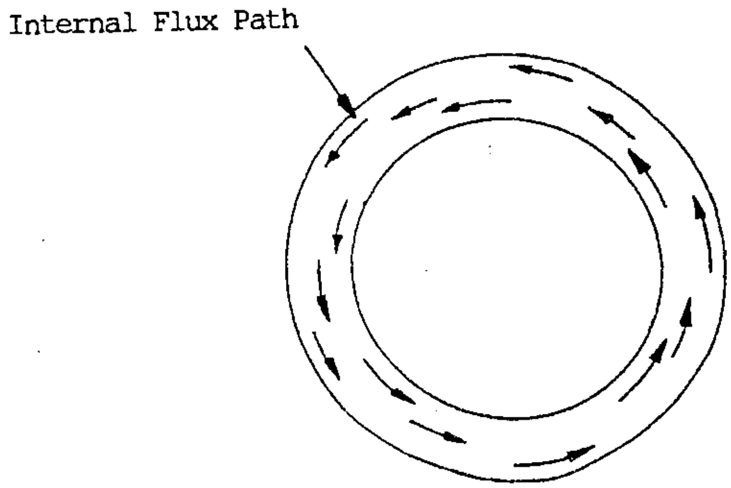
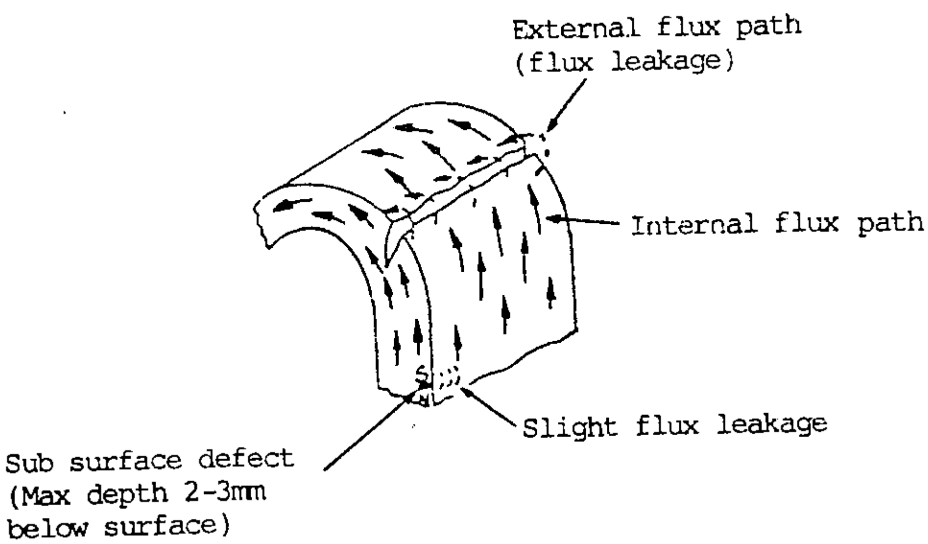


Closed magnetic circuit, No external field

Fig. 5A



Flux leakage

Fig. 5B

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6.2.1.5 **FLUX DENSITY (B)**

This is the term used to describe the amount of magnetism within a specimen and is a measure of the magnetic field strength. It refers to the number of flux lines, or lines of force, per unit area taken at right angles to the direction of the flux.

Conventionally flux density is measured in Gauss.

$$1 \text{ Gauss} = 1 \text{ line/cm}^2$$

The SI unit for flux density is the Tesla.

$$1 \text{ Gauss} = 1 \times 10^{-4} \text{ Tesla}$$

6.2.1.6. **MAGNETISING FORCE (H)**

This refers to the total force tending to set up a magnetic flux in a magnetic circuit.

Conventionally this is measured in Oersteds and, in air or in a vacuum, Gauss and Oersteds are numerically equal.

The SI unit for magnetising force is Amperes per metre.

$$1 \text{ Oersted} = 79.58 \text{ A.m}^{-1}$$

6.2.1.7 **PERMEABILITY (μ) AND RELUCTANCE**

Oersted refers to the magnetising force (H) tending to magnetise an unmagnetised body and Gauss refers to the field (B) so induced in the body.

The ease with which a magnetic field can be set up in a magnetic circuit is indicated by the material's permeability (μ). However, it is not a constant value for a given material but is a ratio of flux density to the magnetising force.

$$\mu = B/H$$

Some of the ferromagnetic materials including soft iron and mild steel have high permeability and can be highly magnetised. Conversely, high carbon steels have a low permeability.

Reluctance can be defined as the resistance of a material to a magnetising force.

6.2.1.8 THE NORMAL MAGNETISATION CURVE

When an unmagnetised piece of ferromagnetic material is subjected to a gradually increasing force (H) and the strength of the induced field in the material is measured and plotted against that force a curve, as shown in Figure 6, is obtained.

Practically this can be achieved by placing a bar of iron in a magnetising coil, and then slowly increasing the amount of electric current passing through the coil.

As H is increased from zero, B increases along the line 'oa' to the point 'a' where any further increase in the electric current (ie. the magnetising force) will produce no further increase in the induced field strength.

'a' is known as the saturation point, and the material is said to be magnetically saturated.

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6.2.1.9 MAGNETIC HYSTERESIS

When the magnetising force is reduced from the saturation point 'a', the flux density does not decrease to zero by the same curve 'a' to 'b', so that some flux remains when the magnetising force has been removed. The amount of flux retained or the residual field is termed the Remanence.

By reversing the direction of the magnetising force the magnetic field is reduced to zero at point 'c'. The force required to achieve this is termed the Coercive Force.

By increasing the reverse magnetising force a point 'd' will be reached where the material is again saturated but the polarity is reversed.

Reduction of the reverse magnetising force to zero and an increase in the positive direction will follow the curve 'd' to 'e' to 'f' to 'a' where saturation occurs once again.

The curve so produced is termed the hysteresis loop, and it should be noted that it is symmetrical (Figure 7).

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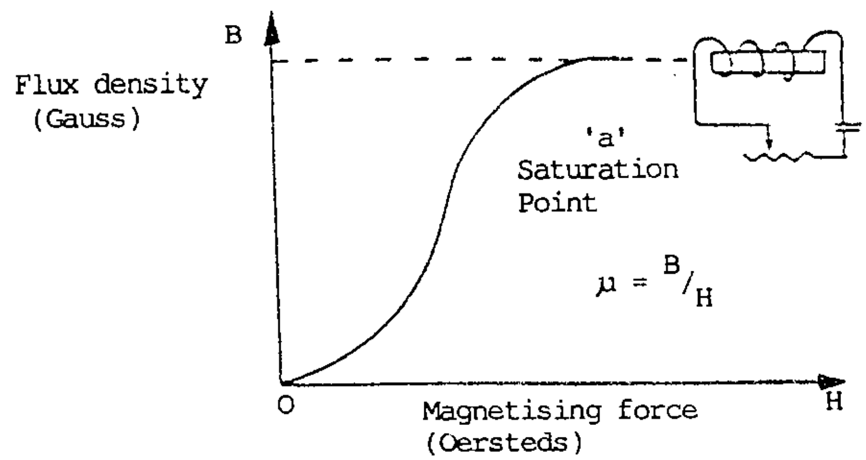

Fig. 6

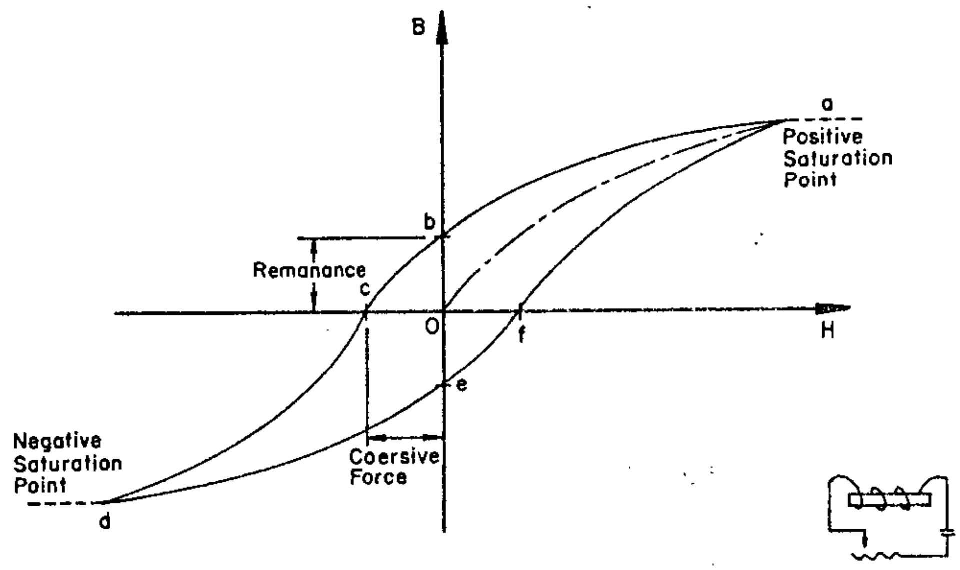

Fig. 7

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6.2.1.10 **RETENTIVITY**

After the application of a magnetising force a material will retain a degree of magnetism (the retentivity or remanence of the material). The amount of residual magnetism is related to the ease with which the material can be magnetised, ie. its permeability.

Materials which are easily magnetised, eg. 'soft' iron, and readily conduct the lines of force, just as readily give up the magnetism when the magnetising force is removed. Similarly, materials which are difficult to magnetise and have a low permeability will attempt to retain whatever magnetic field is applied (Figure 8).

6.2.1.11 **DEMAGNETISATION**

Demagnetisation is achieved by subjecting the magnetised object to an alternating field and gradually reducing the field to zero (Figure 9).

The decaying alternating field may be produced in a variety of ways:-

1. Place the object in a coil which is being supplied with mains alternating current, and then slowly withdraw the object along the axis of the coil to a distance of four to five feet.

2. Perform the above process but move the coil away from the object.

3. Place the object in a coil being supplied with mains alternating current and slowly reduce the current to zero.

4. Slowly draw a wiper magnet along the magnetised object. The wiper magnet is an electromagnet energised by alternating currents.

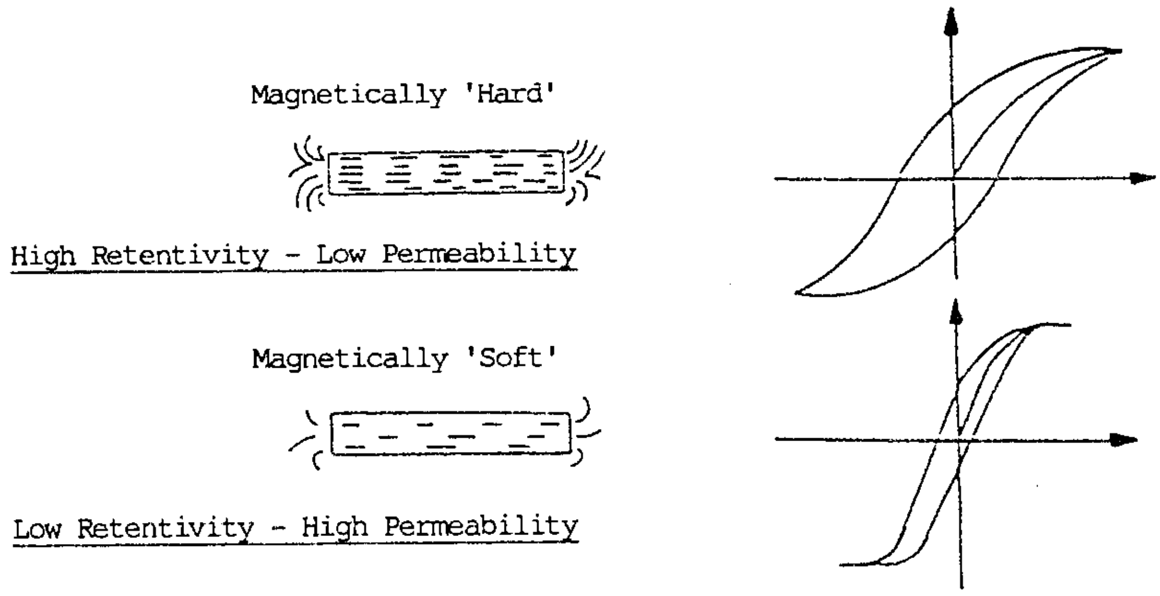

Fig. 8

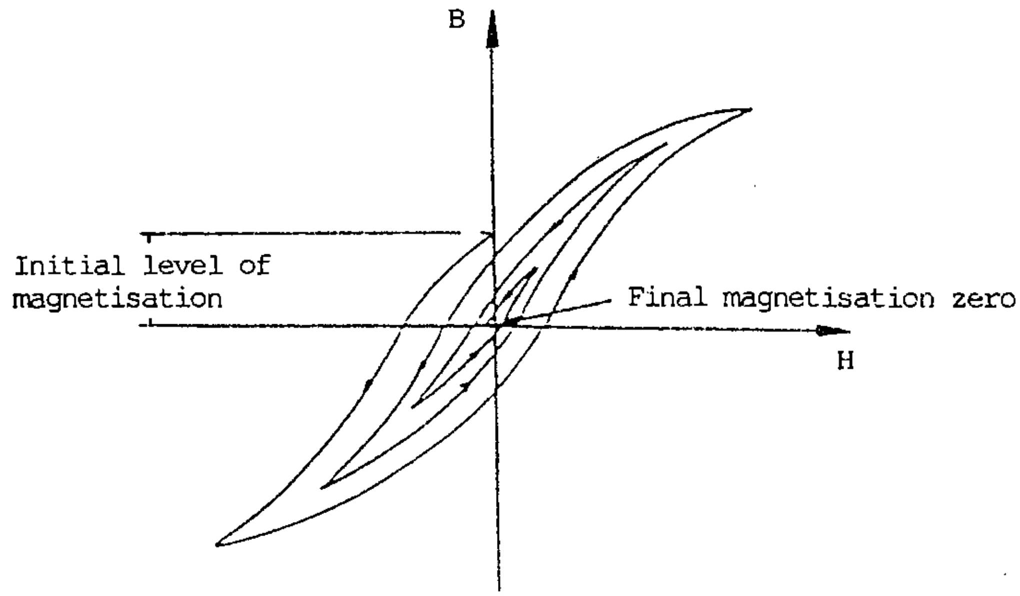

Fig. 9

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6.2.2 PRODUCTION OF MAGNETIC FIELDS

Magnetic particle inspection relies on the flux leakage produced at a defect when a magnetic field is applied to a workpiece. MPI may be accomplished by one of two techniques. The first method relies on the flux leakage produced while the magnetic field is being applied to the area being inspected. The second relies on a prior magnetisation of the part and inspection using flux leakage caused by residual magnetism. Generally speaking, however, residual magnetism is insufficient to obtain a satisfactory level of flux leakage and the first technique is, therefore, preferred.

The magnetic field may be induced by several methods, but in practice the shape and type of objects that we are required to test (ie. jacket nodes, pipes, etc.) limits our choice to the following five methods:

6.2.2.1 PERMANENT MAGNET

Defects transverse to the test direction will be revealed. This is the simplest method of producing a magnetic field but has the disadvantage that large areas or masses cannot be satisfactorily tested. Only that area bounded by the poles and of width slightly greater than the pole pieces can be tested at any one time. The intensity of the magnetic field cannot be varied and, if the magnet is very strong, it may be difficult to remove from contact with the workpiece. It is a single-handed operation and will not damage the workpiece. The lifting power of the magnets should be at least 18 Kg. Refer to Figure 10.

6.2.2.2 ELECTROMAGNET

An electromagnet basically consists of a coil carrying an electric current (AC or DC). The coil is insulated from, but wrapped around, a suitably shaped soft iron core.

When the current is switched off the magnetic field virtually disappears since the retentivity of the soft iron core is very low. The flux density can be adjusted by varying the current through the coil.

Defects transverse to the direction of test will be revealed.

This method is more versatile than using permanent magnets but tends to be bulkier, heavier and a power supply cable or umbilical is required. The area of test is similar to that when using permanent magnets.

An AC electromagnet should have a lifting power of not less than 4.5 Kg. The lifting power of a DC electromagnet should be 18Kg ie. the same as the minimum required for a permanent magnet. Refer to Figure 10a.

NB: When either a permanent magnet or an electromagnet is equipped with adjustable pole pieces to facilitate better contact with non-planar objects, then the field strength will vary with the pole spacing.

6.2.2.3 CURRENT FLOW PROD SYSTEM

For testing of large components the current is passed between two prods pressed onto the surface. The distribution of current (magnetic field) between prods will be approximately circular (elipse).

Defects longitudinal to current path and test direction will be revealed.

Normally low voltages (6V to 24V) and high currents (100's to 1000's A) are used to obtain the required sensitivity. Since high currents are used the prod tips are preferably large and faced with copper gauze or lead to avoid arcing since this could burn the work piece. Burning of the workpiece must be avoided since this can cause localised hardening and initiate cracking.

This is particularly important since MPI is often carried out in fatigue sensitive areas of offshore structures. The likelihood of a defect initiating from such a hardened area is, therefore, multiplied many times. For this reason prods are rarely used for primary weld inspection.

The advantage of this method is that large objects and complex shapes can be tested and the flux level can be accurately controlled. Experience has shown that the length of test with one shot is restricted to the prod spacing and practical prod spacings should be limited to 8 inches for maximum sensitivity.

Refer to Figure 10b.

6.2.2.4 ENCIRCLING COIL

The component is placed within a current carrying coil or a cable is wrapped around the component to induce magnetism (refer to Figure 12).

Defects transverse to the axis of the coil will be revealed.

Low voltages and high currents are used and the magnetic field strength is controlled by varying the current or the number of turns of the coil.

In this case the field strength is quoted in units of Ampere turns.

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This method can be applied to large and complex weld assemblies and the workpiece will not be burnt.

In continuous objects such as the node shown in Figure 13 the diver has to first form the coil and then make the connections to the underwater transformer. As with prods the diver will be encumbered a the transformer and will have to handle a power supply cable, but once the coil is in place he will not have to sustain any further effort. Metal to metal contact is not required and it can be a one man operation.

The coils, usually 2 or 3 turns, are tightly wound around the member, fitted close together and within a few inches of the weld being tested. Only longitudinal weld discontinuities will be detected by this method, although experience has shown defects within plus or minus 45^{o} can also be detected.

6.2.2.5 PARALLEL CONDUCTORS

In this method the coil is formed so that the current is made to flow in the same direction through conductors spaced some distance apart. Normally one part of the loop is positioned a few inches to each side of the weld area being tested. The return parts of the loop must be positioned well away from the parallel section, otherwise they induce a destructive interference field. Currents of between 500A and 1000A are usually used.

With a parallel loop positioned as in Figure 14 only longitudinal weld defects will be detected.

The same deployment considerations apply to parallel conductors as to coil magnetisation, but of course, the same advantages over prods also apply.

In general the coil system is the most commonly used underwater as it is easy to control and maintain the magnetic field strength.

Installation, operation and viewing of the workpiece can be a one-man operation, but the equipment unfortunately remains cumbersome and is often unreliable.

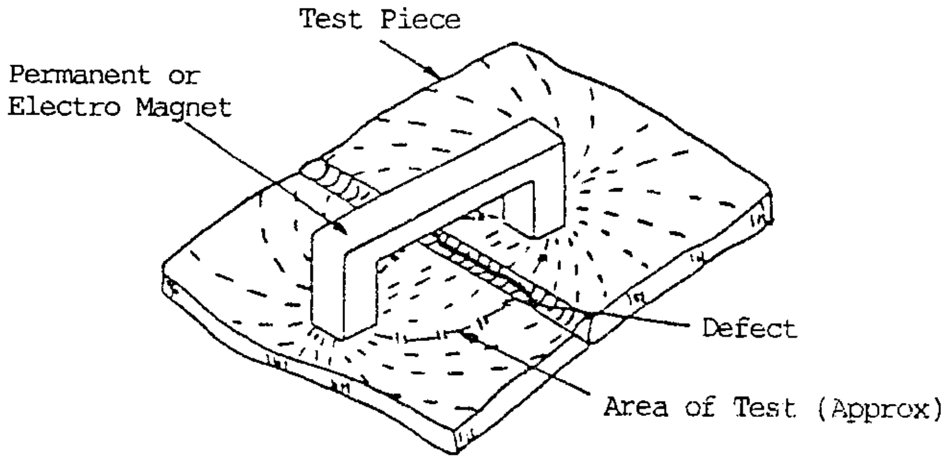

Figure 10a - Permanent/Electro Magnet MPI

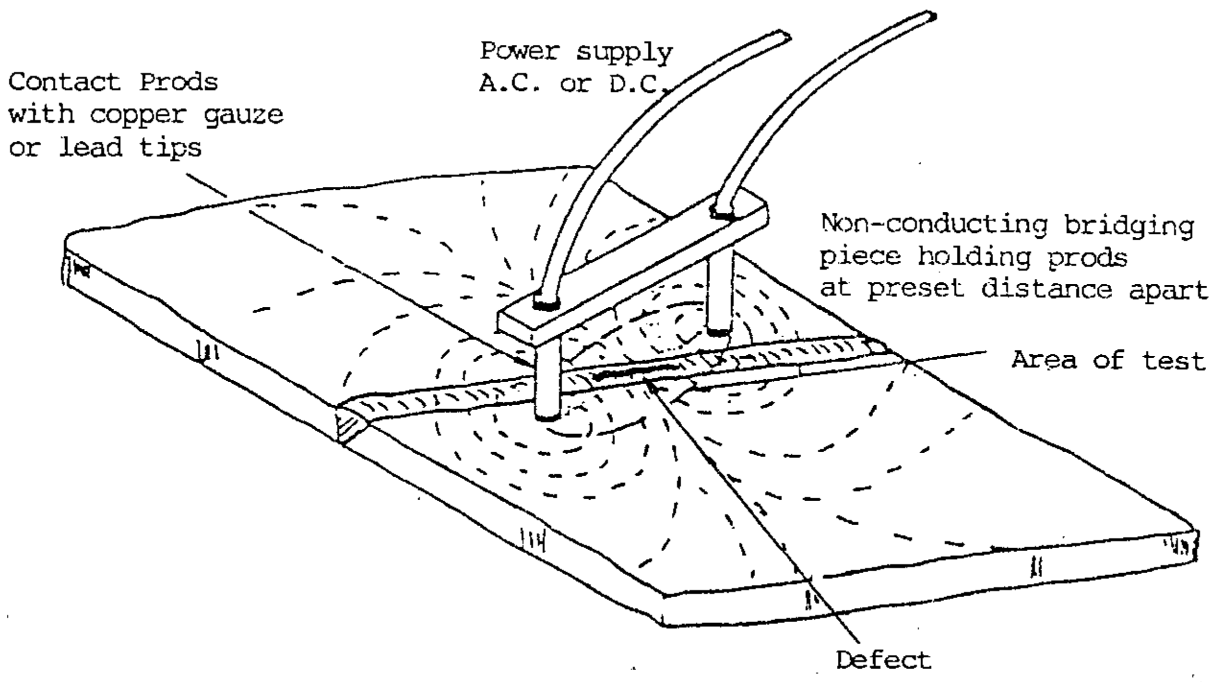

Figure 10b - Contact Prods MPI

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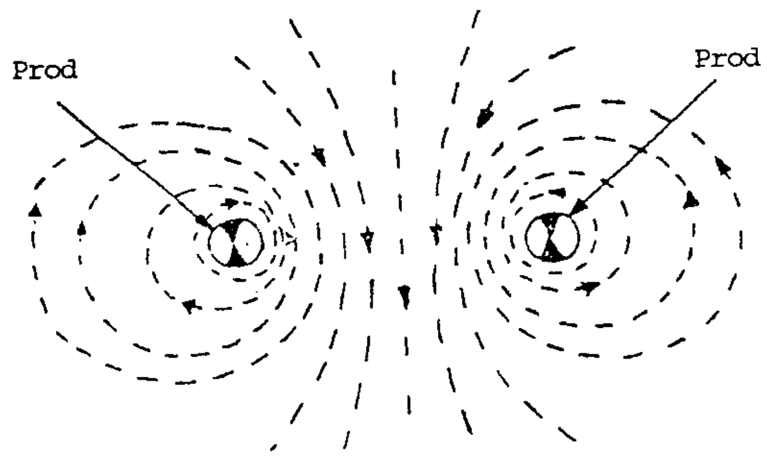

Figure 11 - Current Flow Prods MPI

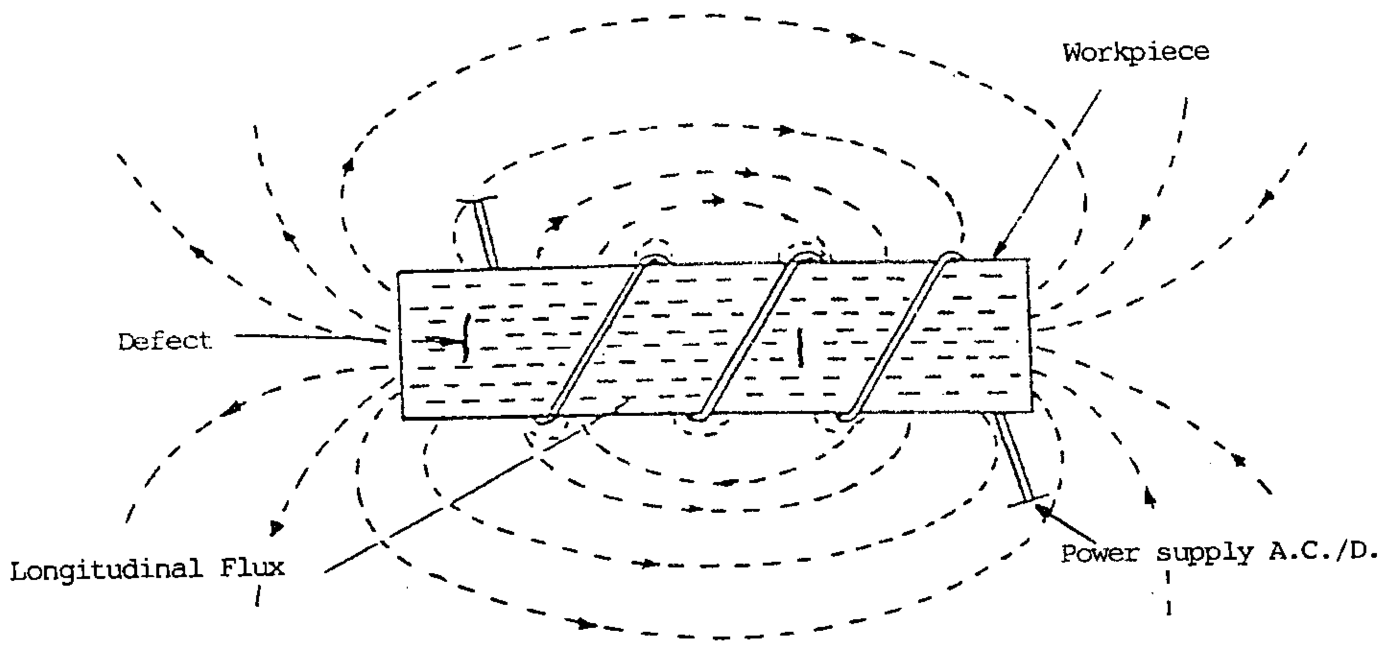

Figure 12 - Encircling Coil MPI

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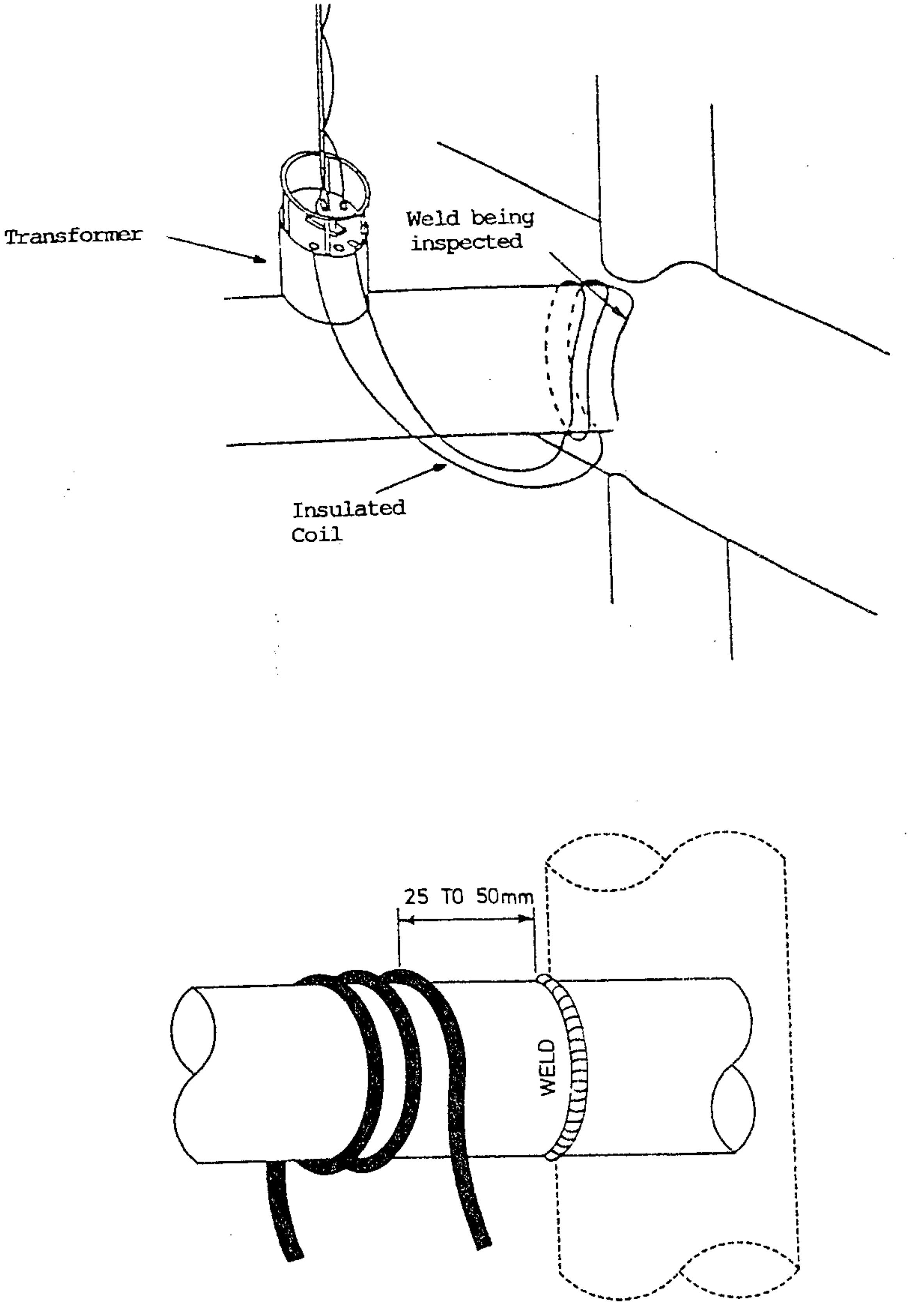

Figure 13 - Current Carrying Coil

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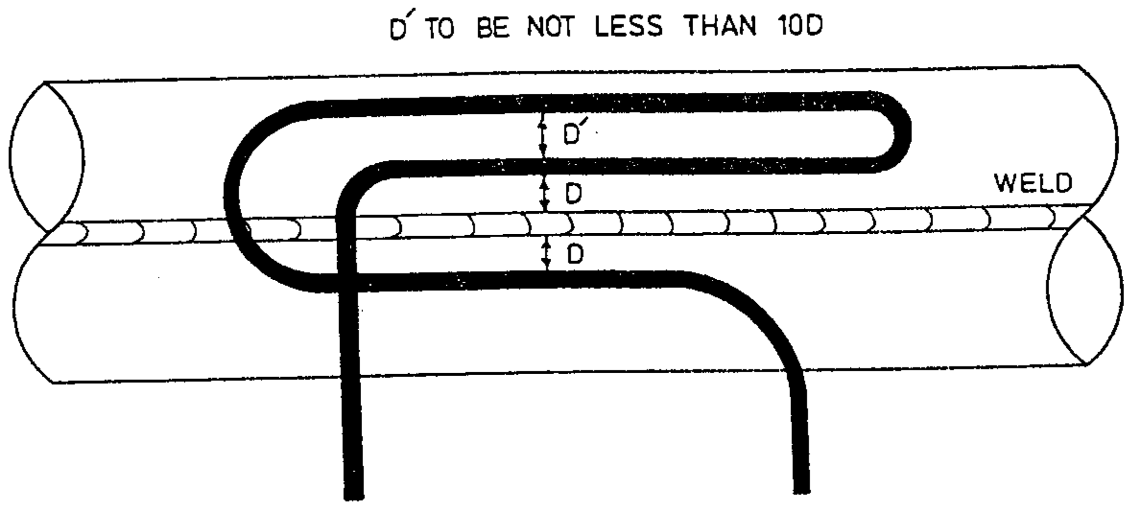

Figure 14 - Parallel Loop MPI

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6.2.3 EQUIPMENT FOR MPI

6.2.3.1 INTRODUCTION

The complement of equipment necessary for underwater Magnetic Particle Inspection can be divided into the following three categories:

- Equipment for inducing sufficient magnetic flux in to the worksite.
- An ultra-violet illumination system.
- Magnetic detection agents.

Most commercial systems combine several methods of creating a magnetic flux with apparatus for creating the visual effect. The common features of these units are as follows:

- A surface unit containing the power supply, control and safety features. Namely, electrical power input/output, ammeter, remote switching control for the optional powered magnetising system and earth leakage equipment.

- A submersible unit comprising a transformer with power outlets, a fluid dispensing/mixing system, the ultraviolet lamp, fluid delivery system and magnetising system. The optional magnetising system may be electromagnetic yoke, prods, current flow cables or as specialised flow cable jig pre-formed to the weld/node geometry.

- An umbilical to connect the surface and sub-surface unit together.

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6.2.3.2 CURRENT SOURCES

The following types of current sources can be used to produce a magnetic field during MPI:

- Direct Current (DC)
- Alternating Current (AC), either single phase or 3-phase.
- Halfwave rectified current (HWDC)
  (halfwave rectified single phase AC)
- Fullwave rectified current (FWDC)
  (Fullwave rectified single phase AC).

The degree of magnetisation of a component depends on the maximum value of the magnetising current. Different currents have various properties and produce different magnetic field distributions in the material under test.

With AC there is a phenomenon known as the 'skin effect' ie. the magnetic field is limited to the surface of the material. In contrast, both DC and rectified AC produce better penetration through the part. Since the majority of underwater MPI is concerned with the detection of surface breaking defects, AC is the preferred method.

6.2.3.3 BLACK LIGHT

The underwater lamp must be configured to produce the correct level of illumination by ultraviolet radiation.

'Black' light is the longest wavelength ultra-violet light and falls immediately below the visible light in the electromagnetic spectrum.

Ultra-Violet	Visible Spectrum	Infra-Red
Black Light	Violet Blue Green Yellow Red	

365 400 500 600 700

WAVELENGTH (nm)

NB: 1nm (1 nanometre) = 10^{-9}m

Black light with a wavelength of 365nm is typically produced by 100, 250 and 400 watt high pressure mercury vapour lights fitted with Woods Filters to remove the unnecessary wavelengths. The full intensity of the lamp is not reached until at least 5 minutes have elapsed after energising the lamp.

BS4489 gives recommendations for methods of assessing black light used in NDT. The intensity of black light should be 50 lux minimum at one metre distance. However, in use underwater, it should be noted that water absorbs black light and, therefore, the light source to test area distance should be kept to a minimum.

6.2.3.4 FLUX INDICATORS

It is not possible to measure the actual magnetic field strength generated in a material. However, flux indicators can be used to indicate if a particular applied field strength is adequate. Burmah-Castrol Type 1 flux indicators are the most common. These comprise three parallel 42mm long slots spaced equidistant across the width of a magnetic foil sandwich. These simulate defects when a magnetic ink is applied under illumination by UV light and the strip is placed across the direction of magnetic flux in the magnetic field.

An applied field of 30 Oersteds (2400 amp/metre) will result in 3 indications occurring on the strip (2 indications are revealed at 15 oersteds).

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6.2.3.5 MAGNETIC INKS

Magnetic inks are used to detect flux leakage and are made of carefully selected ferromagnetic materials of correct size, shape and permeability. They retain very little residual magnetism, ie. have a low retentivity, high permeability and require a very low coercive force to remove them.

Magnetic particles for wet application are suspended in a liquid vehicle (usually water or oil). They may be black, red or fluorescent. The black and red particles contrast against the background of the article to be magnetised, which may be thinly coated with a white contrast paint.

Fluorescent particles are irradiated with ultraviolet light or "black light" from a suitable source, they then fluoresce with great brilliance and so can be detected.

From experience gained from magnetic particle inspections it has been found that an optimum concentration of ink is essential for reliable and valid results. Too many or too few particles will either mask or prevent indications appearing.

Cleanliness of the test piece is also essential. It should be clean and free from dirt, grease, oil, rust and loose scale. If not, the mobility of the inks is hindered to the extent that particles may not be attracted to areas of flux leakage.

Black Inks

The surface of the test area is coated with white contrast paint after thorough cleaning. Black magnetic ink is applied and concentrates at cracks where there is flux leakage.

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The specification (from BS4069) for the composition of non-fluorescent inks is:

Ferromagnetic particles (includes adherent non-magnetic pigments) - not less than 1.25% and not more than 3.5%, both by volume.

Other solid constituents - not more than 10% by weight of the ferromagnetic particles.

Other soluble additives - not more than 10% by weight of the main carrier fluid.

Carrier fluid - the remainder.

Black inks are best viewed in daylight or under strip lighting. Very rarely used underwater.

Fluorescent Inks

Fluorescent inks are ferromagnetic particles coated with a dye which fluoresces brilliantly under ultraviolet light. They require no contrasting paint on the test piece and are more reliable and sensitive than black inks. This is the preferred ink for underwater use.

The factors which determine the perceptibility of fluorescent indications are:

- the amount of particles present.
- the response of the fluorescent dye.
- the intensity of the black light.
- the perception of the viewer.
- the ambient light level.

The specification of above water fluorescent inks is:

- Fluorescent ferromagnetic particles - 0.1 to 0.3% by volume (0.6 to 2.4 $g.l^{-1}$).

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- Other solid constituents - not more than 10% by weight of the ferromagnetic content.

- Other soluble additives - not more than 10% by weight of the main carrier fluid.

- Carrier fluid - the remainder.

- Flourescent inks are the ones most commonly used under water.

Magnetic Ink Testing

Magnetic inks are tested to ensure they are of the required specification. The common method is to use a settling test utilising a graduated Sutherland flask.

Immediately after thoroughly mixing the ink transfer a 100ml sample into a suitably supported Sutherland flask. Allow the sample to stand until the apparent line of demarcation between solids and liquid has attained a constant level, usually 60 minutes. Read off the nearest 0.1ml level reached by the solids and record it as the solids content by volume.

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6.2.4 MPI TECHNIQUES UNDERWATER

6.2.4.1 INTRODUCTION

Magnetic particle inspection always requires human judgement and true defects to one inspector may be false to another. In order to ensure a reliable and valid result, standards and specifications are written in order to establish the exact parameters to be used. A list of British Standards relating to above water MPI is included at the end of this section. It must be emphasised that the effectiveness of MPI rests on the technical competence of the inspection personnel and their ability to interpret indications.

There are no Standards or Codes of Practice for underwater MPI. The major Certifying Authorities issue guidelines which are being continually updated. The underwater MPI testing procedure and equipment adopted by the technician diver will largely be dictated by:

- the platform operator.
- the Certifying Authority.
- availability of equipment.

6.2.4.2 METHODS OF MAGNETISM

The magnetising techniques employed underwater are:

- Magnets and Electromagnets
- Current Flow Prods
- Closed Loop Current Carrying Coil

(1) Magnets and Electromagnets

Both types of magnets are used underwater, but they suffer from the limitations discussed earlier. These are summarised as:

- Permanent magnet field strength is not variable and its strength is unknown.
- difficulty of removing and replacing permanent magnets.
- good pole contact not assured on most nodal welds resulting in weak magnetisation of the area under test.
- the technique is time consuming.
- permanent magnets lose their magnetism with use and storage.

(2) Current Flow Prods

Sufficient current must be passed through the test area to induce adequate magnetic flux. The prods require 4 to 8 volts and up to 1500 Amps, preferably a.c. Because of voltage drop through long lengths of cable, the prod current is delivered from a transformer situated close to the diver/inspector. The transformer is fed mains current from the surface through a heavy duty power cable. Earth leakage trips must be integral with the unit. It is difficult to get good contact with prods in areas of limited access and often two divers are required to carry out this type of MPI.

(3) Current Carrying Coils

Experience offshore has shown this technique to be superior in most applications giving reliable, reproducible results in a shorter time. The principal advantages of coils are as follows:

- A consistent uniform magnetic flux is applied to the total test area in a single application, ie. weld and adjacent heat-affected zones are magnetised and inspected in a single application, compared to inspecting sections of the same area with prods or permanent magnets.

- The technique is 80% quicker and only needs one diver to use the equipment (compared to current flow prods which require two). On recent tests the weld areas and HAZs on a K-node took two divers 45 minutes to inspect using current flow prods. The same node was inspected with one diver using an underwater closed loop system, in only 9 minutes.
- The magnetic particles have more time to be attracted to fine defects and crack tails.
- The test area is inspected 100%, ie. no areas are missed because of incorrect positioning of prod contact points.
- Arc burns from current flow prods, copper contamination and associated cracking is eliminated.
- Demagnetisation can be carried out on completion of testing.
- Testing can be conducted in more turbulent waters such as the splash zone.
- The current flowing through the coil can be more easily monitored on the above surface control unit.
- Photography and T.V. surveying are made easier since there is better access to the inspection area, and the current is activated continuously.

Although this technique will take time to rig up properly, once set up the inspection will proceed rapidly. If several similar butt welds are to be inspected it may be advantageous to use a JIG. This consists of flat copper braid set apart by plastic rods. The JIG is fitted into position and is then connected by leads to the submersible unit.

6.2.4.3 <u>UNDERWATER TEST METHOD</u>

A consistent technique is necessary and is similar to that used above water, and is generally as follows:

1. Prepare the surface of the test area by cleaning to a bare metal finish which should extend to a distance adequate enough to enable intimate contact of the magnetising equipment.

2. Switch on the U.V. light and allow it to reach maximum intensity (ie. 5 minutes must elapse). Ensure the ink is agitated and of a uniform concentration.

3. Visually inspect the weld.

4. Place flux indicators on the test article to check for residual magnetism, demagnetise as necessary.

5. Energise the magnetisation system and apply ink as a diffuse cloud over the test area. Increase the magnetising current until three indications are obtained on the Burmah Castrol flux indicator. Commence weld inspection checking for indications. If found, repeat the inspection test, interpret and record as specified. Repeat flux indicator test at appropriate intervals (normally the 12, 3, 6 and 9 o/c positions on weld).

6. Demagnetise if possible.

7. If required, apply ink and energise magnetisation system 90° to the previous direction.

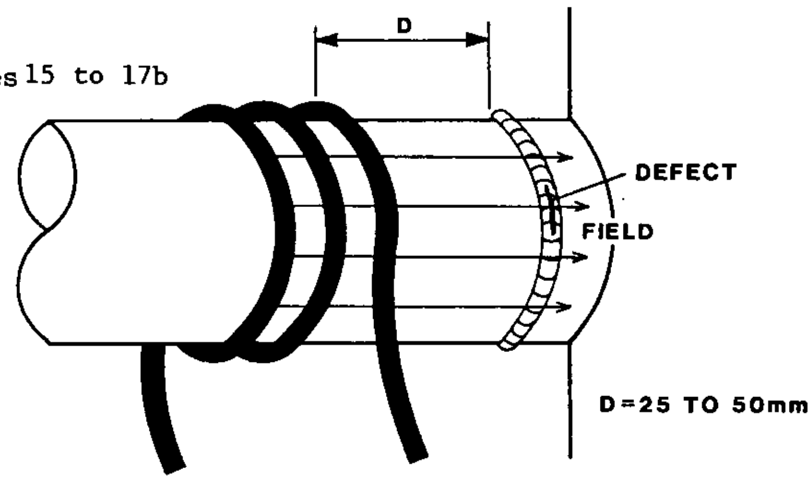
8. Inspect, interpret, record.

9. Demagnetise.

10. Move to next test area.

11. Report the inspection concisely.

Refer to Figures 15 to 17b

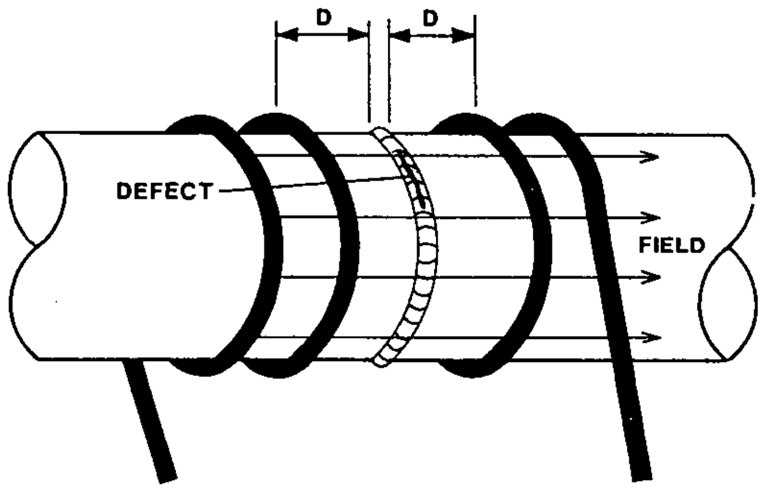


(i) Tightly wrap coils around member side of weld

(ii) Maintain distance D as constant as possible, 25mm to 50mm from weld toe.

(iii) Place flux strip on parent metal on chord side, 25mm to 50mm from toe.

Fig. 15: Coils

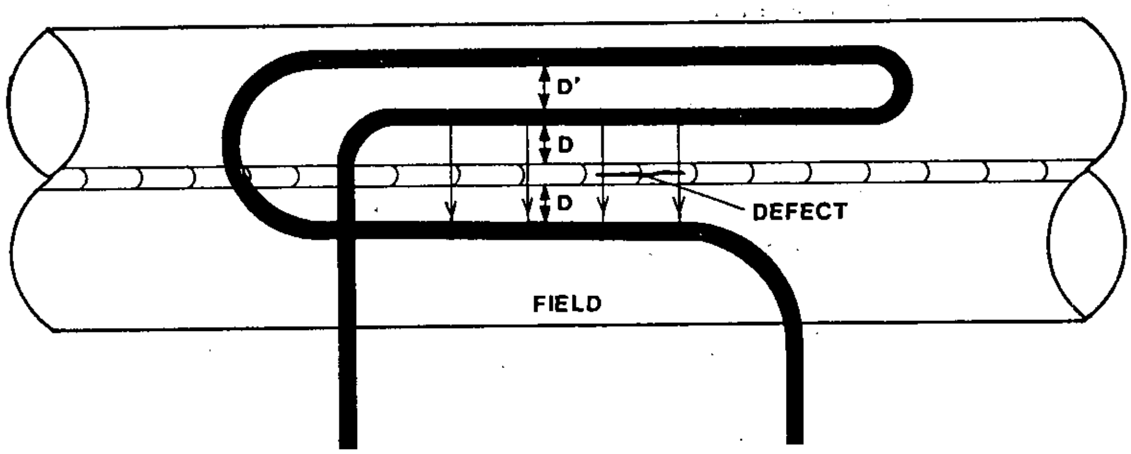


(i) Position each loop 25 to 50mm from nearest toe.

(ii) Reposition coil to have crossover diametrically opposite to ensure full coverage of weld.

(iii) Place flux strip as close as possible to weld centreline.

Fig. 16: Split Coils



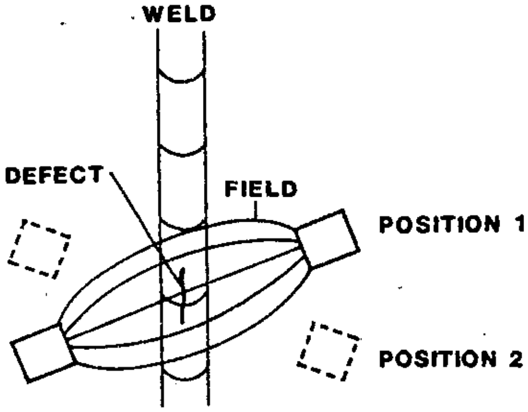
(i) For coils adjacent to weld toes, D = 25mm to 50mm.

(ii) Return loop must be held away from the inspection area conductors by not less than 10 times the distance between the parallel conductors.

(iii) Flux strip to be placed as close to centreline as possible.

Fig. 17a: Parallel Loop

Contents



(i) Position poles to attain maximum pole face contact. Magnets must be positioned twice at each point on the weld to cover all possible orientations of defects.

(ii) Place flux indicator strip at each location, midway between the probes transverse to pole axis.

(iii) Move along major axis of weld, ensuring sufficient overlap to give full coverage. The interpretation must be made only between the poles of the magnet/electromagnet.

Fig. 17b: Permanent/Electromagnet

6.2.4.4 INTERPRETATION OF INDICATIONS

Once an indication is given, its nature and extent must be assessed, ie. the indication must be interpreted. Knowing the history of the test piece and the material of which it is made, serves to form a logical starting point for interpretation of an indication. Knowing what to look for, when and where to look for it, requires a thorough knowledge of the discontinuities, their features and likely locations. It is important to be able to distinguish between:

(1) relevant indications.

(2) non-relevant indications.

(3) false indications.

(1) Relevant Indications

(a) Surface Cracks

These give patterns that are sharply defined, tightly held and usually the ink builds up heavily. Surface cracks appear like the edges of a torn piece of paper. These would include, for example, fatigue cracks, heat treatment cracks, grinding cracks crater cracks and lack of penetration if the back side of the weld is accessible.

(b) Sub-Surface Cracks

These produce a less distinct fuzzy pattern which is often difficult to interpret. The ink is less tightly adherent.

(2) <u>Non-Relevant Indications</u>

These indications are due to magnetic particles being attracted to leakage fields that occur from causes other than discontinuities.

The most common cause of non-relevant indications is excessive magnetisation. Too much current causes flux leakage at sharp edges or at abrupt changes in thickness of the article. Much depends on the permeability of the metal. Each material has a saturation point, which cannot be exceeded, and hence excessive lines of flux are forced out of the material causing flux leakage.

Common non-relevant indications are caused by geometry changes in the specimen, especially at sharp edges. Grain structure changes (ie. change in permeability), grinding marks and surface damage caused by tools give non-relevant indications.

(3) <u>False Indications</u>

These result from magnetic particles accumulating in surface irregularities and being held mechanically or by gravity. They are not formed by magnetic attraction. If the test piece has a rough surface, is dirty or is contoured in such a way that magnetic particles collect, an indication may appear in a shape that looks like a true indication. These are usually removed by flushing the area with clean water.

6.2.4.5 RECORDING

(1) The Essential Content of a Record

The philosophy of inspection recording is discussed in Section 9 Recording of Data. Magnetic particle inspection datasheets will vary in format but the essential information should include:

- Report number.
- Name of Client.
- Contract number.
- Name of Inspector.
- Name of Inspection Controller.
- Date.
- Dive Number.

Information on the object under test:

- Identification; reference number, depth, etc.
- Key diagram.
- Node diagram.
- Weld diagram.

Information on equipment and technique:

- Equipment specification.
- Demagnetisation: pre and post.
- Amps (coil/parallel conductor).
- Flux check, ie. 30 Oe. min using BC strip.

The routine test data should be filled in under the appropriate heading shown above.

Contents

Results, ie. indications, should be recorded on the weld diagram and also written in the comments section using correct terminology as to the type of indication and its strength.

Indications should be reported as being:

- cracklike
- continuous/intermittent
- branching/non-branching
- strong/weak

The length of indication should be recorded and also its position, measured, with reference to the 12 o' clock position. The relative position with respect to the weld should also be given ie. upper toe, lower toe, centre of cap, etc. It is important to obtain as accurate a description of the defect as possible.

It is good practice to run through the completed report with the Inspection Diver to ensure that all pertinent points have been recorded and that all the information is clear and unambiguous.

The record should be signed and dated by the Inspection Controller.

(2) <u>Preservation of Indications</u>

An MPI indication discovered will require preservation or marking in some way.

This is usually accomplished by dot punching the extreme ends of the indication. A paint stick may then be used to link the two ends so that once testing has finished the position and extent of the indication can still be seen.

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Preservation of the actual indication may be accomplished only by using either magnetographic tapes, which will preserve the indication on the tape, or by photography which is discussed below. It may also be possible to preserve the indication by the use of Aquaprint moulding compound.

(3) **Photography: Methods and Considerations**

Photography of fluorescent MPI indication is the method which has undergone most development in preserving indications. It is possible but difficult to produce good and repeatable results.

The essentials are:

- having little or no ambient light.
- using a large amount of artificial light (ie. two strobes/flash) filtered to give transmitted UV light only.
- a reasonably fast film (eg. 400 ASA).
- normal close-up camera.

Care should be taken that magnetic fields produced do not affect magnetic reed switches on camera systems.

6.2.4.6 DEMAGNETISATION

It is important to demagnetise the worksite on completion of MPI in order to reduce the residual induced magnetic field.

Demagnetisation is performed by applying to the worksite an alternating current magnetic field of suitable frequency and then gradually reducing the current to zero.

Any remanence of magnetic field should then be tested using the flux indicators before final de-rigging.

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6.2.4.7 CARE AND CALIBRATION OF EQUIPMENT

Submersible MPI Equipment

Two commercial units are generally approved for offshore use:

OIS, MkII, supplied by Oilfield Inspection Services Ltd.
OSEL MPI unit, supplied by OSEL Offshore Systems Engineering Ltd

Specific operating instructions apply to each unit but the following general checklist should be applied to confirm the unit is ready for operation:

1. All cables, hose and umbilical components to be free from kinks and external damage.

2. All connectors to be free of foreign materials, all electrical connectors to be sprayed with silicon grease prior to assembly.

3. Attachment points to be secure and rigging in serviceable order.

4. Pressure compensating fluid, where applicable to be water free and at specified level.

5. Ink reservoir and dispensing system to be flushed clean with fresh water.

6. Ink reservoir to be replenished with approved dilution of fluorescent MPI ink no more than 1-2 hours before use.

Contents

7. Function power checks to be carried out as follows:

a) Connect up all services with <u>power off</u>.

b) Set current output control to minimum.

c) Test warning lamps light when input power switched <u>on</u>.

d) Switch on output to coils/electromagnet, a small current should be registered by the ammeter.

e) Test UV lamp function by switching on and observing glow. The lamp should not be on for more than 5 minutes on the surface. It should then be allowed to cool prior to immersing in water.

f) Depress control valve on ink dispenser for 15 secs to clear the lines of air and hose contents. Confirm supply and agitator functions.

g) Test ELCB (earth leakage) trips, reset and stop switches.

<u>Fluorescent MPI Inks</u>

Specific mixing instructions will apply to each brand of MPI ink. The following checklist should be applied to confirm the diluted ink is ready for use:

1. Preparations made from powder require the powder supply to be checked. The powder shall be free running and consist of finely divided particles.

2. No more than 10% of volume (at final dilution) of liquid wetting agent shall be employed.

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3. Where powder is used an initial dispersion shall be prepared at approximately ten times the required concentration of MPI particles. The water used shall be fresh and shall be no hotter than 50°C.

4. Dilution to specification shall be with water at ambient temperature. Agitation for not less than 5 mins will precede step five below.

5. A sample (100ml) shall be extracted and used for a settlement test (60mins) in a Sutherland flask. The solids content shall be in the range 0.2 - 0.6% by volume.

6. A non-magnetic strainer shall be used when filling the MPI dispenser. All crystalline particles and aggregation retained on the filter will be rejected (BS 4069: 1982 recommends 99% of a representative sample shall pass a 100 µm filter). At the discretion of the appointed subsea inspection engineer excessive residue shall cause the ink batch to be rejected.

<u>Flux Indicators</u>

The only flux indicator currently approved for use during MPI tests is the Burmah-Castrol Brass Type I indicator. The indicator is suitable for re-use over several applications, subject to the following checks:

1. The strip should be washed off with fresh water so as to be free of retained magnetic particles.

2. There should be no kinks or deformations present which will interfere with the planar contact necessary.

3. A check must be made for residual magnetism in the strip.

Contents

6.2.4.8 SOME BRITISH STANDARDS RELATING TO ABOVE WATER MPI

BS 6072	Method for magnetic particle flaw detection.
BS 4069	Magnetic flaw detection inks and powders.
BS 5044	Contrast aid paints used in magnetic particle flaw detection.
BS 4489	Method for assessing black light used in non-destructive testing.
BS 3683	Glossary of terms used in non-destructive testing, Part 2; Magnetic particle flaw detection.
BS 4360	Specification for weldable structural steels.
BS 499	Part 3, Terminology of and abbreviations for fusion weld imperfections.
BS 4397	Methods for magnetic particle testing of welds.
BS 89	Specification for direct acting indicating electrical measuring instruments and their accessories.

6.3 ULTRASONIC INSPECTION

In ultrasonic testing use is made of the basic physical property that sound waves travel at known constant velocities through any sympathetic medium. By measuring the time for a sound wave to travel through a material it can be determined how far that wave has travelled. In this way sound waves can be used to measure distances. Use can also be made of the fact that sound waves are reflected at an interface between two materials such as steel and air to detect defects.

In order to develop and make the best of these principles the basic physical properties of sound should be understood.

6.3.1 THE PRINCIPLES OF SOUND

Sound is a series of mechanical vibrations or pressure waves which bring about a state of alternative compression and rarefaction, (or dilation) of the molecules or particles in the material in which they are propagated.

To convey sound such as speech or a ringing bell, a medium is required which possesses elastic properties, ie. all solids, liquids and gases. The pulses of sound can be described as discrete events within the material following a wave form.

The higher the density, the lower the velocity.

The higher the strength or elasticity, the higher the velocity.

The velocity of sound is constant for any given medium although it changes from medium to medium.

Contents

6.3.1.1 WAVE PROPAGATION

There are several different types of sound waves. The three principle types are as follows:

Longitudinal or Compression Waves

Longitudinal waves like speech consist of alternate compression or dilation of pressure waves and these vibrations move in the same direction as the energy of propagation, (Figure 18).

The particle mechanism depends on the elastic interconnections, thus as each particle moves from equilibrium it pushes or pulls the adjacent particle and transmits at the velocity of sound.

Transverse or Shear Waves

The particle vibrations are at right angles to the propagating source and can only exist in materials possessing "shear elasticity".

By virtue of its path, the velocity of shear waves is approximately half of longitudinal velocity (.55); thus the wavelength is also halved.

The shear wave motion can be compared to the whip-like action of a rope attached to a wall (Figure 19).

Surface (or Rayleigh) Waves

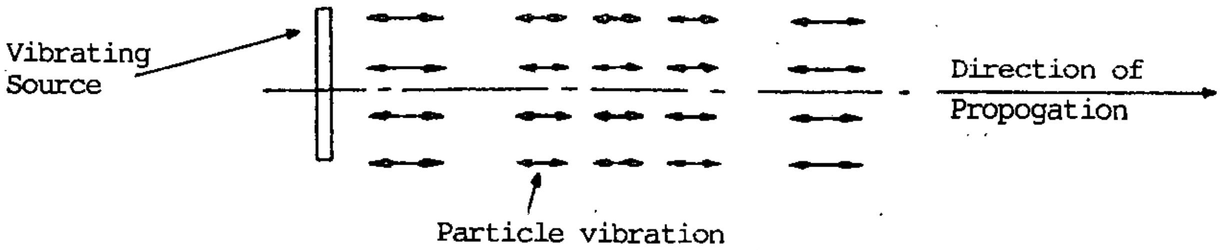
These are similar to transverse waves but differ in that they do not penetrate below the surface by more than one wavelength, and have a velocity of 2% less than transverse waves.

Contents

The particle motions of surface waves are a combination of longitudinal and transverse waves and thus follow a rolling or orbital particle motion, (Figure 20).

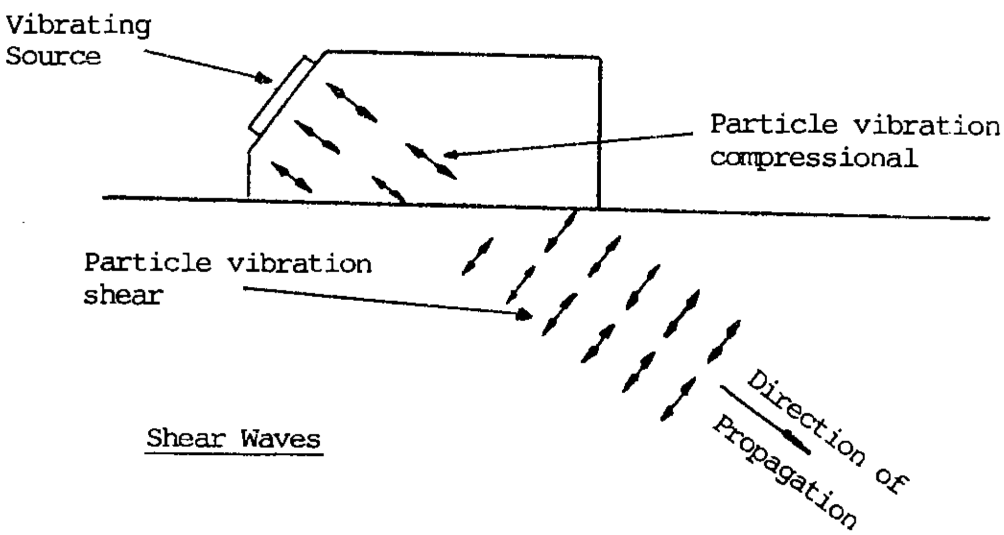
Each material has a unique speed of sound for each type of sound wave ie. the velocity of sound (transverse) is approximately half the velocity of sound (longitudinal) in the same material. Refer to table below.

Material	Compression Velocity m/s	Shear Velocity m/s
Air	332	-
Aluminium	6,400	3,130
Brass (70-30)	4,372	2,100
Cast Iron	3,500	2,200
Copper	4,769	2,325
Gold	3,240	1,200
Iron	5,957	3,224
Lead	2,400	790
Oil	1,440	-
Perspex	2,740	1,320
Steel-mild	5,960	3,240
Steel- stainless	5,740	3,130
Water	1,480	-
Tungsten	5,174	2,880
Zinc	4,170	2,480
Zirconium	4,650	2,300



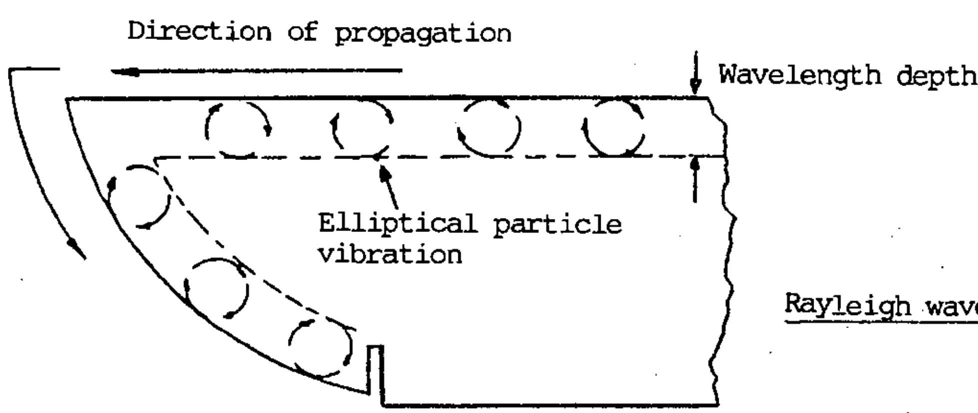
Compression waves

Fig.18



Shear Waves

Fig.19



Rayleigh waves

Fig. 20

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6.3.1.2 **SOUND WAVE TERMINOLOGY**

Amplitude

The size of disturbance of each molecule from its state of rest. The greater the amplitude the louder the noise (Figure 21).

Wavelength (λ)

The distance travelled by a sound wave in the time it takes the source to produce one complete oscillation or cycle is termed the wavelength, (Figure 21).

Velocity (V)

The speed or velocity, measured in metres per second (m/s) that a sound wave travels through a medium is dependent on the elasticity and density of that medium, ie. the material's properties.

Frequency (f)

Frequency is measured in cycles per second or Hertz.

The more vibrations or oscillations each molecule makes in a set period of time the higher the frequency, (Figure 22).

A high frequency sound is said to have a high pitch.

The wavelength (λ), the frequency (f) and the velocity (V) are related by the formula:-

$V = f\lambda$

where λ = wavelength in metres.

F = frequency in cycles/second.

V = velocity in metres/second.

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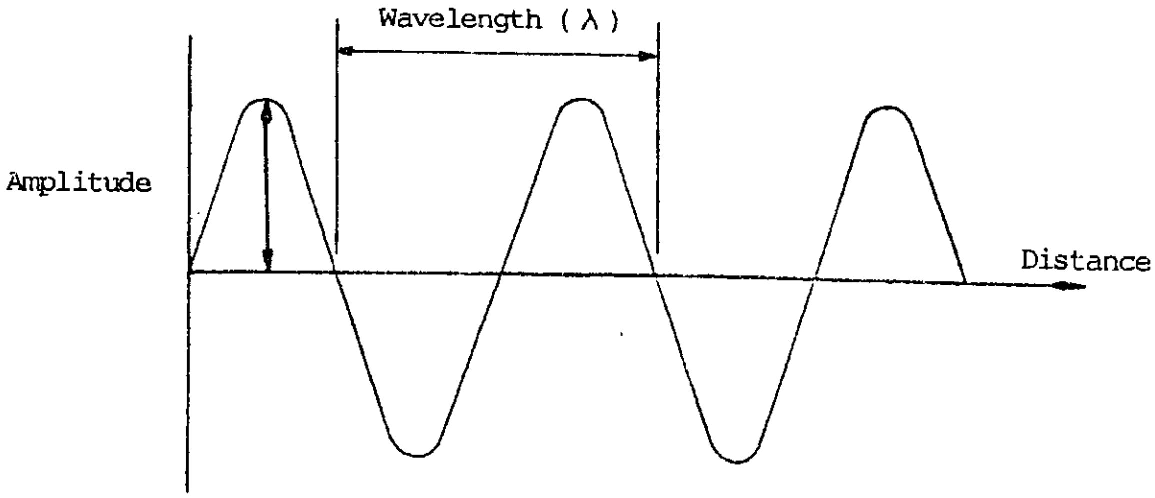
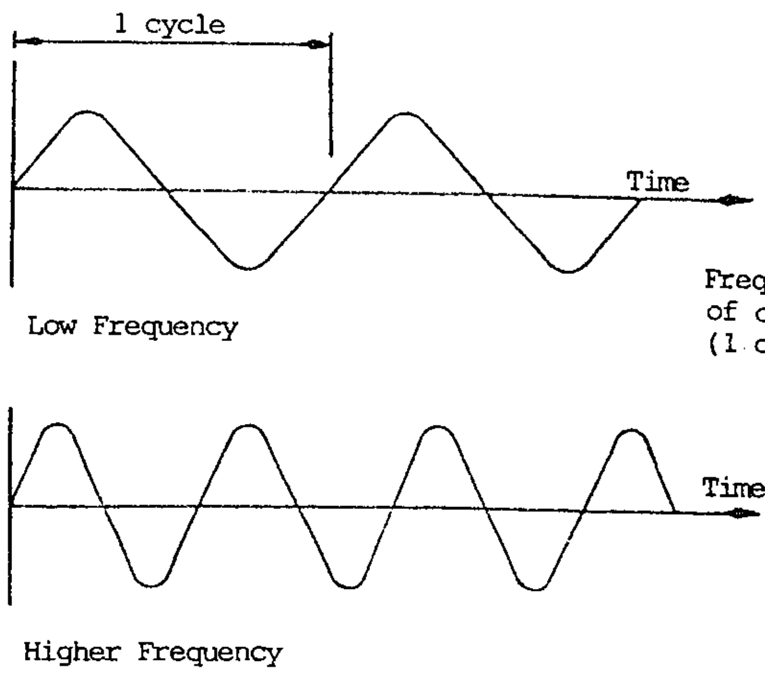


Wavelength is the length of one cycle

Fig.21



Frequency is the number of
of cycles per second
(1 cycle per second = 1 Hertz)

Fig. 22

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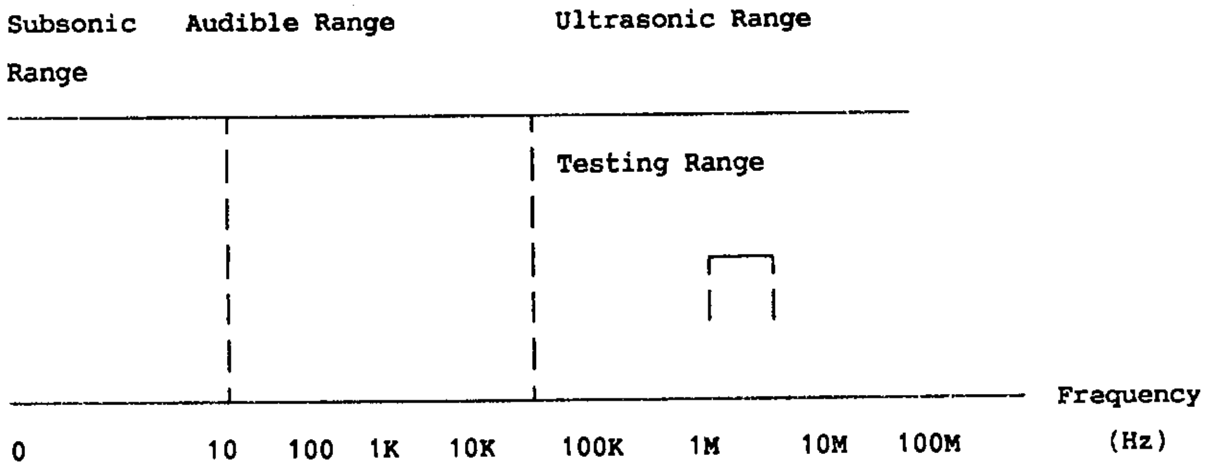
6.3.1.3 THE ACOUSTIC SPECTRUM



1 Cycle per second = 1 Hertz = 1 Hz
1,000 = 1 Kilo Hertz = 1 KHz
1,000,000 = 1 Mega Hertz = 1 MHz
Subsonic Range - below 16 Hz
Audible Range - 16 Hz to 20 KHz
Ultrasonic Range - above 20 KHz
Usual Ultrasonic Test Range 1 MHz to 6 MHz

Vibrations in air molecules can be produced at any frequency but our ears can only detect those within a certain range.

Audible Range: The lower limit is taken as approximately 16 Hz and normally the upper limit is taken to be 20,000 Hz (abbreviated to 20 KHz).

Subsonic Range: Vibrations below the audible range, that is below 16 Hz.

Contents

Ultrasonic Range: Vibrations above 20 KHz are termed "ultrasonic waves". It is generally known that dogs can hear sound waves which are too high a pitch for us to hear, in fact up to 25 to 30 KHz. Bats work at even higher frequencies, between 30 and 50 KHz, at which they practice their own branch of pulse-echo location. Ultrasonic flaw detection equipment is operated at frequencies much higher than this, from 500 KHz to 20 MHz. The most common test range being somewhere between 1 MHz and 6 MHz.

6.3.1.4 BEHAVIOUR AT AN INTERFACE

In common with light, when ultrasonic sound waves encounter an interface some of the energy is reflected and some refracted.

Acoustic Impedance (Z)

This is a measure of the resistance a material presents to sound waves travelling through it. It is a function of the density (ρ) of the material and the velocity (V) of the sound wave.

$$Z = \rho V$$

Reflection

When sound waves encounter a sudden change in acoustic impedance in a material, such as occurs at a steel/air interface, some of the sound will be reflected back into the first material. The amount of sound reflected will depend on the relative acoustic impedances of the two mediums, (Figure 23).

Angle of incidence (i), is always equal to the angle of reflection (r).

Refraction

Some of the incident sound will travel across the interface and continue in a different direction. This change of direction is called refraction. It is a function of the change in speed of sound between two mediums, (Figure 23).

Laws of Reflection and Refraction

The angles of reflection and refraction are governed by Snells Law which is:-

$$\frac{\text{Sin } i}{V_1} = \frac{\text{Sin } r}{V_2}$$

Mode Conversion

Since the various types of waves (compression, shear, etc.) have different velocities in any medium when reflection or refraction take place at an interface, more than one type of wave may be produced. This is known as mode conversion.

For example, a compression wave incident on a material interface may produce a reflected compression wave, a reflected shear wave, a refracted compression wave and a refracted shear wave.

Expansion of Snells Law (Figure 23)

$$\frac{\text{Sin } i^\circ}{V_{1c}} = \frac{\text{Sin } r^\circ s}{V_{1s}} = \frac{\text{Sin } r^\circ c}{V_{1c}} = \frac{\text{Sin } R^\circ s}{V_{2s}} = \frac{\text{Sin } R^\circ c}{V_{2c}}$$

where i° = angle of incident wave.
$r^\circ s$ = angle of reflected shear wave.
$r^\circ c$ = angle of reflected compression wave.
$R^\circ s$ = angle of refracted shear wave.
$R^\circ c$ = angle of refracted compression wave.

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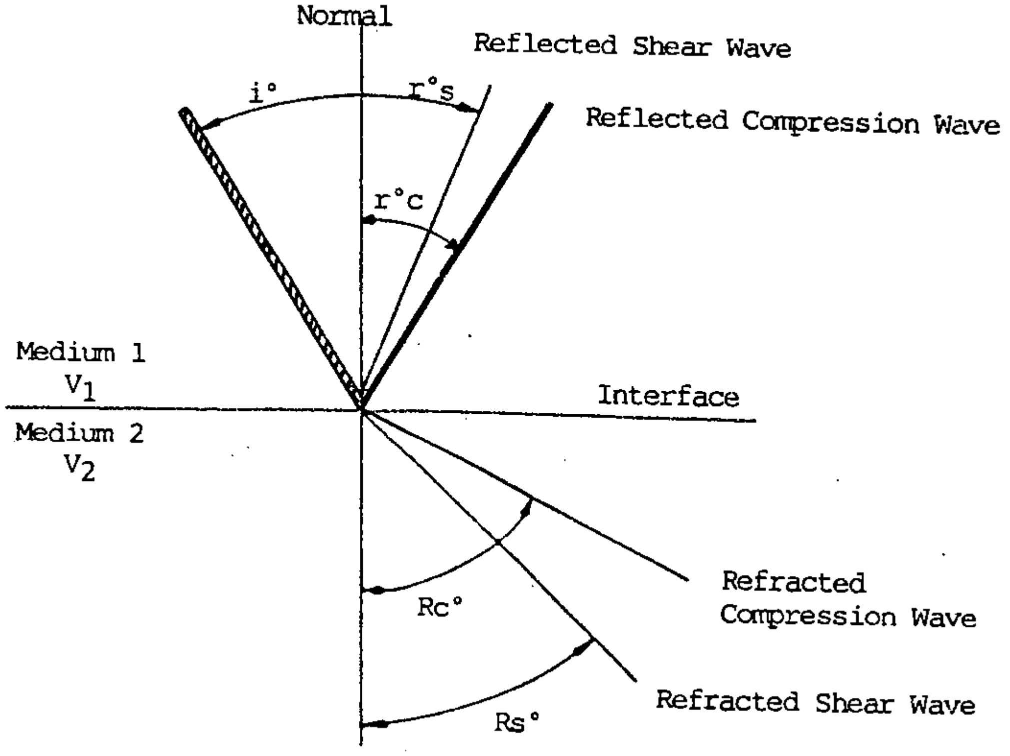
V_{1c} = velocity of compression wave in Medium 1.

V_{1s} = velocity of shear wave in Medium 1.

V_{2c} = velocity of compression wave in Medium 2.

V_{2s} = velocity of shear wave in Medium 2.



Reflection and Refraction: Snells Law

Fig 23

6.3.1.5 ATTENUATION, ABSORPTION AND SCATTER (Figure 24)

Attenuation

When sound waves are emitted they spread out in all directions and therefore their intensity reduces with distance travelled in accordance with the Inverse Square Law. The strength of intensity is, however, also reduced or attenuated by two other mechanisms; absorption and scatter.

Absorption

A sound wave propagates by the vibration and collision of molecules. Such molecular movements require energy and also give out energy in the form of heat due to friction. This energy originates in the sound wave. The sound wave is therefore weakened due to absorption of its energy by the molecules of the medium it travels through.

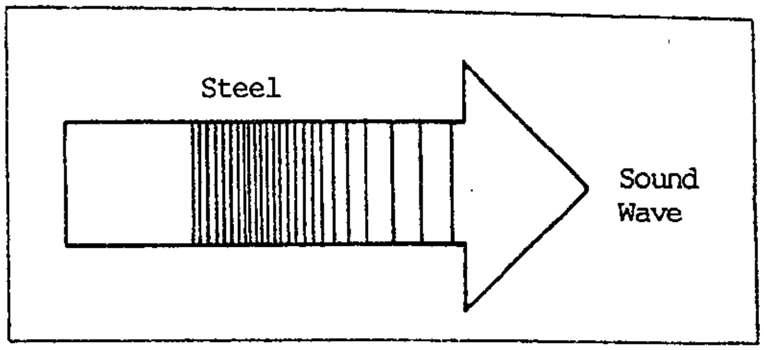
Absorption decreases as sound frequency decreases.

Scatter

Steel, and metals in general, have a grain structure. Grain boundaries refract and reflect a small proportion of the incident sound wave and so tend to scatter it. As a result, less of the sound beam continues in the original direction.

Scatter decreases as sound frequency decreases.

Scatter decreases as grain size decreases.



Attenuation is caused by Absorption and Scatter.
Absorption decreases as Frequency decreases.
Scatter decreases as Frequency decreases.
Scatter decreases as Grain size decreases.

Sound Attenuation

Fig 24

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6.3.2 PRODUCTION OF ULTRASONIC WAVES

In ultrasonic testing sound waves are used with a frequency of 20 KHz upwards. In testing metals a range of 1 MHz to 6 MHz is generally used. To produce these high frequencies use is made of the Piezo-Electric Effect.

6.3.2.1 THE PIEZO-ELECTRIC EFFECT

Certain crystalline substances change their shape slightly when an electrical potential is applied across opposite surfaces of the crystal, and conversely develop an electrical potential when they are subjected to mechanical pressure or shock. This is known as the Piezo-Electric Effect.

If an alternating voltage is applied to the crystal, then it will expand and contract as the voltage changes. Although the expansions and contractions will be of the same frequency as the alternating voltage, each crystal has a natural or resonant frequency at which it tends to vibrate most readily.

The resonant frequency of the crystal is directly related to its thickness. If the crystal in Figure 24A was given a very short pulse of voltage by closing and immediately re-opening the switch then it would vibrate for a very short period at its resonant frequency before the expansions and contractions died away.

If the crystal was to be given a sharp knock by mechanical means, then it would also vibrate for a short period at its resonant frequency producing an alternating potential across its surfaces at the same frequency.

Such devices which convert electrical energy to mechanical energy or vice-versa are termed transducers. In ultrasonic testing equipment the transducer is incorporated in a device termed an ultrasonic probe. A loudspeaker is another common transducer.

Contents

Piezo electric transducers can be manufactured from a number of materials including quartz and ceramics. Common ceramics used in the ultrasonic transducer are barium titanate and lead zirconate titanate.

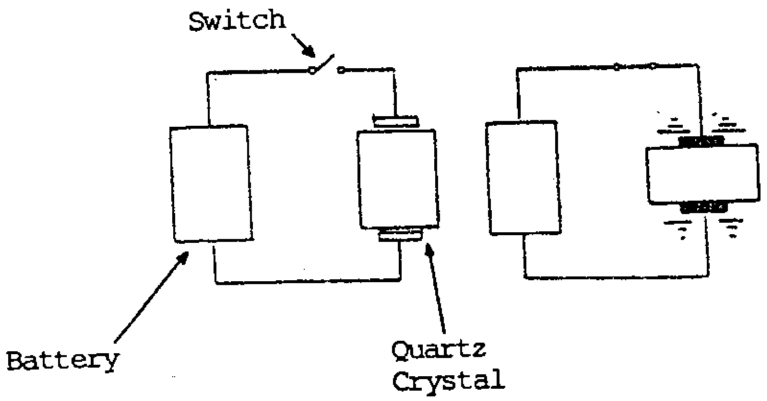
The vibrating crystal is used to produce ultrasonic compression waves within the probe.

6.3.2.2 THE PULSE-ECHO SYSTEM

The most common system used in ultrasonic thickness measurement and ultrasonic flaw detection is the pulse-echo system. Here the piezo-electric transducer is repeatedly excited for a short duration to produce sound wave pulses. There is a delay of micro-seconds between each pulse, (see Figure 25).

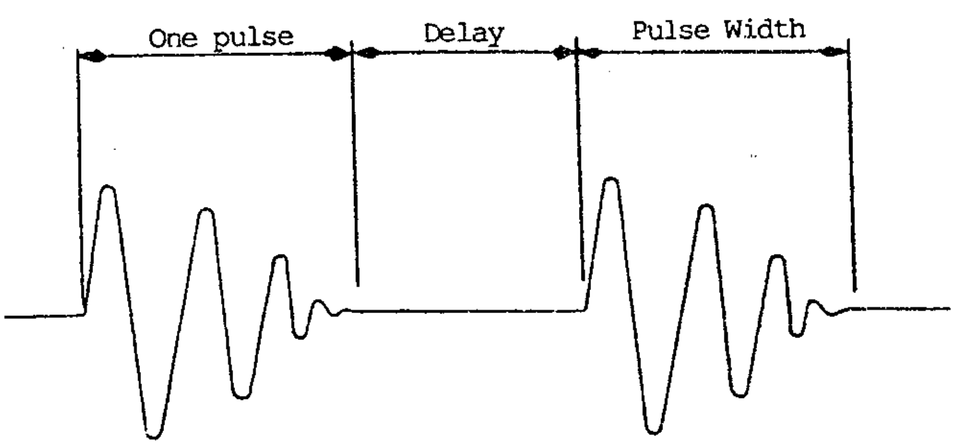
These sound wave pulses travel through the material under test until they meet an interface or boundary, where they are reflected back. If the sound hits the interface at right angles then the reflected sound travels back to the probe as an echo. Echoes coming back to the probe are reconverted into electrical signals and the time between transmitting the pulse and receiving the echo is electronically measured.

By calibrating the ultrasonic equipment for the speed of sound in the test material the equipment is able to display the time taken for the pulse-echo to travel through the material as a distance.



Piezo Electric Effect

Fig. 24A



Pulse - Echo System

Fig. 25

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6.3.2.3 ULTRASONIC PROBE CONSTRUCTION

Compression Probes

The simplest form of compression wave probe is the single crystal probe; this can act as the transmitter of ultrasonic waves and also as the receiver, (Figure 26).

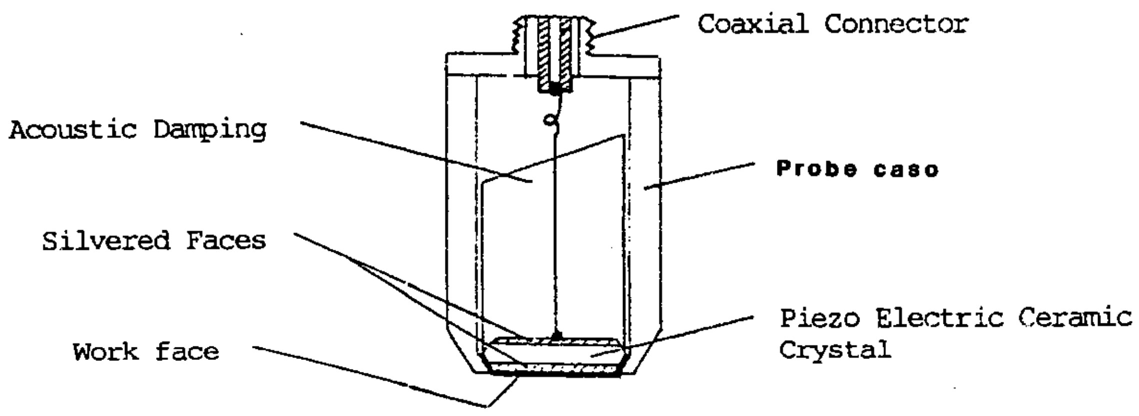
When using a single crystal probe and the pulse echo system, the probe acts as both the transmitter and receiver by 'listening' for the echo during the non-productive delay between emitting each pulse.

The twin crystal probe is basically the same as the single crystal probe but uses one transducer for continually transmitting ultrasonic waves and one for receiving, (Figure 27).

To prevent 'cross-talk' between the two crystals a cork insulator is used to separate the probe into two, and the thickness of the perspex shoe is increased. This has important side effects which will be discussed later.

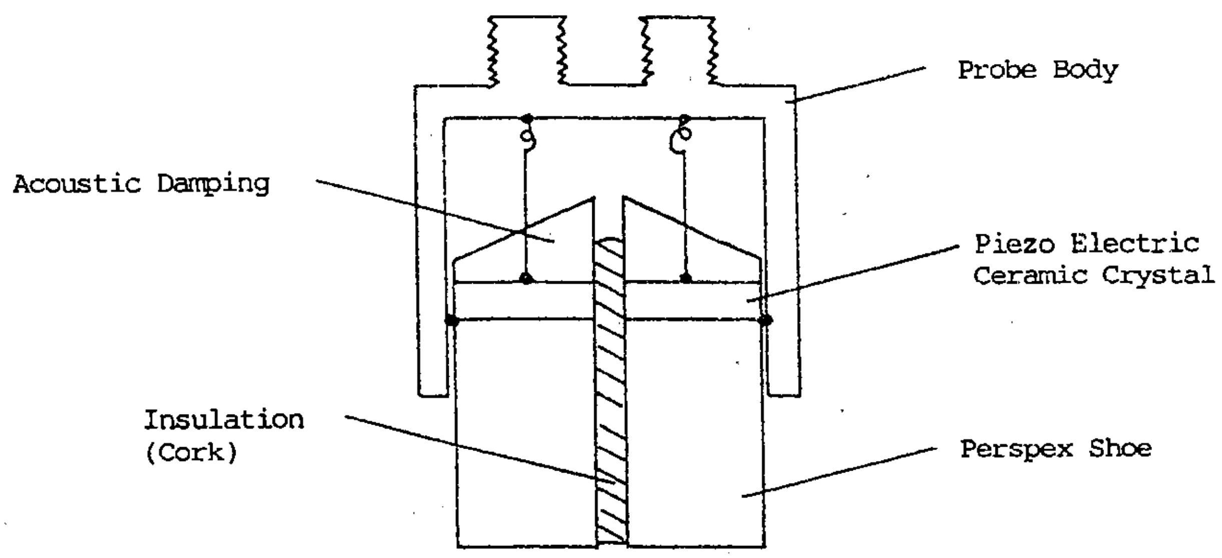
In ultrasonic thickness measurement compression probes are generally used. These will introduce ultrasound into the material at right angles to the surface of the material. No refraction takes place at the first surface and only compression waves enter the material. Thus longitudinal or compression waves are used when normal (0°) compression probes are used for ultrasonic thickness measurement.

All crystals in probes emit compression waves. However, a probe can be designed to operate in the shear mode by having a wedged shaped frontal member so that the probe directs compression waves at an angle to the surface of the test part. The angle of incidence is such that only shear waves enter the material. In general, the angle indicated on the probe refers to the angle from the vertical (normal) in steel.



Single Crystal Compression Probe

Fig. 26



Twin Crystal Compression Probe

Fig. 27

6.3.2.4 THE ULTRASONIC BEAM

So that an ultrasonic beam can be used as method of defect assessment, it will be necessary to produce a divergent beam in the material concerned.

The ultrasonic beam produced by the simplest round single crystal probe is basically as shown in Figure 28.

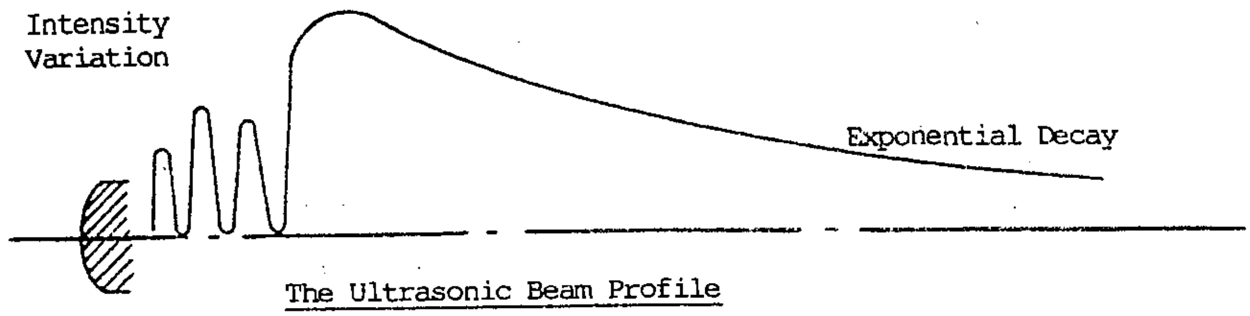
The Dead Zone is a zone where it is not possible to detect defects. Due to imperfect damping of the crystals some waves will interfere with the returning waves. This problem can be overcome by using twin crystals, one transmitting, one receiving. The higher the probe frequency the shorter the Dead Zone.

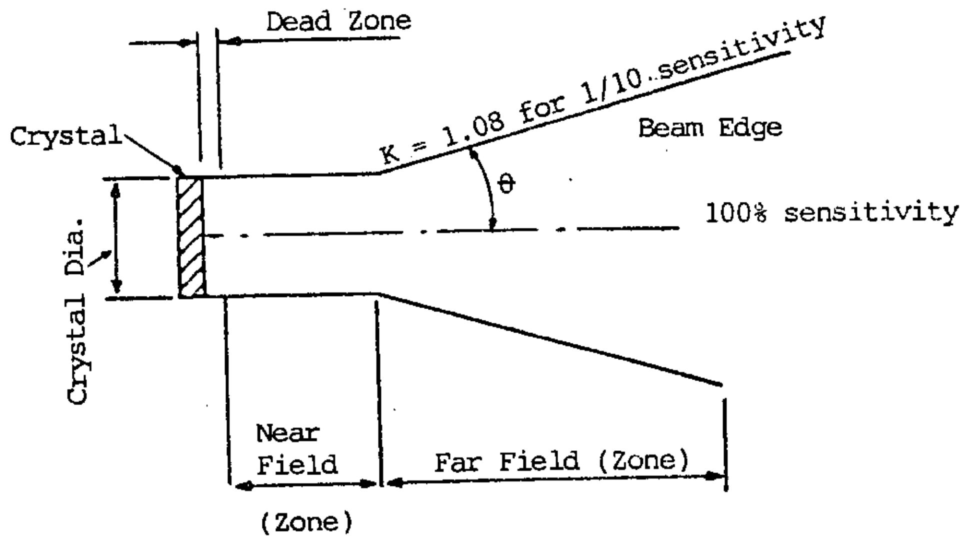
The Near Field is an area of 'turbulence' and varying sound intensity. Due to the effect of interference in the near field the signal height from the same size of defect may increase when it is positioned further away from the crystal. Similarly, small defects may be completely overlooked.

In the Far Field the beam diverges and the signal height from the same size of defect decreases in relation to the distance in accordance with the inverse square law.

It is convenient to define the beam 'edge' as the point, across the beam, where the intensity of sound has fallen to one half, or sometimes one tenth of the intensity at the centre of the beam. Whenever possible we use the Far Field in ultrasonic testing, the near field usually being accommodated within the perspex shoe of the probe.

It can be seen from the formula, (Figure 28) that by increasing the probe diameter or increasing the frequency (shorter wavelength), the solid angle of the beam will decrease.





Near Field

Length = $\frac{D^2}{4\lambda}$

D = Crystal Diameter
λ = Wavelength

Far Field

Angle of Divergence

$\sin\theta = \frac{K\lambda}{D}$

K = 1.08 for 1/10 Edge) Constant
K = 0.56 for 1/2 Edge)

θ = 1/2 beam angle

Fig. 28

Contents

6.3.2.5 COUPLANT

As stated earlier the amount of sound reflected at an interface is governed by the relative acoustic impedances of the two mediums across the interface.

Air has a very low acoustic impedance compared to perspex, and as a result the majority of the sound will be reflected back into the probe if air is present between the probe and the test piece. Therefore, when ultrasonic testing it is important to exclude all air and this is generally achieved by using oil, grease or water as a 'couplant'.

In a diving mode sea water will act as the couplant.

Some typical values for acoustic impedance are given below:-

Material	Acoustic Impedance (Kg/m^2 sec x 10^6)
Air	0.0004
Aluminium	17.3
Brass	37.0
Cast Iron	25.0 to 40.0
Iron	46.8
Lead	27.2
Nickel	48.5
Oil	1.3
Perspex	3.2
Steel (Mild)	46.7
Steel (Stainless)	44.8
Water	1.48

6.3.2.6 SURFACE CONDITIONS

The surface finish of the material to be tested is important. Surface irregularities will cause a deterioration in the coupling conditions resulting in a reduction in sensitivity of the test, increased probe wear, and increased difficulty in probe handling. This, in turn, will make defect sizing and location more difficult. Loose paint, scale, marine growth, etc. will also affect the quality of the test and, therefore, should be removed.

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6.3.3 ULTRASONIC EQUIPMENT

The majority of ultrasonic testing equipment operates on the pulse echo system, ie. the time for a pulse of sound to travel through a material, bounce off a reflector and then return to the transducer is measured.

6.3.3.1 MODE OF PRESENTATION

In the case of simplified equipment, such as the Seaprobe 200, the electronic circuitry has been designed to measure the time of flight of the pulse. This time is multiplied by the pre-set speed of sound in the material and presented, in digital form. The result is precisely half the distance travelled, (ie. the thickness of the material), (Figure 29).

In ultrasonic flaw detectors, such as the Krautkramer USM2 or the Baugh and Weedon PA 1011 the same functions are carried out, but the results are presented on a cathode ray tube (CRT). This type of presentation is known as 'A' scan.

The horizontal distance along the time base of the CRT is calibrated in terms of thickness and the pulse echo is presented as a vertical deflection of the time base. The further the pulse travels through the material the more the deflection of the time base moves to the right, (Figure 30).

The signal obtained from the pulse travelling through the full thickness of the material under test is referred to as the 'back wall echo' (BWE).

The flaw detector is able to present more than one signal simultaneously, (Figure 31).

Digital wall thickness units, however, are programmed to select only the strongest signal and display that. This can sometimes cause problems in this type of unit, particularly when several signals of similar strength are obtained and which result in the instrument 'hunting', ie. the numbers do not stabilise and instead change continuously.

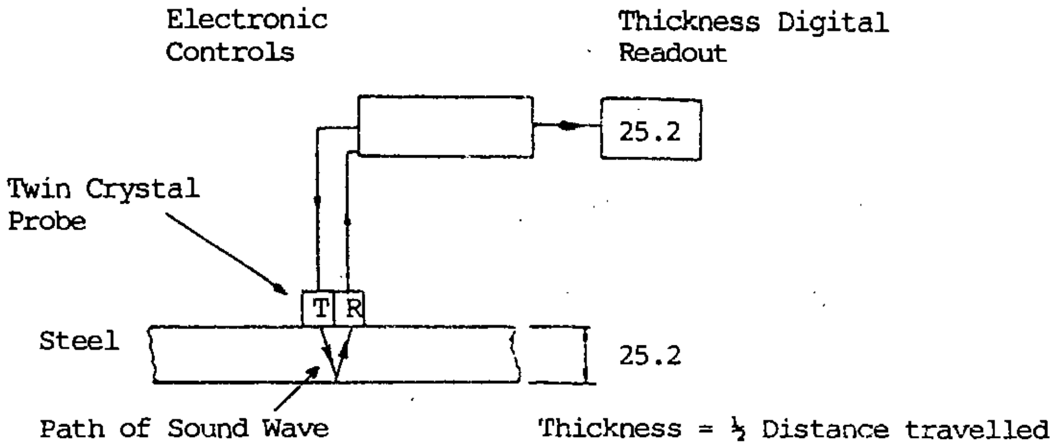

FIG.29

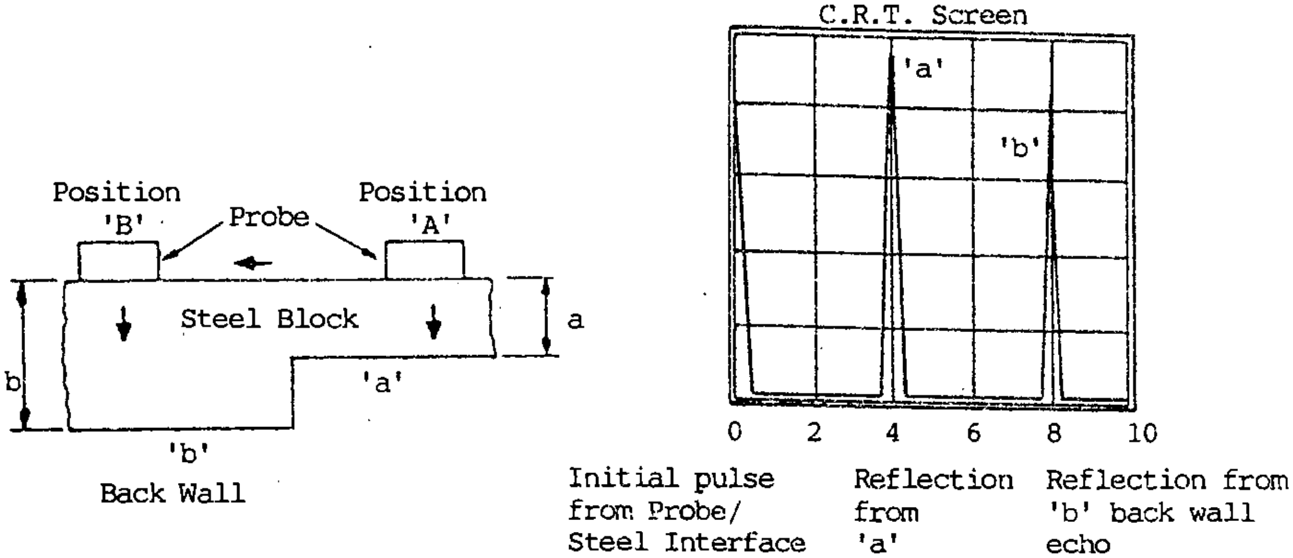

FIG.30

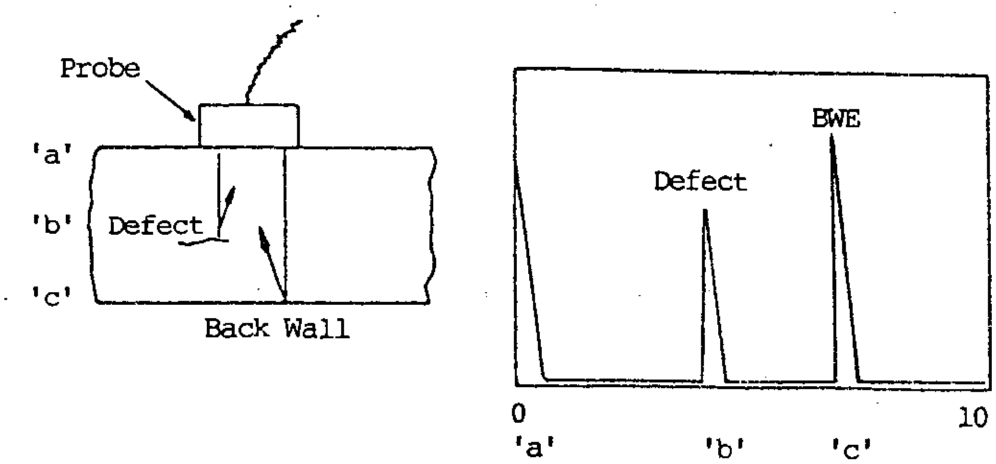

FIG.31

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6.3.3.2 THE ULTRASONIC FLAW DETECTOR COMPONENTS

The display of information can take several forms depending on the type of flaw detector, but all units similar to the USM2 or PA 1011 use a cathode ray tube as shown in Figure 32.

Electrons (-ve) are emitted from a heated cathode and are attracted towards the highly +ve anode. The focus cylinder constricts the electron flow into a narrow beam which passes through the anode cylinder to eventually hit the fluorescent screen causing a bright green display.

The brightness of the display is controlled by the grid which allows more or less electrons to pass depending on how negatively it is charged. The horizontal and vertical movements of the electron beam are controlled by the X and Y plates respectively by applying potentials across the plates. Changing the potential between the X plates, for example, causes the electron beam to traverse the screen.

Figure 33 gives a general block diagram of an ultrasonic flaw detector.

The pulse generator sends a pulse to the probe and also triggers the time-base generator. The time-base generator causes the electron beam to cross the CRT screen at the same rate as the ultrasonic pulse emitted from the probe crosses the steel block and back. The initial pulse appears at point 'a' on the CRT, Figure 33.

The electrical signals from the receiver transducer are amplified and fed to the Y plates where they cause deflections in the electron beam. In Figure 33 the signal from the flaw is represented at point 'b' and the back wall echo is represented at point 'c' on the CRT.

If the steel block was 25mm thick and the speed of sound in steel is approximately 6000m/sec, it would take the ultrasonic pulse approximately 8 millionths of a second to traverse the block and the time-base generator would cause the electron beam to traverse the screen at the same rate. Obviously this is too rapid for the human eye to register the information, so the whole process is repeated many times a second at the pulse repetition frequency (PRF). Increasing the PRF gives an apparently steady display. However, for thick specimens of steel too high a PRF will result in pulses being transmitted before the echoes from previous pulses have been received. Therefore the PRF is adjusted to compensate for changes in range or depth of material being tested.

Both the time-base generator and the amplifier must have truly linear characteristics if the instrument is to be of any value as a flaw detector.

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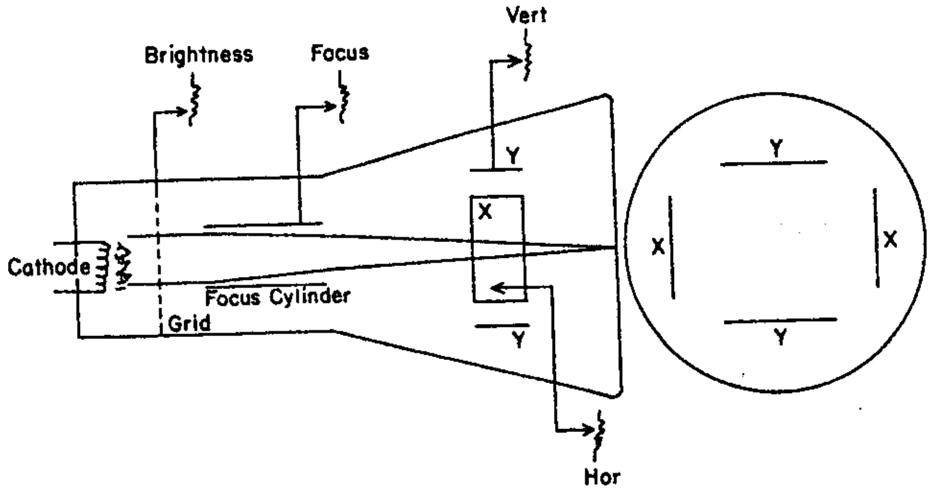

Fig. 32

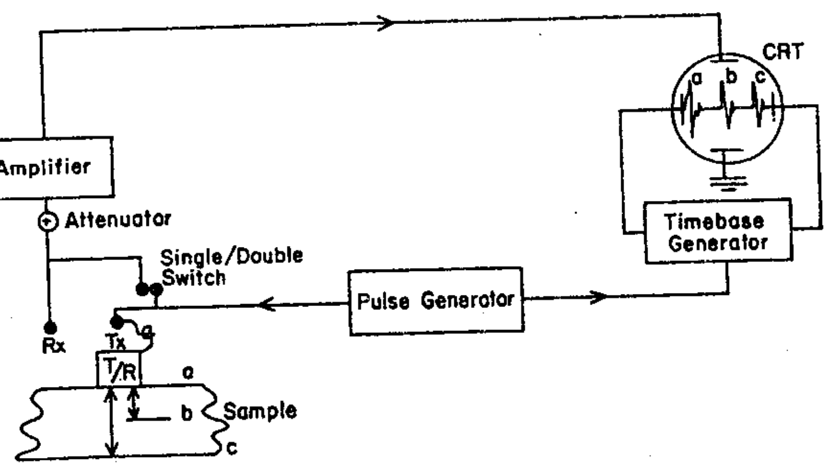

Fig. 33

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6.3.3.3 <u>FLAW DETECTOR CONTROLS</u>

Different makes and models of flaw detectors have different control facilities. Figure 34 illustrates the layout of the Krautkramer USM2, the basic controls of which are described as follows:-

KRAUTKRAMER USM 2
(IN U.W. HOUSING)

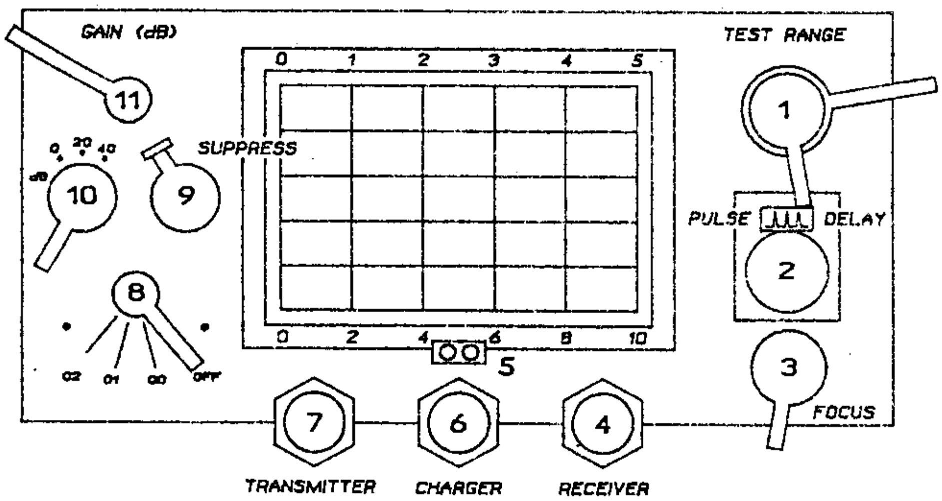

Fig. 34

Depth (or Test) Range Control (1)

To display the full thickness of a steel specimen over the breadth of the screen, it is necessary to ensure that the electron beam (or 'spot' on the screen) takes at least as long to sweep from left to right as it takes the sound to travel to the bottom of the specimen and back.

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Varying the test range control affects the time-base generator so that the spot traverses the screen at the correct speed. Setting the coarse control to 50mm, for example, ensures that the spot traverses the screen's full width in the same time it takes for the ultrasonic pulse to leave the probe transmitter, traverse 50mm of steel and return an echo to the probe receiver. The screen can now be considered as equivalent to 50mm of steel and any defect indications will be displayed on the screen in their correct positional relationships.

The fine adjustment test range control allows the screen width to be made equivalent to thicknesses of steel between the settings of the coarse control, ie. 10mm, 50mm, 250mm and 1m.

The pulse repetition frequency (PRF) is automatically adjusted to suit the test range.

<u>Pulse Delay (or Zero Shift, or Delay) Control</u> (2)

Used in conjunction with the range control when calibrating the instrument, this control allows the whole display to be moved sideways across the screen without affecting the positional relationship of any signals on the screen.

Twin crystal compression probes have a relatively thick perspex shoe, and reflections of sound from within the shoe can cause deflections of the spot to occur on the screen immediately after the initial transmission pulse. Rotating the pulse delay control can move this part of the display off the screen to the left so that other deflections on the screen are not confused.

<u>Focus Control</u> (3)

This control ensures that the electron beam is focused to produce a clear sharp image on the screen.

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Operating Mode Control (8)

This switch (particular to the KKUSM-2) allows the operator to select different modes of operation and pulse energy levels.

Position 1 switches the set OFF.

Position 2 (00) is used when separate transmitter and receiver transducers are to be used, either as two separate probes, or as a twin crystal probe.

Position 3 (01) is used when a single crystal probe is used both as transmitter and receiver in pulse echo mode.

Position 4 (02) is the same as Position 3 but provides a higher transmitter power.

Suppression (or Reject) Control (9)

This control allows the whole CRT display to be reduced in amplitude. It suppresses all deflections between the Y plates and is used to remove unwanted noise or "grass" at the bottom of the screen. It should, however, be used with discretion as it will reduce defect signals and affects the linearity of the screen. This control should not be used when defect sizing.

Gain (or Calibrated Gain, or Attenuator, or Sensitivity) Control (10 and 11)

This control amplifies (or if rotated in the opposite direction, attenuates) the incoming echo signal before it reaches the CRT Y plates. Whereas the suppression control reduces or increases all the deflections of the spot on the screen equally, the gain control alters only the echo signals received by the probe, and reduces or increases these signals by precise fractions or multiples of the amplitude of the pure signal.

The gain control is calibrated in decibels (dB).

The coarse gain control provides two steps of 20 dB to allow up to 40 dB control.

The fine gain control provides twenty steps in 2 dB increments to allow up to 40 dB control.

The coarse and fine gain controls together provide up to 80 dB gain control in 2 dB increments.

The gain control facilitates defect sizing, either for small defects by comparing signal heights with those signals obtained from artificial defect reference blocks, or in the case of large defects, it is used to assist in plotting the defect's extremities.

6.3.3.4 THE DECIBEL UNIT

The decibel is a logarithmic unit used in the comparison of sound intensities or pressures (P).

$$\frac{P_1}{P_2} = 10^n \quad \text{where} \quad n = \text{Bels}$$

$$1 \text{ Bel} = 10 \text{ dB}$$

$$n = \log_{10} \frac{P_1}{P_2} \text{ Bel}$$

$$n = 10 \log_{10} \frac{P_1}{P_2} \text{ dB}$$

Pressure is related to the square of the amplitude or signal height.

$$n = 10 \log_{10} \frac{A_1^2}{A_2^2} \text{ dB}$$

where A_1 and A_2 are respective signal heights

$$n = 20 \log_{10} \frac{A_1}{A_2} \text{ dB}$$

<u>Example</u>:

An echo height difference of 2:1 can be expressed as a 6 dB difference since:-

$$20 \log_{10} \frac{2}{1} = 6 \text{ dB}$$

A Conversion Table covering the range ± 20 dB is given below:

dB	h_1/h_2	dB	h_1/h_2	dB	h_1/h_2	dB	h_1/h_2
0	1.00	10	3.2	0	1.00	-10	0.32
1	1.12	11	3.5	-1	0.89	-11	0.28
2	1.26	12	4.0	-2	0.79	-12	0.25
3	1.4	13	4.5	-3	0.71	-13	0.22
4	1.6	14	5.0	-4	0.63	-14	0.20
5	1.8	15	5.6	-5	0.56	-15	0.18
6	2.0	16	6.3	-6	0.50	-16	0.16
7	2.2	17	7.1	-7	0.45	-17	0.14
8	2.5	18	7.9	-8	0.40	-18	0.125
9	2.8	19	8.9	-9	0.35	-19	0.112
10	3.2	20	10.0	-10	0.32	-20	0.100

Examples of its use outside the range ± 20 dB:-

29 dB = 20 + 9 dB h_1/h_2 = 10.0 x 2.8 = 28

36 dB = 20 + 16 dB h_1/h_2 = 10.0 x 6.3 = 63

46 dB = 20 + 20 + 6 dB h_1/h_2 = 10 x 10 x 2 = 200

-28 dB = -20 -8 dB h_1/h_2 = 0.1 x 0.4 = 0.04

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6.3.4 CALIBRATION OF FLAW DETECTORS

The horizontal and vertical scales on a flaw detector display are only quantitative when they have been calibrated. The horizontal scale, more commonly known as the timebase, can be calibrated to give depth values for different materials and sound velocities. The vertical or amplitude scale can be calibrated to give information on defect size. The method normally employed to obtain quantitative information about a test piece is to compare the screen signals with those from specially machined blocks. These blocks are classified under two headings:-

(1) Calibration Blocks

These are produced from materials of specified composition and heat treatment and are machined to specified shape and surface finish. The calibration block may be a simple step wedge to allow the timebase to be calibrated for accurate thickness measurement, or it may be the more complex "V1" International Institute of Welding Calibration Block which allows for calibration of timebase, plus determination of probe parameters.

(2) Reference Blocks

These are produced from the same material and to the same geometric form as the object to be inspected. Typically a reference block is made up so the ultrasonic operators can gain familiarity with sectional changes and the standard display patterns so formed. The reference block may also contain artificial defects from which the gain to be used in the actual inspection can be determined.

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6.3.4.1 CALIBRATION BLOCKS

Three of the most widely used calibration blocks are:-

(a) The International Institute of Welding "V1" Block (Figure 35)

The block is machined from steel but has a perspex insert at one end. Because the velocity of sound is less in perspex, the time taken for an ultrasonic pulse to travel through the insert is greater than for the same thickness of steel. The perspex insert is machined to such a thickness that the pulse travel time is the same as for 50mm of steel. The insert can therefore be used as a 50mm steel calibration block.

The "V1" block can be used for each of the following assessments:-

i) Calibration of the timebase in terms of thickness.
ii) Assessment of the dead zone.
iii) Checking linearity of timebase.
iv) Checking linearity of the amplifier's gain.
v) Assessing overall sensitivity of probe and amplifier.
vi) Checking resolution.
vii) Determination of beam characteristics.

(b) "V2" Block (Figure 36)

This is a more compact form of the "V1" block, suitable for site use, although somewhat less versatile in its functions.

(c) Institute of Welding (IOW) Beam Profile Calibration Block (Figure 37)

The IOW block is designed primarily for beam profile measurement. Beam profile is the variation in intensity of the ultrasonic beam for various beam lengths.

IIW 'V1' BLOCK

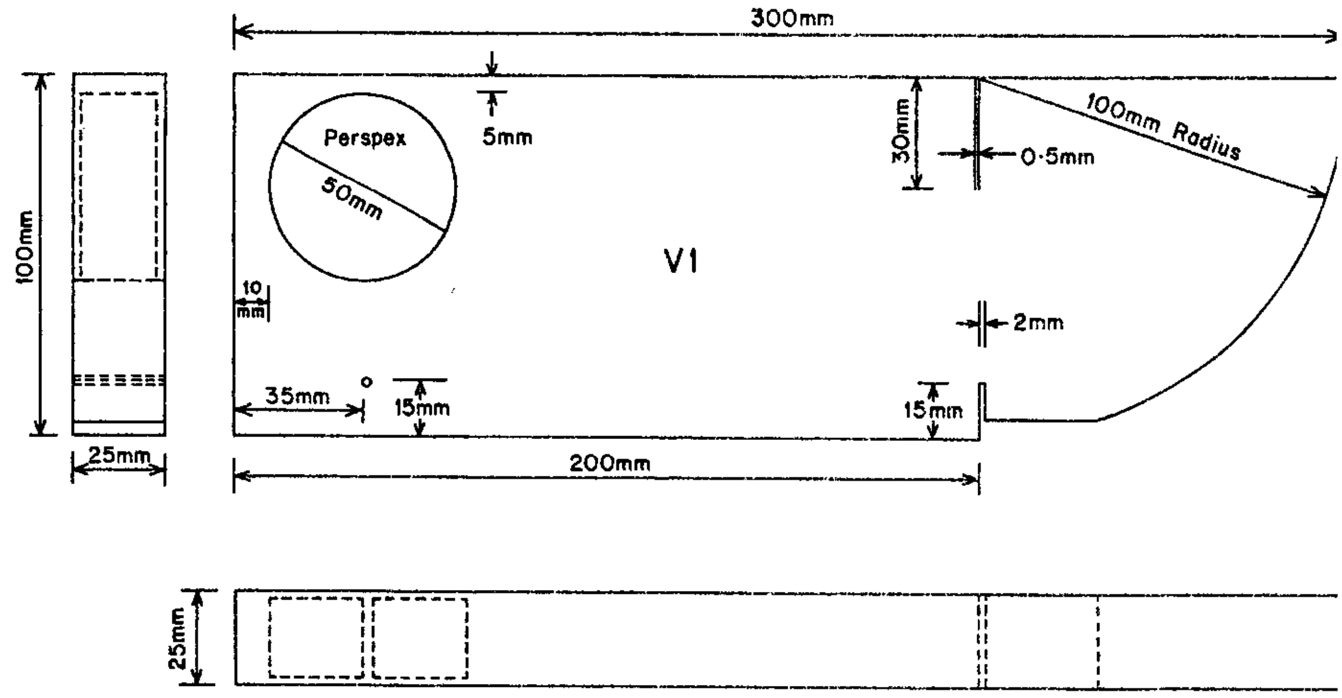

Fig. 35

'V2' BLOCK

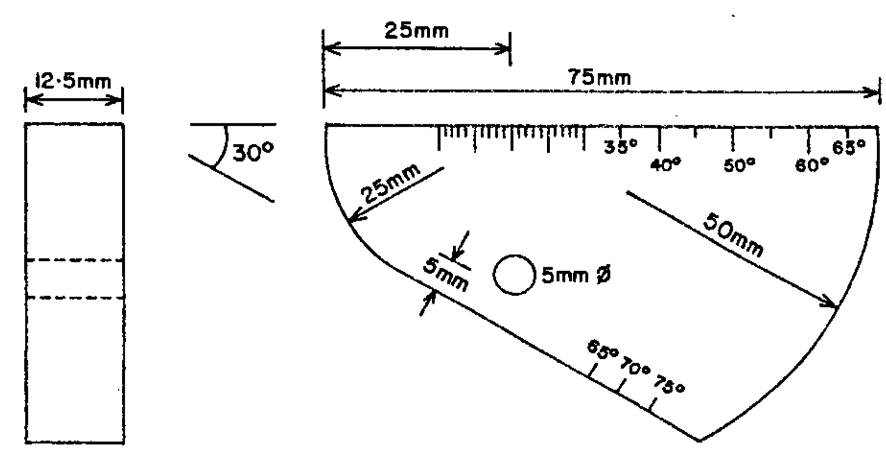

Fig. 36

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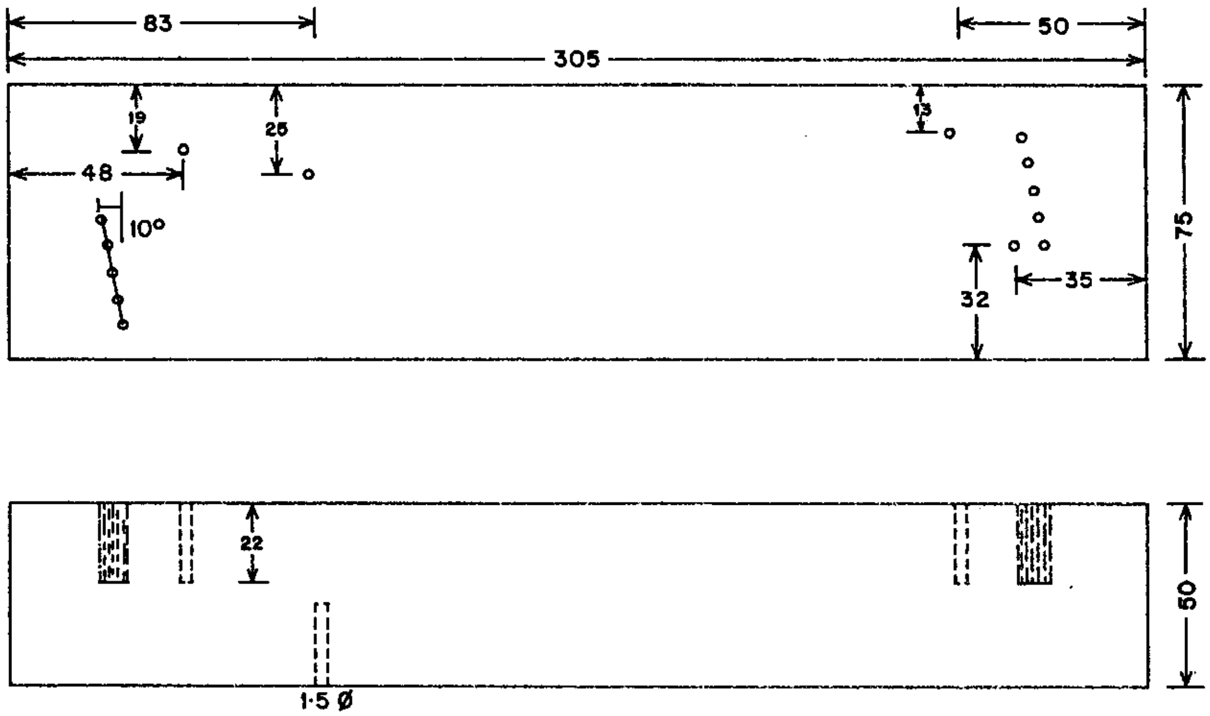
I.O.W. BLOCK



All dimensions in millimetres

Fig.37

6.3.4.2 TIMEBASE AND AMPLIFIER LINEARITY CHECKS

If the timebase (x-axis) and amplifier gain (y-axis) are not linear, the A-scan display will be distorted and accurate positioning and sizing of defects will not be possible.

Unless the instrument can be recalibrated before use, the degree of non-linearity must be ascertained and recorded, usually as a plot, so that accurate readings can be derived. This procedure is not always permitted by some clients, who insist upon the use of instruments accurate within a specified percentage. Calibration figures and correction curves used must always be recorded in the inspection data.

Linearity is checked against manufactured defects of known sizes, normally drilled holes in a calibration block. Multiples of depths should be displayed as consistent multiples of increments on the x-axis. Manipulation of the gain control should result in consistent increases or decreases of display height per unit of gain. Calibration tests must be repeatable before and after actual use of the equipment or results may be nullified. A typical procedure for calibrating the time base linearity using a V1 block is as follows:

1. Connect suitable compression probe to panel and select single probe or double probe position.

2. Switch unit on and allow to warm up for a few minutes - ensure battery is charged.

3. Set Gain to mid-position, range to suit test block, reject (suppression) to off.

4. Apply couplant to side of V1 block and apply probe. Observe signal on screen.

5. Adjust amplitude of traces with Gain Controls so that the 1st back wall echo (BWE) is set to full screen height (FSH).

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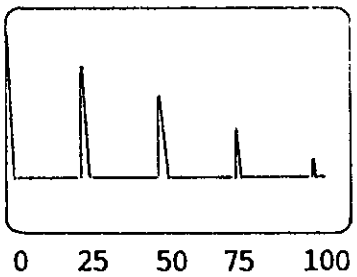
6. Use fine range and pulse delay controls to, adjust first back wall echo to coincide with 2.5 on timebase, 2nd BWE with 5.0, 3rd BWE with 7.5 and fourth with 10.

The position 0 represents the scan surface of the specimen so any resulting distance can be read from the scale.

7. Check by applying probe to perspex insert, the first reflected peak should appear at 5.0 on the time base scale.

8. If four signals cannot be accurately placed an equal distance apart along the time base, then time base sweep is non-linear:



Screen display when unit calibrated for steel thickness 0 to 100mm

6.3.4.3. <u>CHECKS ON COMPRESSION PROBES</u>

<u>Dead Zone</u>

The <u>dead zone</u> on a single crystal probe is determined by calibrating as per normal procedure. The initial pulse on the display screen represents the dead zone and can be directly read off. Twin crystal probes do not have a dead zone.

Controlling factors in the probe affecting the dead zone are:

- pulse length
- dual function of transducer
- amplifier recovery time
- gain setting
- internal reverberations

Contents

Resolution

The resolution is defined as the ability of an ultrasonic unit to display the signals from two small defects close together. Place the probe over the groove in the V1 calibration block. Maximise the signal and adjust gain until all three signals are produced. If the three signals are clearly defined then the set has good resolution.

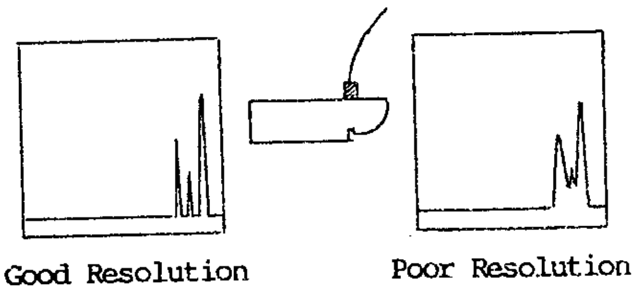


Fig. 38

Sensitivity Checks

Sensitivity is the ability to find the smallest specified reflection at the maximum testing range. Defect detection will depend on the following factors:-

- Material properties.
- Probe and flaw detector combination.
- Frequency of probe.
- Ratio of noise (gain response) to back wall echo.

Sensitivity is maximised by sounding an artificial reflector at increasing ranges and adjusting for amplitude loss against distance (Distance Amplitude Correction).

Ideally, a horizontally drilled 1.5mm hole should register full screen height at maximum range.

6.3.4.4 CALIBRATION OF UNIT FOR 25MM OF STEEL USING TWIN CRYSTAL PROBE

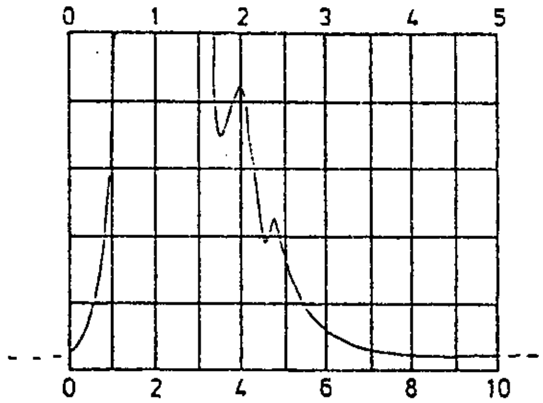
1. Connect probe leads to unit, select twin crystal setting and switch on. Ensure battery is charged.

2. Turn Coarse Test Range to "10mm" position and turn fine control fully anti-clockwise.

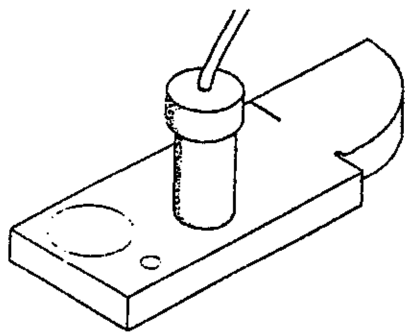
3. Set Coarse Gain Control to 20 dB and Fine Gain Control to 20 dB. Total gain now equals 40 dB.

4. Switch Suppression (Reject) Control to off.

5. Adjust Pulse Delay Control until signal (transmission pulse) appears on screen. Position leading edge of signal at 0 on the grid line.



6. Apply couplant to the 'V1' block and place probe on the block. There should be no change in display since 25mm thickness of block is outside range of timebase at present.

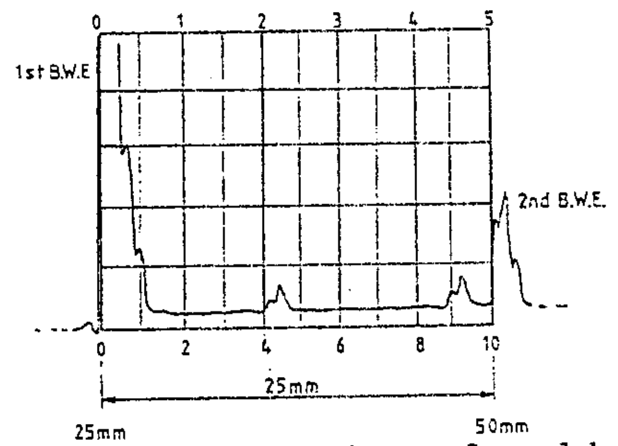


7. Rotate Fine Test Range clockwise slowly. A 2nd signal should appear on the right hand side of the screen. This is the BWE from the V1 block.

8. The initial transmission pulse will have moved to the left whilst the fine gain control was being turned. Adjust the Pulse Delay to bring the initial pulse back on to the screen.

9. Adjust the fine test range and pulse delay controls to obtain both transmission pulse and 'VI' 25mm BWE on to the screen. Adjust pulse delay control until BWE approaches centre of screen. 2nd BWE should now be close to RHS of screen. Continue with pulse delay until 1st BWE is on the 0 grid line.

10. Adjust fine test range to place leading edge of 2nd BWE on extreme RHS grid line. Continue rotating test range and pulse delay until 1st BWE has its leading edge precisely on 0 grid line and 2nd BWE precisely on extreme RHS grid line.

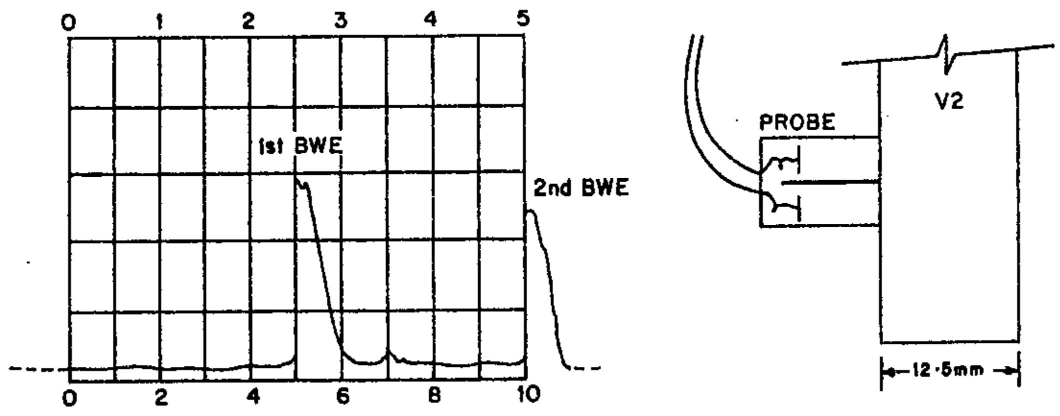


Timebase now represents a thickness of steel between 25 and 50mm.

11. Adjust the pulse delay to bring the 1st BWE exactly to the extreme RHS. Timebase now accurately represents a thickness of steel from 0mm to 25mm.

12. Adjust the fine gain control to bring the 1st BWE to 0.5 full screen height (FSH). The unit is now calibrated for measurements in steel up to 25mm.

13. Check the calibration by measuring the thickness of a "V2" block. Adjust the fine gain control until the 1st BWE is set to 0.5 FSH.



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6.3.5 A-SCAN WALL THICKNESS AND LAMINATION CHECKING

6.3.5.1 INTRODUCTION

Ultrasonic test indications from subsurface discontinuities within the test specimen are usually related or compared to those from standard test blocks having flat-bottomed holes of varying depths or diameters. These comparisons are fairly accurate for evaluating the size, shape, position, orientation and impedance of discontinuities. Test conditions used in the field, and the discontinuities themselves, are sometimes the cause of ultrasonic phenomena which are difficult to interpret. This difficulty may be resolved by experience in relating the ultrasonic signals to the probable type of discontinuity with reference to the test conditions. The experienced operator also learns to discriminate between the indications from actual defects and those of no interest, which are called false or irrelevant indications.

The shape of the defect, the orientation, the contents and even the surface finish of the workpiece itself all combine to alter the amount of reflection. So in fact, if the discontinuity happened to be a large irregularly shaped and diagonally located slag filled cavity, it might only give the same amount of reflected energy as a smooth, flat-bottomed hole reflector.

Only wall thickness, internal corrosion and lamination defects can be detected with A-scan using compression probes.

6.3.5.2 SURFACE PREPARATION

The probe surface requires to be applied directly against the metal surface. Local cleaning must, therefore, precede measurement. Cleaning should remove gross fouling and scale to leave clean bare metal. A poor surface will substantially degrade the results. If satisfactory readings cannot be obtained on heavily corroded or pitted surfaces it may be necessary (dependant on approval) to dress the surface by light grinding.

6.3.5.3 CHOICE OF ULTRASONIC PROBES

Single and Twin Crystal Probes

Twin crystal probes use separate crystals for transmitting and receiving and have thicker perspex shoes, so they do not have a dead zone in the material under test. This means that they are able to test for defects closer to the surface than single crystal probes. The thicker shoe, however, reduces the intensity of the ultrasonic pulse and hence limits the effective working range. Because of this, twin crystal probes are often 'focused' and have an optimum working range.

Single crystal probes have greater penetrating power and are more suitable for testing thick sections.

Underwater we tend to work on thin wall sections and, therefore, generally use twin crystal compression probes.

The higher the frequency the greater the attenuation by absorption and scatter, therefore, when working on coarse grain structures which cause high attenuation a lower frequency probe is selected.

Lowering the frequency has the effect of increasing the beam angle. To overcome this we can increase the crystal diameter.

Generally when testing steels of relatively thin section attenuation is not a problem. We then use higher frequencies which produce a narrow, well defined beam. These higher frequencies correspond to shorter wavelengths and result in shorter pulse lengths which provide a greater ability to resolve small defects and defects close together. In practice, defects with diameters of less than half a wavelength cannot be detected.

A probe with good resolution will be able to detect small defects and will be able to resolve defects which are close together, see, for example, the defects in the I.O.W. block (Figure 37).

6.3.5.4 FLAW DETECTION USING 6 dB DROP METHOD

The oldest method of determining the size of a reflector ultrasonically is by scanning it using the sound field of the probe. By 'wandering around' the reflector, its contours can be estimated.

If this method is used on large flat reflectors (plate tests) then the echo indication, as compared to the maximum indication, decreases by exactly 6 dB if half of the sound beam strikes the reflector and half of it passes by. If, by moving the probe, one looks for the 6 dB drop-off point then the axis of the beam points directly to the edge of the reflector (half-value method).

The procedure is as follows:-

1. Calibrate as required.

2. Obtain maximum signal from defect with probe.

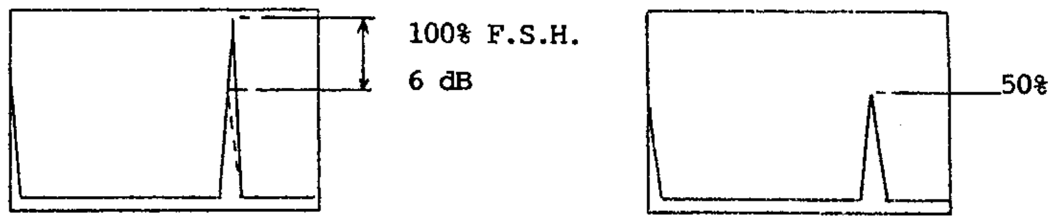
3. Using gain control set signal at 100% FSH.

4. Using gain control reduce signal height by 6 dB and mark screen with wax pencil at top of signal.

5. Reset signal by increasing gain 6 dB.

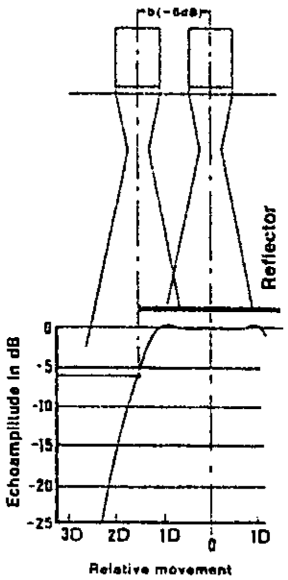
6. Move probe towards edge of defect and stop when last significant echo is reached. This is where the ripple effect ceases and the signal starts to reduce in height. Recheck that signal is still at 100% then continue moving probe till the signal has fallen to the original 50% mark.

Contents



7. When this occurs, a mark should be made on the workpiece to coincide with the centre of the probe.

8. Repeat operations 6 and 7, and plot the edges of the defect.



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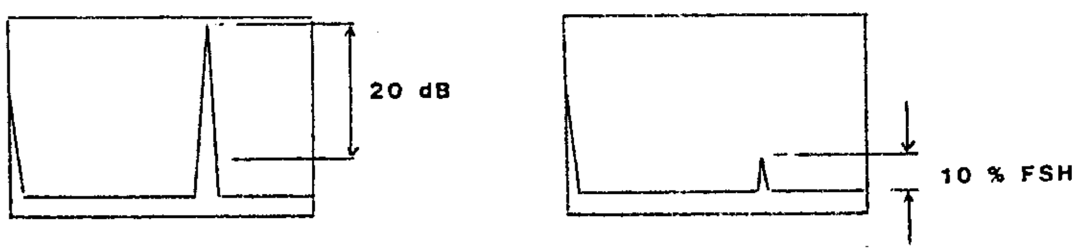
6.3.5.5 FLAW DETECTION USING 20dB DROP METHOD

When great accuracy is needed the 20 dB drop method of sizing is recommended. Here the probe is moved until the signal amplitude has dropped by 20 dB (decrease in amplitude to a tenth of the maximum value) almost to zero. Then virtually the whole of the sound beam passes by the reflector. If the shift is corrected by the width of the sound beam b, then one obtains the position of the edge of the reflector.

The procedure is as follows:-

1. Calibrate as required.
2. Obtain maximum signal from defect with probe.
3. Using gain control set signal to 100% FSH.
4. Using gain control reduce signal height by 20 dB and mark screen with wax pencil at top of signal.
5. Reset signal by increasing gain 20 dB.
6. Move probe towards edge of defect and stop when significant echo is reached. Check signal height is still at 100% FSH then continue moving probe until signal has fallen to the original 10% mark.



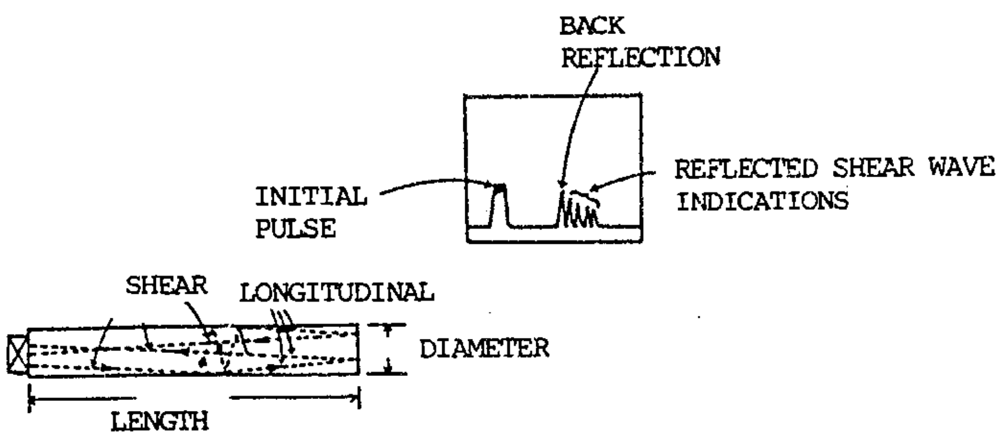
7. When this occurs, note should be made of (a) the position of the signal on the timebase (range) and (b) the position of the probe index in relation to the test piece. The difference gives a measure of the beam width.

8. Repeat operations 6 and 7 and plot the defect.

6.3.5.6 IRRELEVANT INDICATIONS

Coarse grain material causes reflections or 'hash' across the width of the display when the test is attempted at a high frequency. To eliminate or reduce the effect of these unwanted reflections, use a lower frequency probe and/or change the direction of the soundbeam by using an angle-base transducer.

In testing long specimens, mode conversion occurs from the soundbeam striking the sides of the test specimen and returning as reflected shear waves. Changing to a large diameter transducer with a more direct straight sound beam will lessen this problem.



Surface waves generated during straight-beam testing also cause unwanted irrelevant indications when they reflect from the edge of the test specimen. Movement of the transducer will cause the indication initiated by the surface wave to move across the display with the movement of the transducer.

6.3.5.7 PROCEDURE FOR EXAMINING TEST AREA

1. Ensure that surface to be inspected is clean and suitably prepared. Mark up grid if required.

2. Ascertain expected wall thickness and steel type if possible.

3. Select probe to suit job in hand, typically twin crystal, 5MHz, 15mm diameter.

4. Calibrate unit for range of steel thickness to be tested and check that time base is linear.

5. Apply probe to work piece and manipulate until initial BWE is at full scale height. Ensure that the BWE is not from a defect within the steel.

6. Manipulate probe over the surface interpreting signals.

7. Suspected defects to be plotted using 6 dB or 20 dB method as requested.

8. Photograph marked area and take dimensions for report.

9. On surface, check that instrument and probe are still functioning properly and that they are undamaged. Wash down with fresh water, and put on charge.

6.3.5.8 DIGITAL WALL THICKNESS METERS

Digital instruments are designed to convert the time of flight of an ultrasonic pulse through to the back wall of the plate material and its return into a direct statement of thickness.

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Underwater equipment consist of self contained re-chargeable one-piece units. These units have an integral pressure resisting body, a probe facing at one end and a digital read-out at the other. The common units are the Baugh and Weedon Seaprobe 200, the Krautkramer DMU and the Cygnus 1 Ultrasonic Gauge. They are quick and simple to use. The major advantage of the Cygnus 1 unit is that it can be used over coated steel (it internally subtracts the thickness of coating) and so no cleaning to bare metal is necessary. The meters are normally pre-calibrated for steel. No adjustment is possible on-site for the Seaprobe 200 other than by calculation.

The stated accuracy of the Seaprobe 200 is ±0.2mm over the useable range 5mm to 99.9mm. Recharging requires approximately 14-16 hrs and the useable life is approximately 8 hrs, equivalent to approximately 2000 readings. It is normal practice to check the probe against a test block having stepped thickness prior to, during and after use.

6.3.5.9 REPORTING

Type of Report

The order and format of the report is usually defined by the Client. For example, in a very basic report the requirement might be for all the graphics plus a brief report or simply graphics with an introduction.

Should the format not be set, presentation should be logical, clear and accurate, using the best method available to convey information.

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Essential Content

The following information must be included in every report to ensure completeness:-

- Subject(s) of test, location.
- Date, time, conditions (if relevant).
- For whom test performed, tester, dive number.
- Equipment used, calibration/allowance characteristics.
- Marking methods.
- Approach, number of passes.
- Results obtained, sizings, magnitudes.
- Rechecks.
- Recording methods, supporting information.
- Recommendations for further testing, if any.
- Engineer's recommendations, if required.

Reporting Methods

Reports come in both written and graphic form.

Written reports must be intelligible without being too long and should not require illustrations to clarify the text.

Graphics should be completely self explanatory, without separate text, and any scale or exaggeration used must be clearly defined.

Both methods are combined as appropriate.
At all times during the inspection a concise and accurate narrative should be conducted.

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6.3.5.10 SAFETY, CARE AND MAINTENANCE OF A-SCAN UNITS

Health and Safety

The 'A' scan units may present a number of potential sources of hazard, in particular:-

- The battery contains alkaline materials and when charged also contains considerable stored energy. Under failure conditions, the stored energy may cause fire and/or the expulsion of caustic material.

  If a battery is overcharged hydrogen may be produced which could ignite and cause explosion.

- The cathode ray tube, if damaged in any way, may implode. The main hazard is from flying fragments.

- High voltages are generated within the units and particular attention must be paid to electric shock hazard if covers are removed. Users are warned that parts of the equipment may retain electric charges for a considerahle period after the units have been switched off.

Care and Maintenance

Many operational difficulties can be avoided by regular observance of simple routine procedures:-

i) Ensure that all controls, plugs and sockets are kept free of foreign material.

ii) Calibrate for anticipated work and check that the timebase is linear.

iii) Ensure that transducer leads are kept in good condition.

iv) Never operate damaged equipment.

v) Thoroughly wash the subsea housing in fresh water after every dive.

6.4 RADIOGRAPHY

6.4.1 BASIC PRINCIPLES

Radiography is based upon the principle that certain materials are translucent to particular types of radiation. Steel is penetrated by both X-rays and gamma rays. X and gamma radiations penetrate through the test-piece and leave an image on a photographic emulsion. Discontinuities in the test-piece affects the density of the photographic image. A cavity for example absorbs less radiation than the parent material and its image appears black on the developed film.

X-rays and gamma rays are high energy electromagnetic waves (photons) having the ability to penetrate solid matter. X-rays are produced by the collision of fast moving electrons with a metal target. The X-ray tube achieves this circumstance and as such the radiation can be switched on and off.

Gamma rays are produced by certain radioactive materials, or radioisotopes. Most commonly used are Cobalt 60, Caesium 137, and Iridium 192. These sources are always active, and are stored in lead lined containers. The radiation may be released at a target by means of a shutter in the container. The power of these sources will decay over a period of time, varying from months to years dependent on the radioisotope and its respective 'half life'. The gamma ray source is portable, suitability of a source depending upon; the strength of source (activity), size and rate of decay (half life).

6.4.2 RADIOGRAPHIC TECHNIQUE

Radiography is similar to photography in many ways, although the process produces a "shadowgraph" rather than a photograph. This results in an internal picture of the target, where registration is accomplished using an X-ray film.

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The radiation source is directed at the test piece, and a film plate (sensitive to the radiation) is placed on the opposite side of the test piece. A timed exposure is followed by development and examination of the film. Therefore, by employing a radiographic technique documentary proof of a defect (film) is obtained, specifying the nature of the fault, position and extent.

Radiography is primarily used to detect volumetric flaws (ie. cavities, inclusions, porosity) and is not suited to the detection of planar defects. As with other NDT techniques, it is possible to calibrate a system with the use of standardised test pieces which contain a range of known flaws.

X-rays have not been used underwater, although gamma rays have been used infrequently with varying degrees of success. The technique has most often been applied under controlled conditions, as in habitat repairs of pipelines.

For tubular weld inspection the Double Wall Single Image (DWSI) technique is used. This system requires that the film pack is positioned directly over the area to be radiographed while the radiating source is placed on the other side of the tubular, diametrically opposite the film pack.

Usually a single radiograph only will be recorded for each exposure of the source. For long welds, a mosaic series of exposures shall be recorded with sufficient overlap allowance to ensure a continuous picture of the weld can be built up.

Lead I-dents are used and Image Quality Indicators (IQI) must be included in each exposure. The IQI is used to determine the ability of the radiograph to show small changes in thickness and detail.

6.4.3 SAFE WORKING METHODS

Radiography as an NDT tool involves the use of X and Gamma ray sources which are harmful to life and radiological protection is of vital importance in radiographic practice.

Personnel involved in the execution of radiography must ensure all operations are conducted in compliance with the various acts, regulations and code of practice detailed below:

1. The Radioactive Substances Act 1960.

2. The Ionising Radiations (Sealed Sources) Regulations 1969.

3. The Radioactive Substances (carriage by road) Gt. Britain Regulations 1974.

4. The Code of Practice for the Carriage of Radioactive Materials by Road - published by the Department of Environment.

5. The Merchant Shipping (Dangerous Goods) Rules Class 7.

6. The International Air Transport Association Restricted Articles Regulations.

7. The Code of Practice for Site Radiography issued by the Health and Safety Executive.

8. International Atomic Energy's Regulations of 1973 for Safe Transport of Radioactive Materials.

9. Guidance Note GS 41 from the Health and Safety Executive - radiation safety in underwater radiography.

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Radiography is a specialised subject and is the prerogative of suitably trained and qualified technicians who are normally contracted in to conduct the work. When using radiography a few important points need to be borne in mind. They are as follows:-

1. The effects of ionising radiations on the human body are accumulative. Persons are allowed a maximum dose of radiation over a life-time and this is used to set the maximum permissible level (MPL) of exposure to radiation. If the MPL is exceeded at any one time, then the worker must not be exposed further to radiation until a period of time has lapsed for the dosage to fall below the MPL.

   Persons under 18 years of age, and pregnant women must not be exposed to ionising radiations.

2. The radiation doses received by persons working with ionising radiations is carefully monitored. This is a requirement of law. The doses they receive are measured on a film badge or a thermoluminescent dosemeter that is worn during working hours. The badges or dosemeters are sent periodically to the National Radiological Protection Board Centre at Harwell where the dosages are measured.

3. Persons not classified for work with ionising radiation must be kept from entering exposure areas.

   On-site exposure areas will be cordoned off with radiation notices and audio-visual warnings. A radiation meter is used to demarcate the boundary where the dose falls belcw the MPL for unclassified persons.

   Where space is restricted, the exposure area will be enclosed in a lead-lined exposure bay. The bay will have interlocking safety devices to prevent persons from being trapped inside during exposures.

4. Radioactive isotopes are kept in safe containers when not in use. Several designs are available that safely expose and retract the isotope from its container during use.

5. Exposures are kept as short as possible.

Underwater the radiographer/diver uses the excellent shielding properties of sea water to provide protection from the radiation.

Once the test station had been prepared the diver would approach the source, unlock the window mechanism and rotate the window to the open position. The diver would then retreat to a safe position and await the completion of the exposure. At the end of the exposure the diver would return to the source and close the window, locking it closed with the key.

An alternative operation to the above involves the use of either a mechanical winding technique or a pneumatically operated system. If using a pneumatically operated system the line must be bled down prior to recovery of the source, otherwise the trapped air could operate the window as the ambient pressure decreases and result in exposing personnel to radiation.

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6.5 EXLORATORY AND REMEDIAL GRINDING

6.5.1 THEORY: DEFECT SIZING AND STRESS REDUCTION

Geometrically sharp contours in a weld, especially in the toe, can cause an increase in the local stress level, ie. become "stress raisers". For this reason structural welds calculated to have a relatively low fatigue life would normally be profiled during fabrication. Profiling is a carefully controlled grinding process which smoothens the parent metal, HAZ and weld into a single homogeneous profile. All ripples, edges and depressions are removed, thereby maintaining an even stress level over the whole contour.

During weld inspection defects located, eg. longitudinal defects or sharp undercut, will almost certainly be acting as stress raisers and could be crack initiating or crack propagating, depending on their stage of life. It is these defects that will need on-site profiling in order to try and reduce local stress levels.

MPI indications will normally be ground out to a specified depth to determine their extent, and along their entire length. This is carried out in specified depth increments to a maximum, when either:

- the defect will have been removed and the depth grinding can then be profiled.
- the defect remains as an MPI indication in the bottom of the depth grinding - the decision as to subsequent action will be initiated ashore.

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6.5.2 EQUIPMENT AND TECHNIQUES

Normally pneumatic or hydraulic grinders will be used with variously shaped tungsten carbide burrs, depending on geometry and state of grinding.

- For profiling, spherical or nearly spherical burrs will be required.
- For depth grinding conical or "flame" type burrs will be required.

It is advisable to conduct surface trials before carrying out any grinding underwater. In this way instruction and selection of personnel can be accomplished as there are no British Standards or approved procedures for profile and defect grinding underwater. Figures 39 to 41 show the type of procedure to follow using a specification of defect grinding in 1mm increments to a maximum depth of 4mm.

As can be seen in this example the defect still remains after the maximum permissible depth has been reached. This situation should now be referred to shore side for further action, whether it be investigation using 'A'-Scan ultrasonics, further grinding, other action or simply to monitor as part of the ongoing recertification inspection programme.

Photography at various stages of grinding and at least upon completion will usually be required.

Control of grinding, especially depth/defect grinding is critical, but is also difficult to measure precisely due to weld geometry.

One system which gives good results is a comparative system using a Welding Institute "pit" gauge. By taking an initial reading on an adjacent unground area and then a second reading on the ground area, a simple subtraction will give the depth obtained. This technique is illustrated in Figure 42.

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First stage grinding
to follow crack and
fix grinding depth

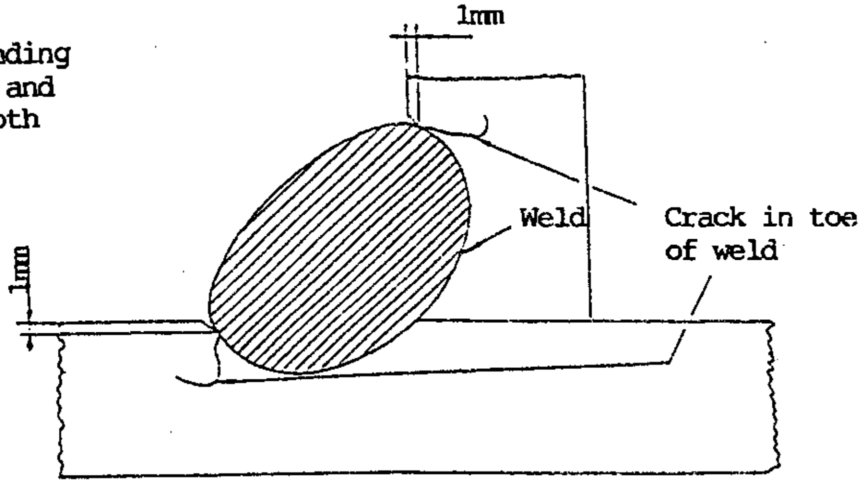

FIG.39

Second stage grinding
to round off edges for
next inspection

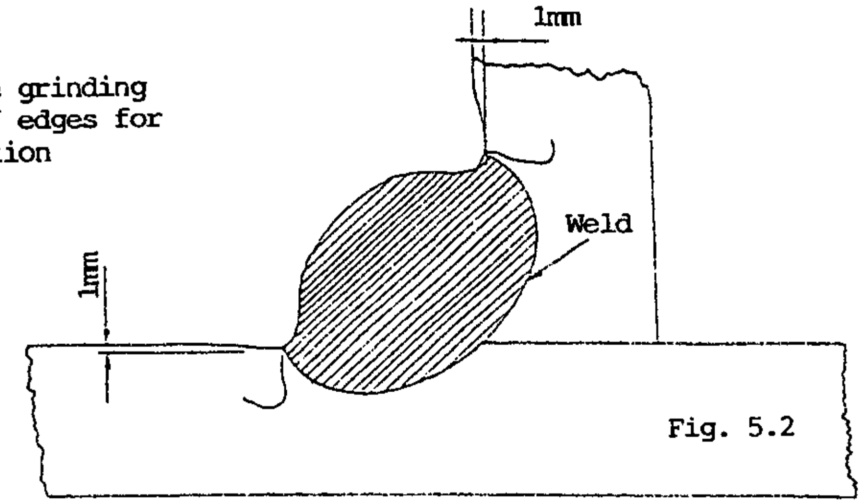

FIG.40

Profile weld on completion
of all grinding and m.p.i.

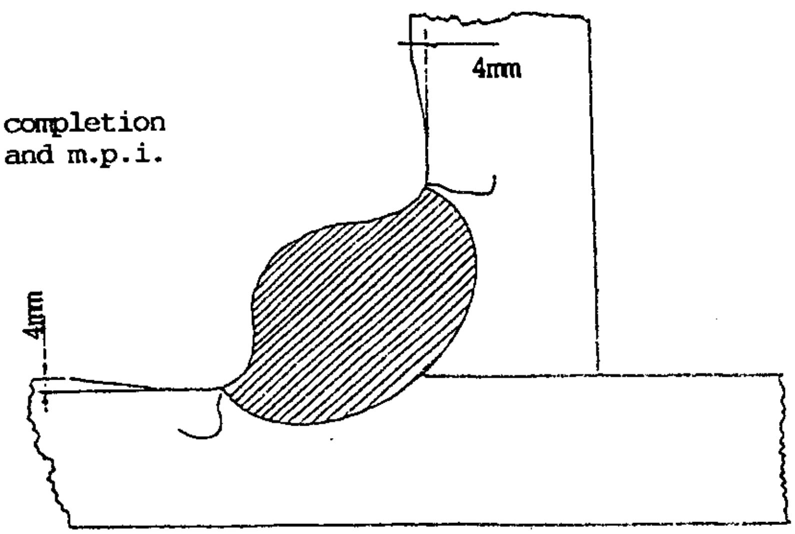

FIG.41

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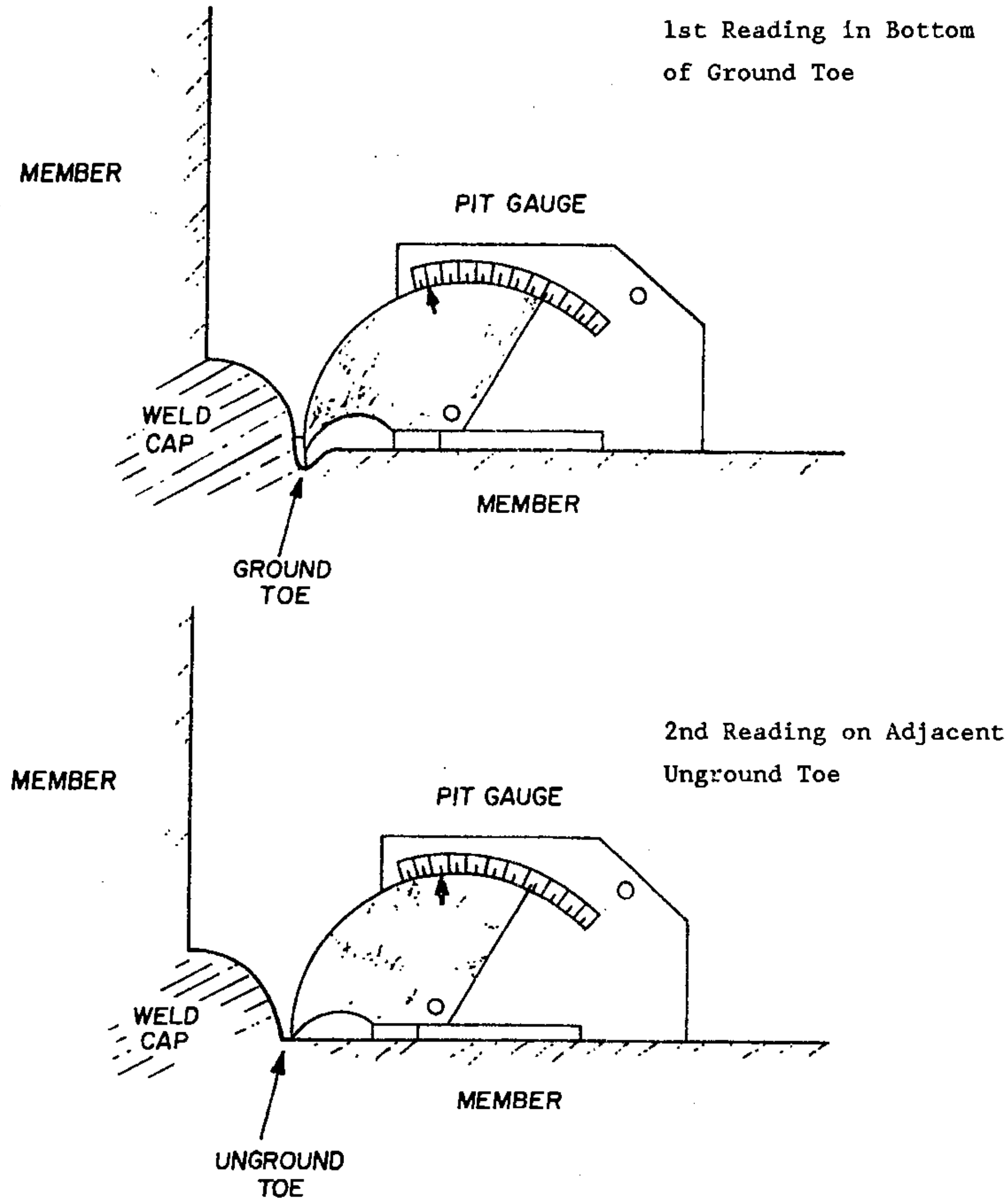
Fig. 42: Procedure for Measuring Depth of Defect Grinding



By subtracting one reading from the other a measurement will be obtained which will be the actual depth of the grinding.

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6.6 EDDY CURRENT

Eddy current testing uses a magnetic field produced by a current carrying conductor. The principle is based upon the fact that a coil carrying an alternating current produces an alternating magnetic field. If the coil is placed in close proximity to a conductive metal surface, the changes in magnetic field will produce eddy currents in the surface of the metal, which in turn produce a magnetic field of their own. The technique is more properly referred to as Electro-Magnetic Detection (EMD) of surface breaking defects.

The interaction of these magnetic fields produce measurable changes in the impedance of the coil. These impedance changes remain constant unless changes in metallic composition or a discontinuity is encountered. When this occurs, it is manifested as a voltage change outside the expected range for the material under test.

This technique is limited to the detection of defects at or near the surface, such as cracks, pits or voids. However, one clear advantage is that it may be applied to non ferromagnetic materials.

There are several drawbacks to the use of eddy current testing, which can be summarised as follows:

- Some cleaning and surface preparation is normally required
- The probe is extremely sensitive to changes in stand off distance, surface condition, grain size, and irregular changes.
- It is difficult to apply the technique to complicated geometrical configurations (ie. node welds).
- Operators require training, for both application and interpretation of results.

Presently, this technique is not commonly used for underwater structural inspection.

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6.7 ACPD

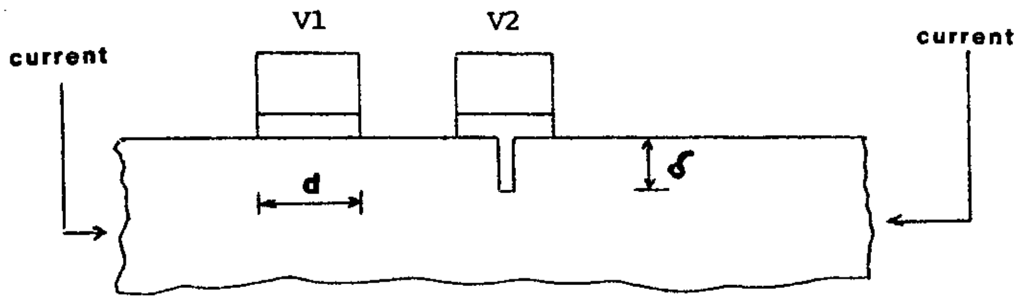
Alternating Current Potential Drop is primarily used as a means of determining the depth profile of a surface breaking defect.

High frequency alternating current when passed through a conductive material will flow in the surface layer of the material. If a defect breaks the surface, the field will follow the profile of the defect. Measurements of the drop in potential between two contacts, a known distance apart (d), both over the defect (V_2) and just off the defect on sound metal (V_1) will enable the defect depth to be determined according to the relationship.

$(V_2/V_1 - 1)\ d/2 = \text{defect depth}\ (\delta)$

This method of using alternating current potential difference measurement to determine defect depth has its limitations. In the ideal case where the defect is planar and normal to a flat surface, defect depth can be determined. Unfortunately, this is rarely the case and at this time the method is unable to take into account the variables involved eg. branching defects, differing grain structure and an irregular surface.

An example of equipment on the market is the Underwater Crack Microgauge developed by OSEL Inspection.



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6.8 FLOODED MEMBER DETECTION

The detection of internal flooding on a sub sea member is an excellent indicator of the existence of a through-wall defect somewhere on the member. Once flooding is detected, a more detailed inspection programme can be instigated to locate the defect.

Currently the most common method of detection is based on the principles of ultrasonics. Much greater attenuation occurs when ultrasound is transmitted through air than through water and much greater losses occur at a steel/air boundary as compared with those at a steel/water boundary. The presence or absence of water can therefore be detected by transmitting an ultrasonic pulse through a tubular member and interpreting all echos (see the following figures).

Another technique which has been developed utilises gamma radiation. The absorption of gamma rays in a material is dependent on the material density, and since there is a vast difference between the densities of air and water, this effect can be used to indicate whether or not a member is flooded. A gamma radiation source of known intensity is positioned on one side of the member and a radiation detector on the other. The measurement of transmitted radiation then indicates whether or not the member is flooded.

A technique currently under research and development is thermographic flooded member detection. This method is based on flooded members absorbing more heat than non-flooded members.

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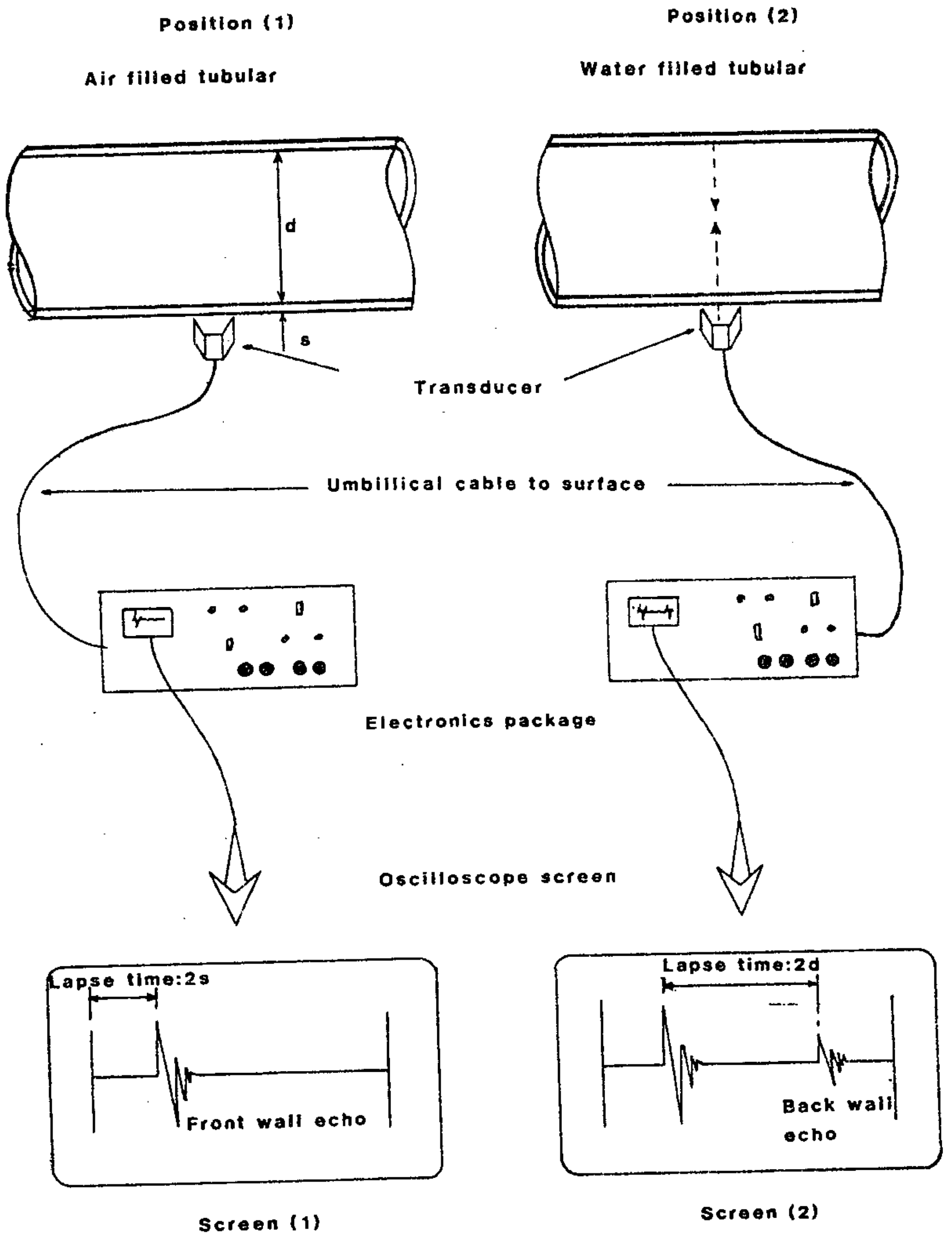

Gascosonic Flooded Member Screen Displays

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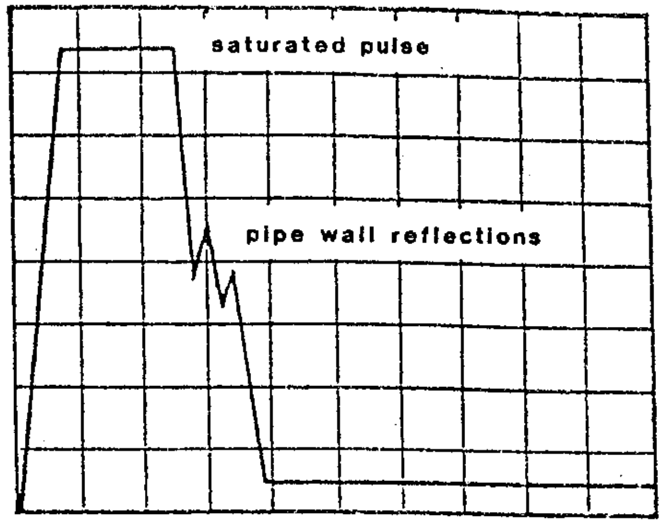
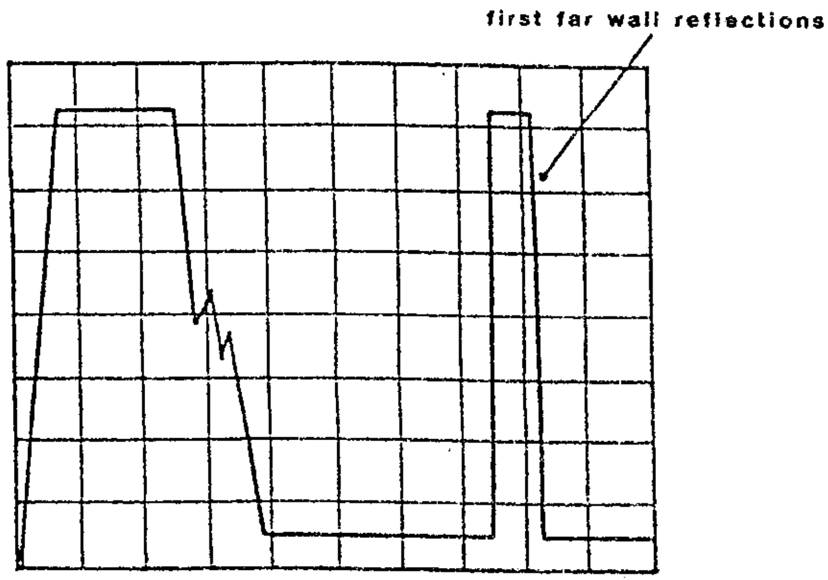
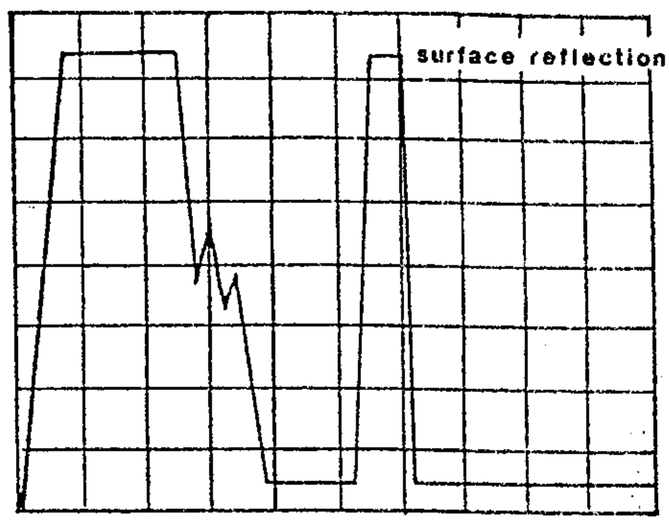


(1) GOOD PROBE CONTACT - NO FLOODING



(2) GOOD PROBE CONTACT - FLOODED MEMBER



(3) GOOD PROBE CONTACT - PARTIALLY FLOODED

Rovprobe,Cathode Ray Tube Displays.

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6.9 MOULDING

Moulding is a useful technique when a permanent record of structural features and defects is required. The purpose of this technique is to produce an accurate 3D copy of the surface under investigation from which measurements can be taken. It relies on the application of a polymer based compound which is then left to cure (curing time is dependent on the substance used). On recovery, an impression of the surface profile in obtained. The two common processes are:

- Epophen
- Aquaprint

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7. DIVING PRACTICE RELEVANT TO INSPECTION

This module is aimed primarily at those with little or no diving experience. Knowledge of diving physiology and commercial diving procedures, combined with an appreciation of weather conditions, health and safety will ensure that a complete understanding of the problems involved in putting a man underwater to do a job of work are realised.

7.1 THE DIVER AND HIS BODY

7.1.1 THE EFFECTS OF PRESSURE

Before discussing the effects of pressure on the diver we need a few definitions:

The unit of pressure is the BAR, with 1 bar being equal to 1000mb. 1 bar is approximately equal to 1kg/cm^2.

Pressure is measured as either ABSOLUTE or GAUGE pressure. ABSOLUTE PRESSURE is the pressure measured relative to a vacuum, whereas GAUGE PRESSURE is the pressure measured relative to atmospheric pressure.

AMBIENT PRESSURE is the pressure surrounding the gauge. On the surface, ambient pressure is equal to the local atmospheric pressure, typically 1 bar absolute. A gauge calibrated to read gauge pressure, and open to its surroundings, will read zero at sea level

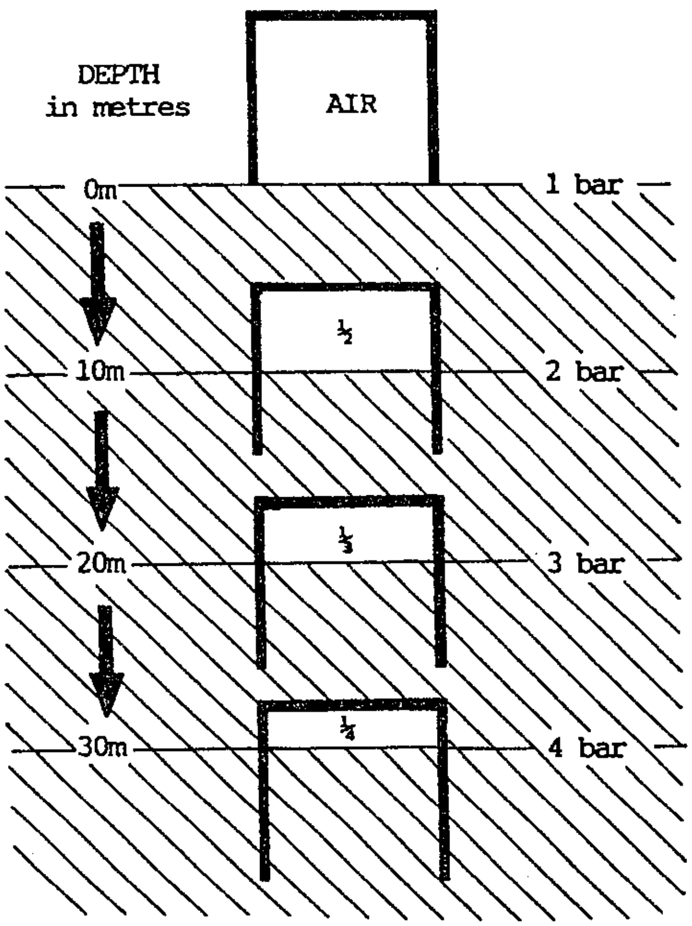
Compared to air, water is a dense medium, and it exerts a significant pressure on any object immersed in it. This pressure is referred to as HYDROSTATIC PRESSURE. Hydrostatic pressure increases linearly with depth at a rate of 1 bar for every 10m of depth. To find the absolute pressure at depth, the atmospheric pressure is added to the hydrostatic pressure. Hence at -10m the absolute pressure is 1 bar (atmospheric pressure) + 1 bar (hydrostatic pressure) = 2 bar. At -30m the absolute pressure is 4 bar.

As the human body consists largely of liquid, it takes up the ambient pressure with only a minor decrease in volume, but the spaces that contain air (eg the lungs) will be compressed unless they are artificially filled to an equivalent air pressure.

Boyles Law

At a constant temperature, if a gas is compressed, its volume varies inversely to the absolute pressure, a phenomenon first realised by a physicist named Boyle. As a formula it can be expressed as $P_1V_1 = P_2V_2$. For the example below $V_2 = \frac{P_1 \times V_1}{P_2}$

Fig. 7.1



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Refering to Fig 7.1, an inverted bucket full of air at the surface is only half full at -10m or 2 bar absolute, and only a quarter full at -30m or 4 bar absolute. It can be seen that the fractional change in volume decreases with depth to the point where, at great depths, volume change is very small. Thus an air diver, limited to 50m, is affected by pressure change to a much greater extent than a saturation diver. Any compressible air space, be it in a diver's body or his equipment, will change its volume during descent and ascent, and if not equalised or controlled, physical or material damage can easily occur.

Buoyancy - This pressure/volume change must obviously effect buoyancy. Assume a diver in full dress, wearing a variable volume dry suit, weighs 384 pounds (lbs) and displaces 6.5 cubic feet (ft^3) of water. Because sea water weighs 64 lbs/ft^3, the buoyant force acting on him is 416lbs, thereby giving him a positive buoyancy of 32 lbs. He would float with 0.5 ft^3 of him above water and 6 ft^3 below. To obtain neutral buoyancy, where he neither rises nor sinks, he must either vent 0.5 ft^3 of air from his suit or add 32lbs of weight.

Upthrust = Volume x Density (U = V x D)

During design the buoyant force acting on all submerged objects eg. pipelines and structural members must be calculated and allowed for.

7.1.2 BREATHING AIR UNDER PRESSURE

As mentioned previously, a diver must breath air at a pressure equal to the total pressure acting on him. Unfortunately, breathing air under pressure has its side effects.

For our purposes, air is composed of 21% oxygen and 79% nitrogen. At a pressure of 1 bar, the fractional pressure exerted by each constituent gas is equal to its volumetric percentage of the whole

ie. 21% oxygen exerts 0.21 bar
79% nitrogen exerts 0.79 bar

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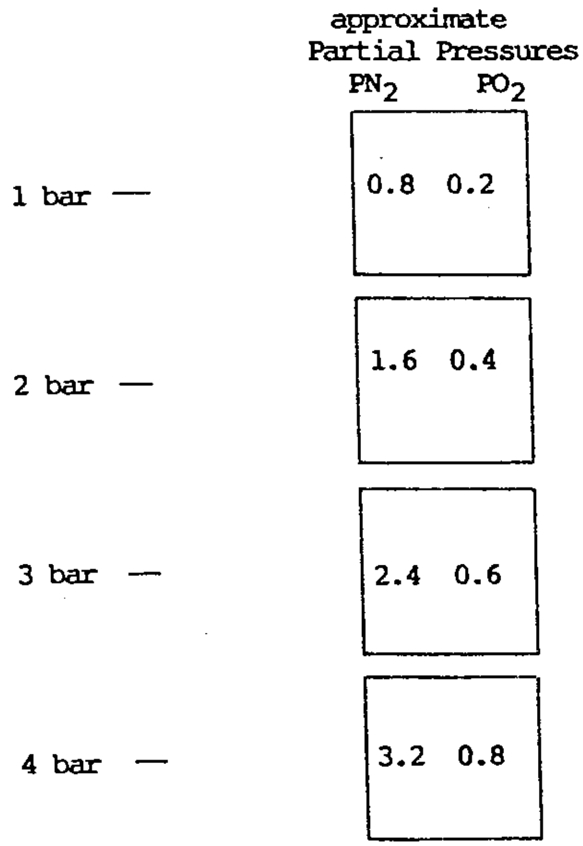
This is the law of partial pressures, first recognised by Dalton.

As the pressure increases so the partial pressure exerted by each constituent gas increases. Thus at 40m where the pressure is 5 bar, absolute, oxygen exerts 1 bar, and nitrogen 4 bars. As a formula:

$$\text{partial pressure} = \frac{\text{percentage of gas} \times \text{pressure}}{100}$$

Fig. 7.2



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The physiological effect of a gas depends upon its partial pressure and Daltons law reveals itself in such cases as oxygen poisoning, carbon dioxide and carbon monoxide poisoning and nitrogen narcosis. Each condition is described below.

<u>Oxygen</u> (O_2) can become toxic during an air dive, at a partial pressure (PP) of approximately 1.6 bars absolute (see section 7.1.3.3). At 21% concentration, this is equivalent to a depth of around 75m. At 100% concentration, 8m is an approximate limit (refer to O_2 decompression, section 7.2.4.2). Chronic oxygen poisoning is a long term effect which primarily effects the respiratory system, causing irritation, congestion, coughing and considerable discomfort, resulting in some cases in permanent lung tissue damage.

Acute oxygen poisoning is more likely to effect a diver because he would rarely be exposed to a high enough oxygen partial pressure (0.4-0.6 bar) for a sufficiently long period to suffer from chronic oxygen poisoning. As such it is considered a short term problem.

The symptoms are twitching, dizziness, nausea and irregular breathing leading eventually to unconsciousness and convulsions.

<u>Carbon Dioxide</u> (CO_2) is a waste product of the body, produced in conjunction with water as part of the oxidation process. At nominal levels eg. 2%, CO_2 causes little disturbance to the diver. Levels in excess of 10% can have marked medical effects leading finally to convulsions and unconsciousness.

<u>Carbon Monoxide</u> (CO) can be a lethal contaminant of breathing air. It is a colourless, odourless gas produced by petrol and diesel burning engines and cigarettes for example. It is dangerous because its affinity for haemoglobin , the oxygen carrying pigment of the blood is some 210 times greater than O_2. Just 0.05% of CO will put half of the haemoglobin in the blood out of action, two thirds could result in death. The maximum allowed in a diver's breathing gas should not exceed 1 ppm. (DSM No 7 1984)

Nitrogen Narcosis and its effects have been shown to be appreciable at a depth of 30m and are probably present to a lesser extent at shallower depths. It causes a reduction in working efficiency by impairing a diver's reasoning ability, by slowing his reactions and generally by giving him such a sense of detachment that, in many cases this has resulted in death. For this reason, the Health and Safety Executive have stipulated that no commercial air diving must take place below 50m.

Narcosis may be prevented by substituting helium for nitrogen in the breathing mixture but this also has disadvantages as will be discussed.

7.1.2.1 DECOMPRESSION SICKNESS AND BONE NECROSIS

When a gas is brought into contact with a liquid, for example when air in the lungs comes into contact with the blood, some of the gas will dissolve in the liquid. The amount that dissolves and the rate of transfer depends on the following - pressure, contact area, temperature and the maximum solubility of the gas in the liquid. As the gas in the liquid nears saturation level, so the rate of transfer decreases. If gas has dissolved in a liquid and the conditions vary, so the amount of dissolved gas will vary. This relationship was established by a physicist named Henry. The fact that gas will dissolve into the bloodstream and be released again when the ambient pressure is reduced, gives rise to the problems of decompression sickness.

The exchange of oxygen and carbon dioxide through the lung tissue is dependent on differential pressures. Because the muscles and other body tissues are continually using oxygen, there exists a differential pressure between these tissues and the bloodstream, hence oxygen transfer. Generation of CO_2 through the oxidation process brings about an excess pressure in the body tissue thus causing diffusion into the bloodstream and into the lungs.

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Unfortunately, nitrogen is a different matter entirely. The body is saturated with air at normal atmospheric pressure. As ambient pressure increases so the amount of dissolved gas increases. Those areas well supplied with blood, eg. heart, kidneys, will rapidly accept the dissolved nitrogen until the new saturation level is reached. Those areas poorly supplied with blood eg. fat, cartilage and bone will take much longer. The process is reversed as the ambient pressure decreases. The problem arises when the rate of pressure decrease is greater than the rate at which nitrogen can diffuse back into the bloodstream.

DECOMPRESSION SICKNESS (BENDS)

Decompression Sickness results from bubble formation in the body tissues and bloodstream with an associated blood clot formation. It becomes apparent either during decompression or within a few hours of reaching surface.

BAROTRAUMA

Barotrauma is the term used to describe the tissue damage which occurs as a result of an imbalance between pressures within the gas spaces of the body and the body tissues. Barotrauma is a pressure related injury not dependant on time and depth, it can be caused during descent or ascent. Symptoms can vary from a simple "squeeze" to a burst lung (Pneumothorax) or arterial gas embolism, the latter is life threatening and requires immediate recompression in a chamber, normally to 50 MSW. This reduces the bubble(s) to 1/6th of their original volume (in accordance with Boyles Law) which normally clears the obstruction.

BONE NECROSIS

Bone necrosis or to use the medical term, dysbaric osteonecrosis, in the short term often goes unnoticed, only coming to light during an x-ray or radio isotope survey.

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Many theories exist, but it is probably caused by the formation of minute bubbles within the bone capillaries. This effectively blocks the blood flow to the bone and the bone dies. It can happen to any diver undergoing decompression and it can happen at any time in his career; a trainee diver is as susceptible as an experienced one. The incident rate is very low, and of these only a few cases become serious.

7.1.3 BREATHING MIXED GASES UNDER PRESSURE - WHAT IS SATURATION

All the time a diver is under pressure, his body tissues are absorbing his breathing gas. The rate of absorption varies with time but eventually a point will be reached when no more gas is absorbed - the body has reached gas saturation. The time taken to decompress from this stable state is now independent of the time spent under saturation. The following sections will explain the use of helium in the breathing mixture and the advantages and disadvantages of its inclusion.

7.1.3.1 ADVANTAGES OF HELIUM OVER NITROGEN

Helium is presently the dilutent gas for virtually all diving below 150 fsw (feet of sea water). It was in 1938 that the real advantage of using helium was discovered - its lack of narcotic properties. This, combined with the following, has led to its universal use as a mixing gas:

- It is light and easy to breath

- It has a low solubility, ie. a smaller volume is required to achieve saturation

- It has a high diffusivity enabling easy elimination during decompression.

7.1.3.2 DISADVANTAGES OF HELIUM

Helium has its drawbacks, but at the present time it has no substitute. Those factors effecting its use can be summarised as follows:

- It is expensive, being available from only two or three locations in the world.

- Helium being less dense than air, affects speech giving rise to the characteristic, high-pitched "Donald Duck" squawk.

- The thermal conductivity of helium is 6 times that of air, causing a reduction in the temperature range in which the diver is comfortable.

- Helium has a high leak rate, allowing it to ingress into instruments.

- High pressure nervous syndrome (HPNS), develops from breathing gases of low lipid solubility. Helium, and to a lesser extent neon, are associated with HPNS because they allow high hydrostatic pressures to be applied without a compensating narcotic effect. It is an effect that becomes increasingly important below 600 fsw, causing brain wave interference resulting in "helium tremors" or shakes.

  Careful compression rates, and in some cases the reintroduction of nitrogen, alleviate the problem.

7.1.3.3 OXYGEN: METABOLIC NEEDS AND TOXICITY

The oxygen partial pressure to which man is adapted is 0.21 bar inspired. Blood oxygenation can be maintained at a PPO_2 (partial pressure of oxygen gas) of about 0.16 bar, whilst the upper toxicity limit is about 2.8 bar, depending on exposure time. It should be noted that prolonged exposure to PPO_2 in excess of 0.5 bar can cause irreversible pulmonary damage, culminating in convulsions, paralysis and finally death.

Pressures between 0.25 and 0.4 bar seem to be an optimal operational level for indefinite periods, while pressures up to 1 bar may be maintained safely for a few hours.

During decompression sickness treatment, an exposure to 2.8 bar for several 20 min periods can be endured.

7.1.3.4 OTHER BREATHING MIXTURES

Considering there are three objectives - to keep a diver working steadily at depth, to decompress him as quickly as possible, and to ensure that he arrives back at surface without any physiological and physical disturbance, experimental work using different breathing mixtures continues. The following section is simply to make the reader aware of their existance.

Tri-mix - Commonly helium, nitrogen and oxygen. Inclusion of nitrogen tends to counterbalance the low lipid solubility of the helium and it also has financial implications, being far cheaper than helium.

Hydrox - Hydrogen and oxygen. Although highly explosive when mixed together in certain proportions, enough oxygen can be added to meet metabolic needs but remain below flammability levels. Unfortunately, storage and transfer of pure hydrogen under pressure could prove to be extremely dangerous and would probably involve very expensive equipment. The major physiological advantage is that hydrogen appears to counteract the neurological disturbances associated with helium.

Nitrox - Nitrogen and oxygen mixtures having a greater oxygen fraction than air are sometimes used, the added oxygen reducing the amount of inert gas and hence reducing decompression time.

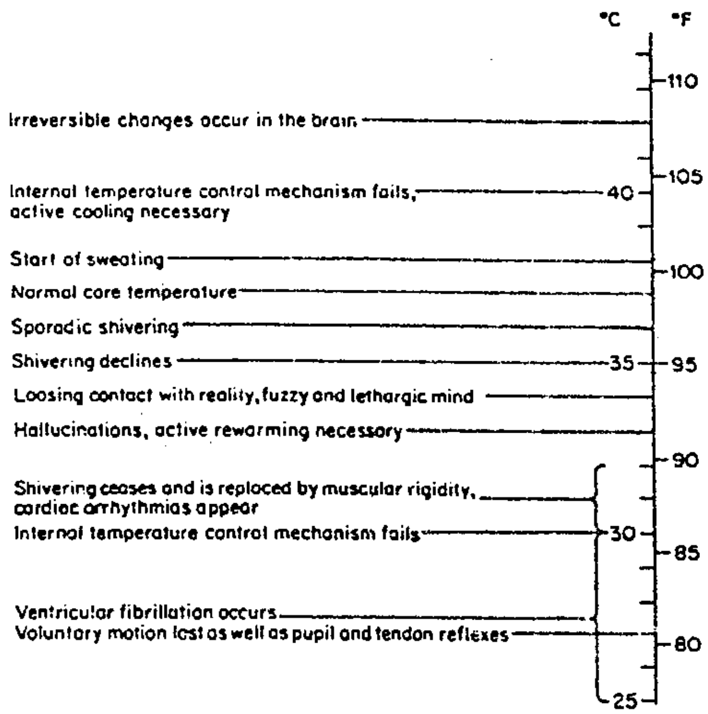
Nitrox - Nitrogen and oxygen mixtures having a greater oxygen fraction than air are sometimes used, the added oxygen reducing the amount of inert gas and hence reducing decompression time.

7.1.4 THERMAL PROTECTION AND PRESENT DAY DEPTH LIMITATIONS

Man's natural body temperature is nearly constant at about 37°C. For long duration exposures, this core temperature should not exceed 39°c or fall below 35°c.

Table 7.1 indicates the physiological effects of core temperature changes whilst Table 7.2 indicates the type of thermal protection required and the effect of water temperature on the diver.

It should be noted that in the North Sea it is rare for a diver to use anything other than a hot water suit.

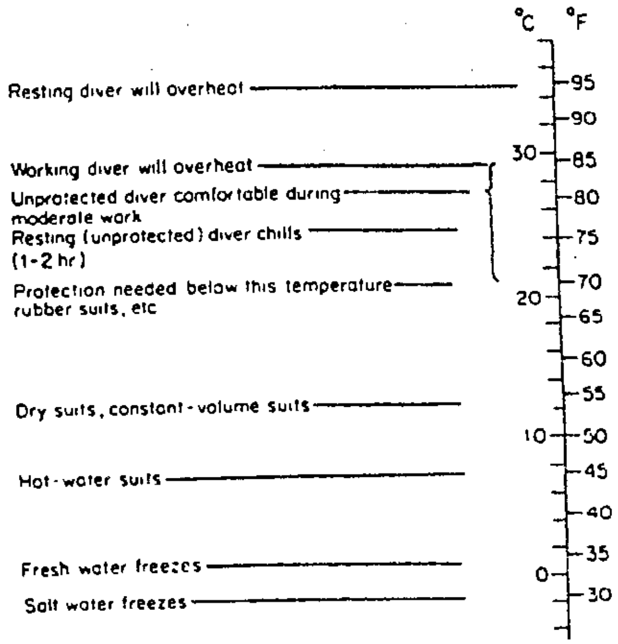


Physiological Effects of Core Temperature Changes

Table 7.1

Courtesy of J. Wiley and Sons Ltd

Contents



Thermal Protection Vs Water Temperature

Table 7.2

In addition to the diver's external exposure to cold water, the breathing of cold gases can induce hypothermia. If the breathing gas is not warmed, heat is lost directly from the core, quite independently from what is done to prevent heat loss from the body surface. The effect increases with the density of the breathing gas mixture and hence with the increase in depth. In general, helium-oxygen mixtures at depths greater than 150 msw (metres of sea water) ie 495 fsw require heating to prevent a serious loss of body heat. Current regulations make the use of gas heaters compulsory below 150 msw.

Mixed gas technology exists to blow a man down to a working depth of 2000 fsw. Unfortunately the problems in keeping a diver warm at those depths are more difficult to overcome. Closed circuit hot water suits are available but the equipment is bulky and difficult to store. Development is continuing in the field of electrically heated suits and many feel this could ultimately solve the problem.

7.2 COMMERCIAL AIR DIVING

Now that the problems of breathing air and mixed gas under pressure have been explained, and the physical laws that relate to diving outlined briefly, it is necessary to discuss the diving procedures that are followed and the equipment that is used by the commercial diving industry.

All commercial diving carried out in this country is subject to the conditions and regulations laid down by the Department of Energy. The section concerned with diving within this department has the authority to shut down any operation it deems to be unsafe, and the contractor must comply with all recommendations before being allowed to recommence. Diving safety bulletins are issued by the D.O.E. when necessary, referring to equipment modification, hazardous diving practice and operation of dynamically positioned vessels.

7.2.1 EQUIPMENT

Hat Types

There are two basic types of diving hat in use in the North Sea today - band masks and helmets.

Band masks differ from helmets in that they make a water tight seal around the face only, whereas helmets keep the diver's head completely dry.

Advantages of Helmets Over Band Masks

a. The head remains dry, thus decreasing risk of ear infection, especially in saturation diving.

b. Provides better voice communications.

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c. Some divers find helmets more comfortable to wear for long periods, especially when in saturation.

d. Provides physical head protection

e. Better suited to gas recovery systems

f. Provides a stable platform for head mounted TV camera/light.

<u>**Advantages of Band Masks Over Helmets**</u>

a. Lighter and smaller to wear.

b. Some types can be quicker to put on.

c. Easier to swim in and diver can work in a 'head down' positon.

d. Greater head mobility.

e. Usually cheaper.

The most popular hats are the KMB band masks and associated Superlite helmets.

The KMB range consist of a variety of band masks and helmets which have been gradually developed over a number of years. Many of the parts are interchangeable and a variety of attachments are used to increase its versatility, such as welding visors, camera clamps and gas reclaim units.

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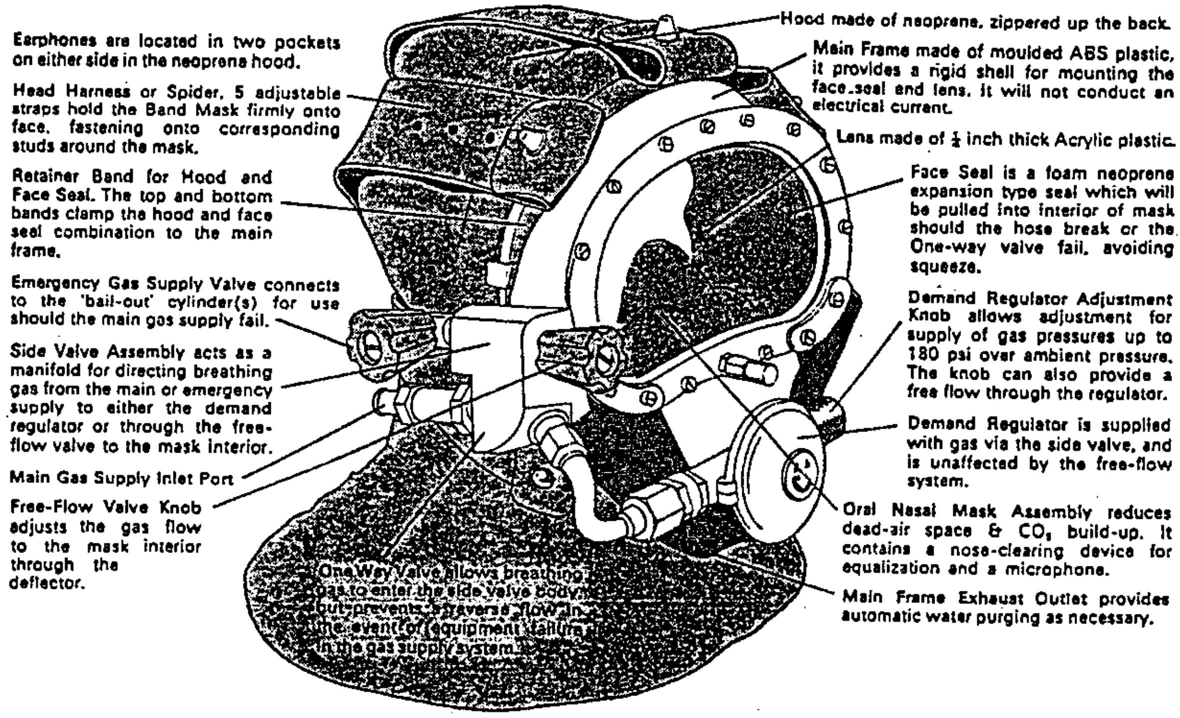
Fig 7.3 KMB Bandmask



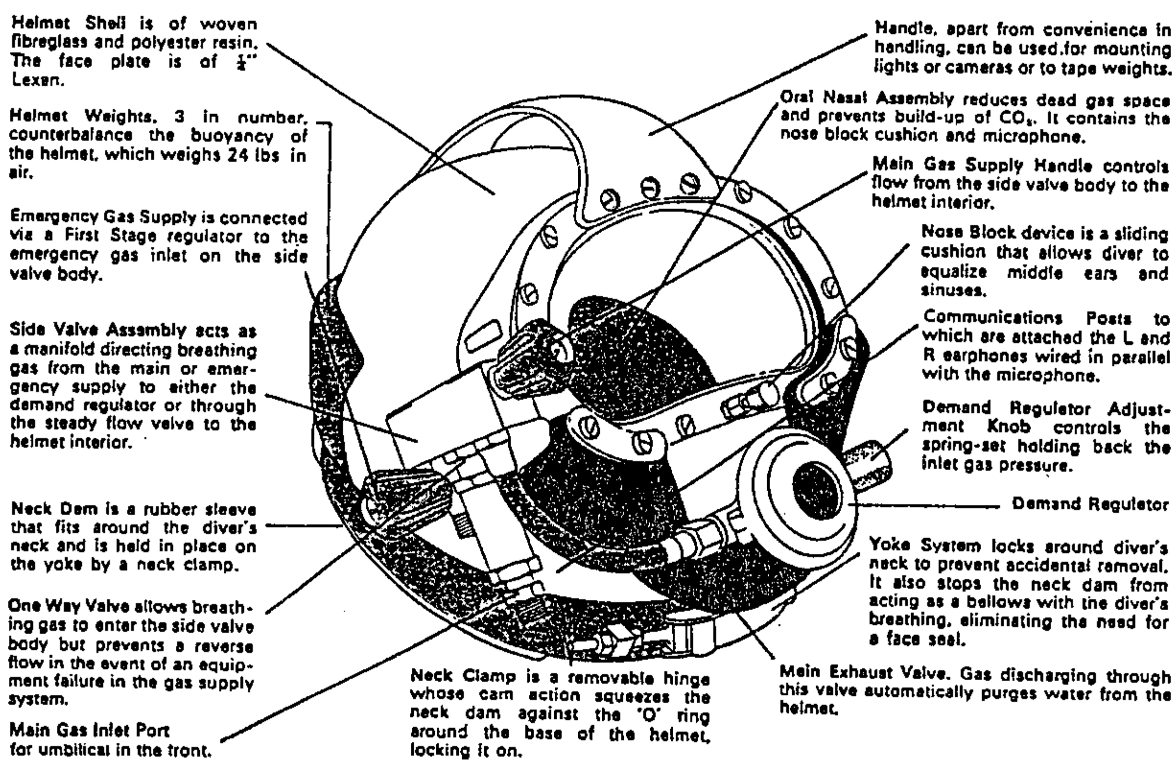


Fig 7.4 KMB Superlite 17 Helmet

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Umbilical

The divers umbilical serves a multi-purpose role, providing:

a) Air/gas at sufficient pressure and rate.

b) A means of recovering the diver in the event of emergency or other.

c) A means of determining his exact depth via a pneumofathometer.

d) A source of communications.

e) A means of gas recovery.

f) Power and light to helmet mounted video systems.

g) Divers hot water supply.

It is composed primarily of three spirally wrapped lines; usually one for air, one for depth and one for hard line communication, but it increases in diameter when other additional functions are required, eg. gas recovery in saturation diving. If hot water suits are being worn, an extra hose providing hot water will be incorporated.

A diving tender at the surface ensures that the correct tension exists in the umbilical at all times, paying out or taking in slack as requested by the diver. At the diver's end, the air and communication lines are attached to his hat and the pneumo is looped at a convenient point through his harness. The weight of the umbilical is carried by a carabiner buckle also attached to his harness, which is vital in ensuring that drag on umbilical etc. does not pull the helmet off.

Suits

The main aim of any form of thermal protection is to keep the body core and skin temperature normal so the diver can work at maximum efficiency.

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Basically, there are 3 ways of providing thermal protection to a diver working in the North Sea today. These are:- wet suits, thermal underwear and dry suits and hot water suits. Each will be considered separately and its relative merits discussed.

Wet Suits

How to Use

A close-fitting garment worn next to the diver's skin. Water enters the suit at its edges, cuff and neck etc. and is retained against the wearer's skin by the close fit of the suit.

Material

Closed-cell expanded foam neoprene, a synthetic rubber-like material full of minute 'closed cells' of nitrogen gas. These cells are not interconnected and the material does not soak up water.

Thermal Protection

The minute 'closed cells' of nitrogen gas within the neoprene form an insulating layer. The diver's body heats the film of water between the diver's skin and the wet suit and so assists in providing insulation.

The pressure of water at depth compresses the gas filled neoprene. At 20m (65ft) a diver's wet suit is about half its original thickness and its insulation quality is also approximately halved.

Advantages

1. Relatively inexpensive.
2. Easy to repair.
3. If punctured the suit can still provide thermal protection and buoyancy.
4. Comfortable to wear.
5. Easy to swim in.
6. Little care and maintenance required.
7. Urination does not cause loss of efficiency.

Disadvantages

1. Flushing can occur if the suit is too loose or there are too many holes or zips.
2. Compresses with depth which reduces thermal protection.
3. Little thermal protection if there is a wind chill factor.
4. Loses buoyancy with depth.

Dry Suits

How to Use

The diver is intended to remain dry in these suits, which have seals around the cuffs and the neck and/or face. Thermal underwear is usually worn underneath to provide insulation as a protective layer, or to soak up sweat. In all cases gas must be able to flow into the suit, because under pressure the gas in the suit is compressed until the suit is squeezed against the body which is painful,restrictive and causes loss of buoyancy. This can be overcome by having suit inflation equipment or by using a 'constant volume' dry suit which is kept automatically at a preset volume, (eg. Poseiden Unisuit or Viking Dry Suit).

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Thermal Protection

The main thermal protection comes from the layer of gas trapped between the diver's skin, thermal underwear and the suit. This layer can be increased or decreased with suit inflation/deflation facilities.

Potential Thermal Protection Problems

When used with heliox the dry suit's thermal protection is reduced as the heliox does not provide an insulating layer but rather conducts the diver's body heat away into the surrounding water. Consequently the dry suit is usually only used for diving in shallow cold waters up to 50m (165ft).

Advantages

1. Thermal protection can be varied to suit the conditions.
2. Can be very rugged.
3. Can protect the diver in polluted or infected water.
4. Fit is not so critical.

Disadvantages

1. If punctured, there is a loss of thermal protection, possibly some buoyancy and the dive may need to be aborted.
2. Blow up possible.
3. Urination leads to discomfort and loss of insulation.
4. Requires careful maintenance/repair.

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Hot Water Suit

How to Use

A loose-fitting suit with tubing to distribute the heated water around the inside of the suit. It has a control manifold so the diver can regulate the amount and distribution of hot water. It usually includes gloves and boots and should be worn with a protective undersuit to avoid scalding in case of malfunction.

Material

Foamed neoprene insulation material with double-sided nylon lining.

Thermal Protection

Hot water is produced at the surface and transferred, either directly or via the diving bell, through insulating tubing to the diver for use in his hot water suit. The circulation of the warm water around the diver's body creates an active insulation barrier which allows the diver to easily maintain a normal body temperature and normal blood circulation. The hot water sacrifices its heat to the environment in place of the heat that would otherwise be drained from the diver's body. The diver himself is still losing metabolic heat from his body to the water in the suit. He is however losing heat slowly enough from his body to sustain the heat loss comfortably. The hot water around the diver should not fall below 32°C (90°F) or hypothermia can result; nor should it rise above 45°C (113°F) or the diver can be scalded.

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Advantages

1. Safe, comfortable and effective.
2. Diver able to regulate the amount of thermal protection.

Disadvantages

1. Can be difficult to swim in.
2. In diver lock-out submersible operations, special consideration should be given to efficiency of heat conservation.
3. In some open circuit suits constriction can cause scalding.

For hot water suits, specially insulated umbilicals are required to carry the hot water to the diver. Even so, heat loss from the umbilical can make controlling the temperature of the diver difficult, especially during deep dives.

Communication Equipment and Procedures

Underwater telephone is the primary source of diver/surface communication. Distortion and total breakdown are common place, often resulting in the diver being recalled to the surface. The following is a recommended procedure for surface to diver communication.

1. Speak clearly and steadily.
2. Use simple, short sentences of one breath or shorter. The diver may have to shut off his air or stop breathing to hear you.
3. If you want a message repeated say 'say again' or 'come back'.
4. Never assume that a message has been received; repeat it until you get a response.

5. If a message is failing to get through and you decide to say something different, say 'cancel that last' before giving the new, different message.
6. When acknowledging a message, it is better to repeat all or some of it rather than just say 'Roger'. 'Roger' on its own does not indicate the message has been correctly understood.

Finally, ensure both diver and topside are familiar with the names of all tools and components to prevent any misunderstanding.

During an inspection dive, it is usual to have a 3-way communication system that incorporates the diver, the diving supervisor and the data recorder. Once the diver is on the job, the supervisor whilst remaining in constant contact with the diver will hand communications over to the Inspection Controller.

7.2.2 Diver Deployment

In commercial air diving, a variety of ways of getting into the water exist. It would be difficult to say which method is most used, vessel design often dictates location of the dive spread and this can in turn place limitations on type and size.

Perhaps the most common is an over-the -side, or over-the-stern deployment using a swinging A-frame, hydraulically powered, which lowers a wet bell or cage into the water. In this manner the diver is carried through the splash zone and towards his job location, thus conserving his energy and protecting him from possible injury during the initial entry and final recovery operations.

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This system has other advantages. The bell or cage acts as working platform, aiding the diver in his task by providing a stable base on which tools and other equipment can be stored until required. Emergency breathing supplies and umbilical storage facilities can also be incorporated. The cage is invaluable for use in in-water decompression dives. The wet bell has the further advantage of allowing a diver to sit. The air pocket trapped in the dome provides the diver with a "safe haven" in the event of equipment failure of loss of gas supply, under normal circumstances the diver would never remove any part of his equipment in water.

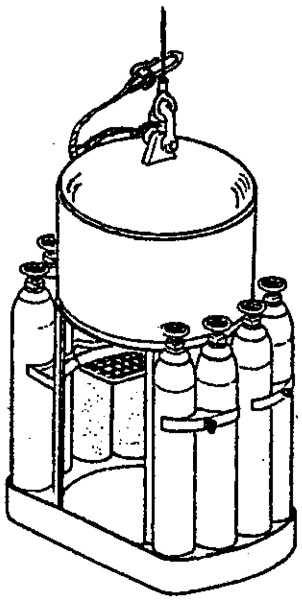

Fig. 7.5

Occasionally, direct entry is still used, whereby the diver jumps into the water and uses a ladder to emerge.

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Once in the water, the first diver will establish a downline to the job. This not only acts as a guideline on successive dives but it also provides the means for lowering equipment. Further swimlines can be used to lead away from the initial downline. In all instances, a weak link or breaker should be incorporated, designed to part in the event of a pull-off or emergency.

Once the diver is on the job, depending on the task and sea conditions, he might consider tying himself onto the structure to provide stability and to leave his hands free. This can be a time consuming but necessary procedure and topside personnel must be aware of and accept its importance. Any 'tying' on is, strictly speaking, discouraged and must only be done if a quick release system is used.

As previously mentioned, at all times a diving tender is in attendance on deck, handling the divers umbilical.

DOE regulates safe working umbilical lengths - 50m is the norm. In some instances, longer lengths, up to a maximum of approximately 65m can be used.

Special Note: The standby divers umbilical should always be longer than the divers umbilical.

Umbilicals come in various states of buoyancy; positive buoyancy can hinder the divers progress, constantly pulling him away from the job, and negative can drag him down. In general, when air diving in mid-water either positive or neutrally buoyant umbilicals can be used, whilst negatively or neutrally buoyant umbilicals are used in saturation. Neutrally buoyant umbilicals are also used with gas recovery systems.

7.2.3 DYNAMIC POSITIONING AND DIVING REGULATIONS

After a series of fatalities the DOE has issued guidelines for the operation of diving activities and in particular air diving activities from a dynamically positioned vessel.

It recommends that the divers umbilical be restricted in such a manner that it is impossible for the diver or his umbilical to come into contact with any thruster or propellor.

The approved method when air diving is to deploy a wet or conventional bell, positioned as close as possible to the worksite, with a bellman in the bell tending the working diver.

The possibility of immobilising the nearest thruster to the worksite should also be considered.

7.2.4 TIME AND DEPTH RELATIONSHIP

The gradual elimination of inert gas from the body after a dive is called decompression. Decompression is accomplished by holding the diver at a series of diminishing depths, called decompression stops, for varying periods of time, to allow the excess inert gas to equalise to the ambient pressure. Note, this state is never quite achieved, a residual pressure always remains after decompression. The need for decompression was recognised in the late 19th Century. The first decompression schedules were used on the Brooklyn Bridge project in 1878, but it was 1907 before the first successful tables appeared, produced by Professor J S Haldane for the Royal Navy.

After many years of research, tables now exist to cover both air and mixed gas decompression.

The most commonly used are those developed by the U.S. Navy, adopted by many commercial diving companies for their own use, but Royal Navy, Comex and other tables exist and are referred to.

Briefly, each table consists of 4 or 5 columns, detailing maximum attained depth, time spent at this depth (measured from point of leaving surface to time of leaving bottom), ascent rate and the decompression stops required. The Supervisor controlling the dive constantly monitors the depth and bottom time of each diver.

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Company policy, sea state and on board facilities dictate the decompression profile. When the supervisor decides to curtail the dive, he will instruct the diver to commence his ascent, stipulating whether an in-water or surface decompression table will be used (see following section). If the dive has been of a sufficiently short period, the diver may avoid decompression altogether.

Referring to Table 7.3 observe how the allowable bottom time (referred to as the no-stop time) decreases with increasing depth if decompression is to be avoided.

U.S. NAVY TABLE (STANDARD AIR DECOM)

DEPTH (feet)	BOTTOM TIME (mins)	TIME TO 1st STOP (min:sec)	DECOMPRESSION STOPS (feet) 50	40	30	20	10	TOTAL ASCENT min:sec
150	5						0	2:30
	10	2:20					1	3:30
	15	2:20					3	5:30
	20	2:10				2	7	11:30
	25	2:10				4	17	23:30
	30	2:10				8	24	34:30
	40	2:00			5	19	33	59:30
	50	2:00			12	23	51	88:30
	60	1:50		3	19	26	62	112:30
	70	1:50		11	19	39	75	146:30
	80	1:40	1	17	19	50	84	173:30
160	5						0	2:40
	10	2:30					1	3:40
	15	2:20				1	4	7:40
	20	2:20				3	11	18:40
	25	2:20				7	20	29:40
	30	2:10			2	11	25	40:40
	40	2:10			7	23	39	71:40
	50	2:00		2	16	23	55	98:40
	60	2:00		9	19	33	69	132:40
	70	1:50	1	17	22	44	80	166:40

Table 7.3

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If the deepest depth falls between two depth increments, the no-stop time for the deeper value is referred to. The manner in which tables are interpreted varies from company to company and supervisor to supervisor. Few hard and fast rules apply and it is beyond the scope of this module to explain fully the use of decompression tables.

Physiological parameters vary greatly from diver to diver, and this when combined with numerous other factors, eg. sea state, temperature, exertion and physical condition, combine to produce a steady stream of divers who, at some stage, have or will suffer from decompression sickness (DCS).

A few points concerning the time/depth relationship and how it relates to inspection diving should be mentioned. Referring to US Navy tables, at 40fsw, a diver has a no-stop time of 200mins. At 60fsw he has 60mins. Consider the times involved and how they relate to job duration. For example, a riser clamp at 40fsw takes two divers working together 180mins to replace - 1 dive. At 60fsw, it would take 3 dives to accomplish the same task.

This illustrates how the practical use of decompression tables can reduce this apparent drastic increase in task duration. By increasing the bottom time followed by in-water or surface decompression, it would again become possible to complete the same task in 1 dive. But that is with US Navy tables, other tables would and do interprete such a profile differently. The point to stress is that the diving supervisor is running the dive; he knows the tables he is using and the safety of his divers is his prime responsibility. His is the last word.

7.2.4.1 VERTICAL EXCURSION

Provided the no-stop time for a maximum depth is not exceeded, there is no requirement to control vertical excursion. However, if the dive plan involves decompression, at no time must the diver swim upwards more than half his maximum absolute pressure.

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7.2.4.2 IN-WATER AND SURFACE DECOMPRESSION

There are arguments for and against both types of decompression and again preferences vary.

In-Water Decompression

In-water decompression can be a long, tiring and tedious process. The diver will leave the bottom at a standard air ascent rate - 60ft/min. The supervisor will check his depth at intervals using the pneumofathometer and stop him at his first decompression stage. As he approaches the surface he becomes increasingly affected by wave action and swell. If it has been a long, arduous dive he is already tired and thus hanging on to the structure trying to maintain depth will tire him further. Poor circulation in his arms as he hangs on and a varying hydrostatic pressure combine to increase the chances of decompression sickness.

The alternative is surface decompression, using either air or O_2 as the breathing medium. Breathing pure oxygen decreases the partial pressure of N_2 in the lungs, thus greatly increasing the rate at which nitrogen comes out of the body. Its use is limited to 40fsw, equivalent to (2.2 bar), but it can be used down to 60fsw (2.8 bar) for therapeutic application.

Surface Decompression (Air)

The procedure for surface decompression breathing air is as follows (as stipulated by US Navy tables). An ascent rate of 60ft/min is maintained up to and between in-water stops, 10fsw being the shallowest. Time taken to reach surface from the last stop, strip off equipment, enter the deck decompression chamber (DDC) and recompress to 20fsw must not exceed 3.5 mins (termed the surface interval). Once at 20fsw, the diver decompresses as in in-water stops. Because of the extended decompression times necessary for all but shallow dives, this table is rarely used.

The procedure for surface decompression using oxygen is somewhat different.

Surface O_2 Decompression

On leaving bottom, an ascent rate of 25ft/min is maintained up to and between in-water stops, 30fsw being the shallowest. The surface interval in this instance must not exceed 5 minutes.

Oxygen on "bibs" is breathed immediately on entering the chamber which is blown down to 40fsw. This depth is maintained for the stipulated time after which the diver is brought back to surface in 2 minutes (this is often extended). Air breaks of 5 minutes duration are sometimes included but the total time spent breathing oxygen must not alter.

There is an increasing reaction against the use of surface decompression; the argument being that during the surface interval a bend is induced and then surpressed before the symptoms can materialise. Strong medical evidence supports this. The Department of Energy may, in future years, stipulate the use of a diving bell with deck decompression chamber mating capability, thus providing a continuous decompression cycle.

One other factor should be mentioned in the operation of DDC's. An air spread will have one, sometimes two on board. If only one, no diving can be carried out whilst a diver is in the chamber, unless it is calculated that he will be out before the in-water diver enters decompression time. This chamber must also be of twin lock construction, ie. have an outer chamber such that if a bend develops in a diver already 'out of decompression' this diver can be put under pressure in the outer lock.

7.2.5 AIR SAT., AIR AND MIXED GAS BOUNCE DIVING

Air Saturation

The principles of saturation were outlined in section 7.1.3. In air saturation, the difficulty arises in partial pressure build up. To avoid exposure to excessive PPO_2 and PPN_2, storage depths (section 7.3.3) tend to be around the 10m mark (PPO_2 = 0.4 bar, PPN_2 = 1.6 bar) which allows an excursion down to 30m (PPO^2 = 0.8 bar, PPN_2 = 3.2 bar).

Because of the physiological effects of breathing air at these partial pressures, its use is limited. With the advances in mixed gas reclaim efficiency and the development of shallow water excursion tables the usefulness of air sat is becoming more and more restricted.

Air and Mixed Gas Bounce Diving

If a diver could be lowered to his working depth in a one atmosphere environment followed by a rapid blowdown, maximum utilisation of his bottom time would be achieved.

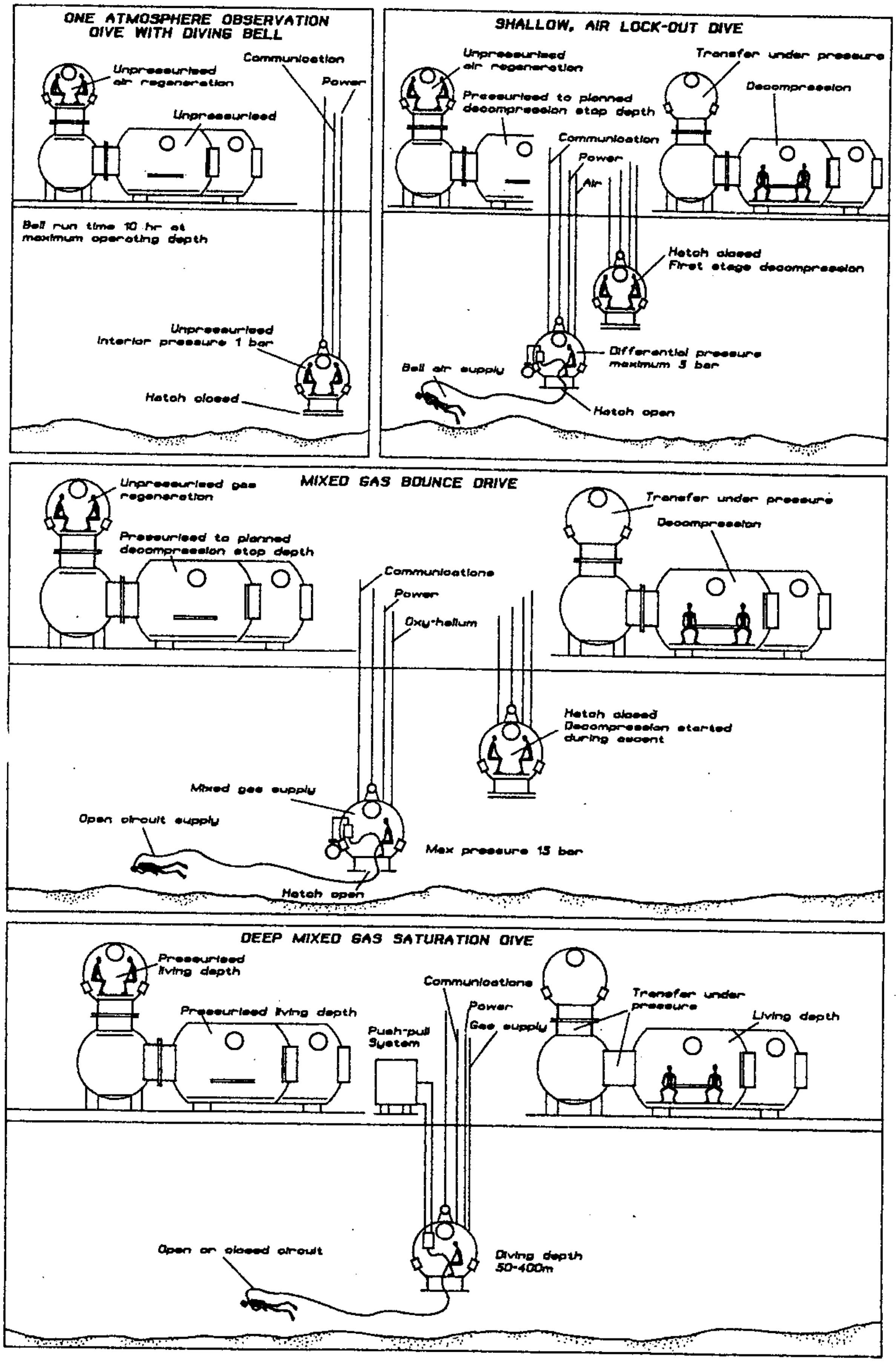
This is the principle of bounce diving. Breathing air, divers can be bounced to 50m in a bell, complete the dive and commence decompression as the bell is recovered to surface. Decompression is completed after mating with a DDC.

For mixed gas the initial breathing medium is air until about 30-40m where it is switched over to heliox; the reason being that if heliox were breathed directly from the surface, the low PPO_2 would adversely affect the diver.

Maximum operating depth is about 140msw. Decompression is commenced during ascent and continued after mating with a DDC.

Bounce diving tends to be restricted to one-off jobs where the required bottom time lies between the surface diving air range and full saturation.

Some typical Diving Systems compared



Drawings courtesy of Submex

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7.3 COMMERCIAL SATURATION DIVING

Much of the background behind saturation has already been discussed. This section will continue to describe in greater detail the equipment and the procedures which are followed to operate a full saturation diving spread in the North Sea. It will also explain the function of storage depth and excursion profiles and its implication to inspection.

7.3.1 SATURATION SYSTEMS - A TYPICAL LAYOUT

A saturation diving system comprises of five main parts:-

Diving bell
Bell handling and dive control
Deck compression chamber complex
Chamber control
Life support equipment

Diving Bell

A bell may be a two or three man unit, the latter usually being used for construction tasks needing two divers out of the bell working together. A variety of mating systems exist - some are bottom-mating, others side-mating.

A typical bell layout is shown below:

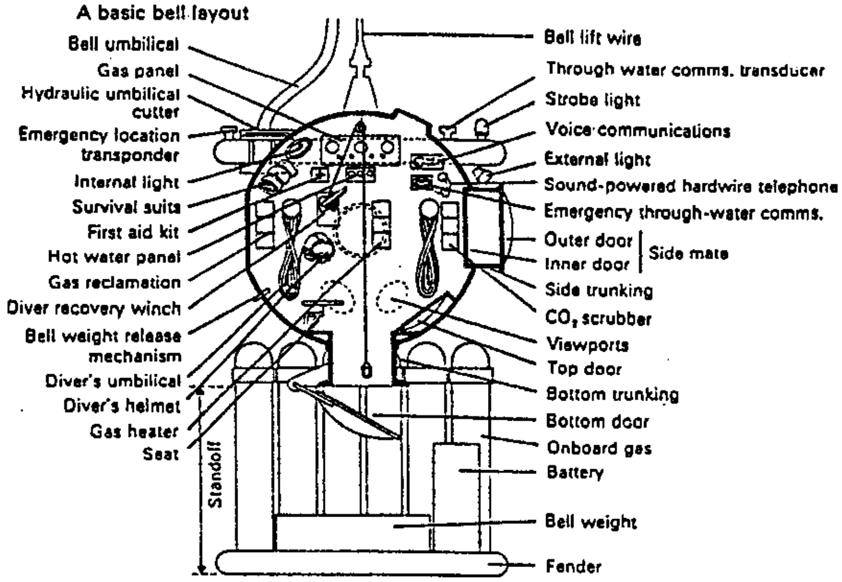

Fig. 7.6 - Drawing courtesy of Submex

Bell Handling and Dive Control

The dive control station is the normal location of the diving supervisor and inspection co-ordinator during the dive. It is usually positioned alongside the launching point for the bell to allow easy control of the launch and recovery.

A means of increasing the foul weather bell handling capability is provided by use of a bell cursor. The cursor may be 'active' or 'passive'. The passive cursor may be a heavy weight secured on vertical rails and can be attached to the bell. It is lowered by additional winches and allows the bell to sink steadily through the air/water interface. The bell is released from the weight near the bottom of the vessel where the water movement is not so great.

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The active cursor may have a similar means of restraining the bell against a vertical rail system. It would have, in addition, an active drive system to move the bell up and down the rails. Cursor systems are usually seen in dedicated DSV's with moonpools.

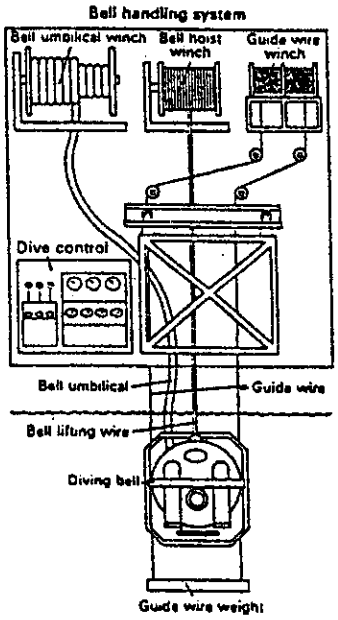

Fig. 7.7 - Drawing courtesy of Submex

<u>**Deck Compression Chamber Complex**</u>

The chamber complex may consist of up to five or more interconnecting chambers. The chambers themselves may be sub-divided internally by pressure bulkheads or simple partitions. The various locks provide sleeping, eating, showering, changing, toilet and storage facilities. One chamber, usually called the transfer chamber, receives the bell. It is used to store wet clothing, for kitting/de-kitting, and contains showering and toilet facilities.

Smaller 'medical' locks allow the transfer of food and small items in and out of the main chambers.

Chamber Control

This is the main base of the life support technician and is the central point of life support control for all the chambers and the bell.

Chamber control includes the following functions:-

- Regulation of all chamber compression and decompression procedures.
- All routine gas analysis for the bell, chambers and gas banks, although bell gas analysis during the dive is usually checked out by the Diving Supervisor.
- All voice communications with chamber occupants.
- Regulation of gas mix in chamber, its temperature and humidity control.
- Control of medical locks including meals and material transfers.
- Control of all chamber electrics.
- Control of any entertainment facilities such as radio, cassette tape, film etc.
- Control of sanitation unit, showers, etc.
- Treatment of divers requiring medication for say, ear infection, colds, etc.

Life Support Equipment

The life support equipment tends to be grouped together for convenience. The exception is normally any oxygen handling equipment which should be located well away from areas of possible oil contamination, high temperatures, electrics and poor ventilation.

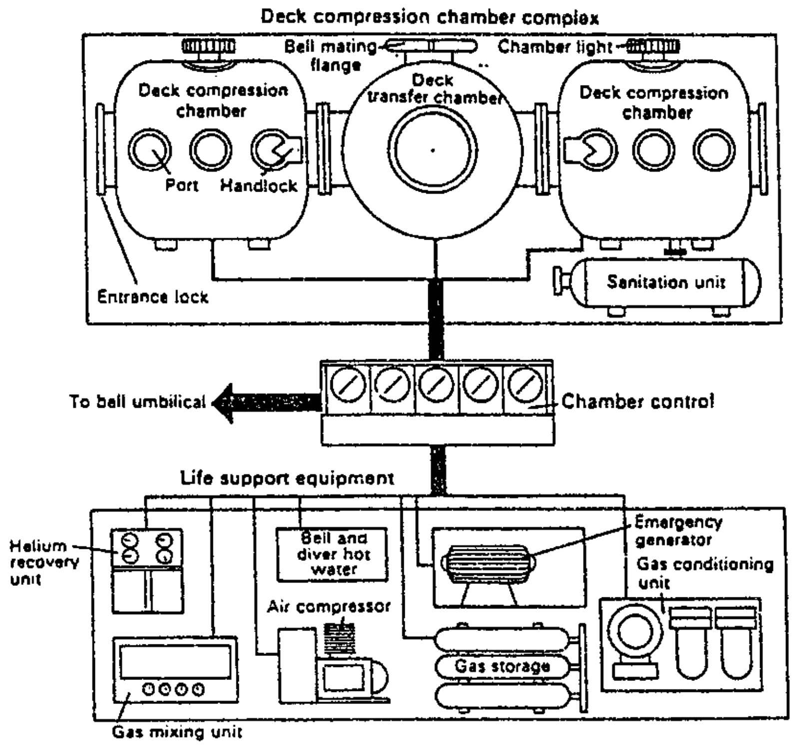

Fig. 7.8 - Drawing courtesy of Submex

7.3.2 WORK EFFECTIVENESS - A COMPARISON WITH AIR DIVING

A typical bell run will last for 8 hours. This usually means that in a two man operation, each man will lock out of the bell for 4 hours.

Bearing in mind the continual race against time that exists whilst air diving, saturation diving by comparison rarely operates under such stress. The diver has more time to assess the task and decide his approach, and the increase in dive duration greatly increases job continuity.

7.3.3 STORAGE DEPTHS AND VERTICAL EXCURSIONS

As an inspection programme progresses, living or storage depths must be decided in advance. Common practice is to start shallow and work down. There is no time factor involved in increasing a diver's absolute pressure, but decompression to a shallower holding depth takes time. Vertical excursion from the storage depth varies depending upon the diving tables in use and the 'storage' depth. Note that once a diver has a maximum excursion downwards, 24 hours must lapse before he can achieve a maximum upward excursion or longer depending on depth. The reverse is not the case; maximum downward excursion can immediately follow maximum upward excursion.

'Split' level diving, which is often required to optimise use of a diving spread, requires teams of divers stored at different levels. This, in turn, requires a deck decompression chamber layout which will support this type of operation.

Split level diving can also involve selecting a storage depth which will allow divers to reach one lower point with a maximum downward excursion and the other point with a maximum upward excursion, provided that a 24 hour interval elapses between dives.

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Vertical excursion is a complicated procedure and company policies differ. At the start of a diving contract, it is necessary for all interested parties to sit down and discuss the parameters involved.

Intelligent planning can greatly increase the effectiveness of available dive time.

7.3.4 DECOMPRESSION RATES

All divers ready for decompression typically wait for approximately 4 hours after returning from the last dive to ensure stabilisation of tissue gases.

At this point oxygen is added to the atmosphere to raise its partial pressure to about 0.5 bar typically, thus prompting an advanced inert gas release from the body.

Decompression to the surface then follows the company's table of standard saturation decompression rates.

On reaching surface the divers are checked over and then placed on a bend watch to ensure all is well before being released from the ship and observation. The actual duration of the bend watch will depend upon the decompression tables which have been used and whether air transportation back to the beach is to be used.

7.3.5 COMMUNICATIONS

The voice distortion associated with breathing helium is alleviated by the use of electronics. Heli-boxes or unscramblers alter the electrical signal input to provide an output that is closer in sound to normal speech.

It is still a problem, however, and constant exposure to helium affected speech is the only effective way of understanding a diver breathing heliox.

7.3.6 GAS RECLAIM

The expense of helium has always been a problem, hence the continued interest in the use of other dilutent inert gases. Closed circuit breathing systems which involve the recycling of exhaled gases have been developed with varying degrees of success.

Up to eighty five percent of gas costs, transport, handling and storage can be recouped by recovering the helium that would otherwise be vented into the water.

7.3.7 ENVIRONMENTAL CONTROL UNIT (ECU)

The primary function of the ECU is to monitor gas levels, temperatures and humidity conditions in the living chambers and dive bell.

The following illustrates typical chamber atmosphere limits:

Atmosphere	Parameters
Oxygen partial pressure	0.30 - 0.50 bar
Carbon dioxide partial pressure	0.005 bar or 0.5%
Carbon monoxide	10 ppm
Helium	Balance of total pressure
Temperature	85-90^{o}F regulated to diver comfort (NB. as helium content increases with depth, the comfortable temperature range narrows)
Humidity	50-70% (as required for diver comfort)

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7.3.8 LIFE SUPPORT TECHNICIAN

Life support technicians are the backbone of a diving spread, very much the silent service of the diving operation. Besides environmental control, it is the LST's job to ensure the divers are fed, laundered and maintained in a good state of health. They are the saturation diver's main link with the outside world.

Recent legislation stipulates that all LST's must undergo a formal, recognised training programme and examination.

7.3.9 THE DIVING SUPERVISOR

Diver safety is the ultimate responsibility of the diving supervisor. It is his decision and his decision alone to commit a diver to the water. Weather, swell, equipment condition and many other factors all combine to present a go or no-go situation. His decision, once made, cannot be overruled by anyone on board. Recent legislation stipulates that all diving supervisors must undergo a formal, recognised training programme and examination.

7.4 HEALTH AND SAFETY

7.4.1 DIVER SELECTION

Men and women can be selected for diver training if over the age of 18 years. The upper limit is flexible. They must be physically fit with no history of respiratory, pulmonory, cardiovascular or mental illness.

Any physical disablement or old injury that prevents hard strenuous work underwater is also disqualifying.

Once qualified, a major physical medical examination is required annually, with long bone X-rays to be taken every 3 years.

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There is a very justifiable and continuing medical research effort to establish any long term physical and physiological effects related to diving. To date, the only detrimental effect of any significance discovered is dysbaric osteonecrosis (refer to section 7.1.2).

7.4.2 TREATMENT OF DCS

Decompression sickness occurs despite strict adherence to tables. Human error, accident or physiological disorder result in a steady stream of 'hit' divers.

Symptoms appear usually within 6 hours after surfacing but can be delayed up to 36 hours afterwards. As a generalisation, there are two types of symptoms of decompression sickness.

Type 1 Mild

Symptoms include pain, itching and fatigue. Pain is the most frequent; it occurs deep, in or near a joint, and varies between mild and severe.

Type II Serious Central Nervous System - CNS

Urgent and dangerous. Shock, nausea and hearing difficulties are common signs. Abdominal pain is frequently followed by weakness, paralysis or numbness of the limbs. Chest pain, shortness of breath, tunnel vision, extreme fatigue, collapse and unconsciousness indicate serious decompression sickness.

Therapeutic tables exist for the recompression and treatment of divers suffering DCS. Examples of these are US Navy tables 5, 6 and 1A. In-water recompression is possible but used usually only as a last resort when a DDC is unavailable.

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7.4.3 CHAMBER HYGIENE

With saturation pressurisation, cleanliness of the chamber complex is of paramount importance to the health and safety of the divers that enter it. Required atmosphere conditions have already been outlined in section 7.3.7. It is unfortunate that they also provide ideal growth conditions for bacterial organisms which, given the chance, will thrive.

There are three major categories of bacterial disease:-

1. Internal disorders such as gastro-enteritis.
2. Fungal infections of the skin such as dhobie itch and athletes foot.
3. Outer ear infections.

It is the last two which most commonly affect divers.

Preventive treatment in the form of drugs, medicines and ear drops cannot guarantee 100% success in the close confines of a pressured chamber.

Great heat, intense cold, direct sunlight and chemicals are all agents that can destroy bacteria. Of these, chemicals is the only one applicable to the chamber.

'Panacide' and 'Panaclean' are common disinfectant detergent trade names.

The interior of each chamber is thoroughly swept and cleaned with 'Panaclean' prior to the disinfection with 'Panacide' on a regular basis with special emphasis to the toilet and shower facilities.

The one point to remember is that infection generated or taken into the chamber will, if untreated, be passed on to all members of the dive team, with the possibility that the sat would have to be aborted.

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7.4.4 SHORE BASED MEDICAL SUPPORT

An increasing number of trained medical staff, conversant with diving medicine, are available to carry out emergency treatment under saturation conditions offshore.

Should it be necessary to medivac a diver, mobile chambers capable of being man-handled into a helicopter are now available. These small TUP's (Transfer Under Pressure) are nothing more than a tube which is mated to the main chamber and into which is inserted the casualty. He is carried to the helideck and again transferred into a manned larger chamber within the helicopter, ready for transportation back to a shore side hyperbaric medical centre.

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7.5 WHEN TO DIVE - THE WEATHER

Before conducting any dive it is the diving supervisors responsibility to assess the weather, sea and current conditions, and to attempt to ascertain any likely changes in those conditions during the period in which the dive will be made.

Jobs begun under marginal weather conditions may be aborted at short notice. In all events the decision lies with the diving supervisor. The Master of a vessel or OIM can terminate a dive if weather conditions are severe and the vessel can't hold position.

For a saturation diving spread, operating from a DSV, the following parameters illustrate the type of conditions that can be expected to exist before diving operations are halted:

Current	1.5 knots
Wind range	22-27 knots
Wave height	12 feet
Sea state	Approaching sea state 6

Particular combinations of these factors may result in unsuitable diving conditions even when all factors appear to be within the nominal limits.

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7.6 CAPABILITIES AND LIMITATIONS OF ROV'S, SUBMERSIBLES AND ATTACHED SYSTEMS

Various individual subjects are dealt with in this section but perhaps the most significant fact that has a bearing on all of these is PLANNING.

By accurately assessing what is required and utilising the best equipment for the job, success can be achieved. What may have appeared to be a major job several years ago can be tackled with relatively small, low powered ROV's or submersibles today.

7.6.1 THRUSTER CONFIGURATION

Most ROV's employ propellers or thrusters for propulsion. Several of the larger ROV's have shrouded propellers with Kort Nozzles for greater thrust in high slip conditions.

Six degrees of motion are experienced by ROV's;
Three are translational : Thrust, Heave and Sidle or Sway;
Three are rotational : Yaw, Pitch and Roll.

Very few ROV's obtain all of these motions dynamically.

The positioning of thrusters on ROV's is vitally important. Maximum forward propulsion with lateral and reverse thrust as auxiliary control units is adequate, for example, for navigation. This, however, is inadequate when the vehicle is holding station, aligning a work tool or inspection device or carrying out a range of tasks.

For these dive elements the ideal vehicle should provide the same thrust and offer a similar hydrodynamic drag in forward, reverse, port and starboard directions.

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As an example, some ROV's employ dual thrusters in the lateral plane in order to counter strong side currents, with two or more thrusters fixed for minimum forward and aft movement.

Other vehicles are fitted with vectored thrusters which allow an even or near to even performance in any direction.

Vertical thrusters are usually configured to allow the vehicle to power down through the surface interface quickly to avoid undue turbulence or damage. However, it may also be possible to create the opposite situation to assist with lifting of heavy loads in construction type work.

Basically, the design characteristics of any ROV is usually subject to a trade off situation and affected very much by commercial and market forces.

7.6.2 **SPEED**

This is subject to power pack size, thruster type and output, but is also very much dependent on the individual ROV's dynamics and hydrodynamics. For example, speed can be affected by the 'control margin', a term applied to thrusters or rudders. Applied to a thruster, the term is defined as the difference between the maximum thrust that the unit can provide and the thrust level needed to maintain a given operating condition, eg. forward speed or station holding against current. The difference represents the margin or excess of thrust available to the pilot to control or manoeuvre the vehicle while maintaining this condition.

Speed can be affected by:

- reduced propeller efficiency caused by effects on the inlet and exit flow.
- Forces exerted on the vehicle by the interaction of the inlet and exit flow with installed equipment and structure.

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- The interaction of different thrusters.

- Whether the ROV is deployed with or without a tether management system (TMS)/Garage.

7.6.3 MANOEUVRABILITY

This is very much related to similar conditions as highlighted in Speed, (above). There are the implications also of negotiating a structure or subsea template and consequently the inherent situation of restricted access. The stability and manoeuvrability may be seriously affected by high payload requirements.

A pilot's lack of experience or expertise can have a strong bearing on manoeuvrability. The nature of the work is also most important as the vehicle may be deployed in a heavy, neutral or light mode, each situation affecting the vehicle's performance.

Thruster power sharing can also create difficulties. For example, when vertical thrust is applied in the case of certain ROV's forward thrust is automatically reduced. The result is a constant jockeying back and forth to maintain station in the presence of even moderate currents.

7.6.4 LAUNCHING METHODS

Various systems exist. No matter what type is used, it is obviously of prime importance to launch and recover equipment safely and efficiently. Surprisingly, it is often the case that more emphasis is placed on the subsea component of an ROV package with launch and recovery equipment taking a back seat.

Generally, the most commonly used launch systems are as follows:

a. Articulated HIAB Type Crane
b. A-Frame
c. Fixed deployment Cursor/Guide Wire System

The HIAB Crane can be fitted with a docking mechanism at the head of the boom which allows for a relatively smooth and troublefree launch/recovery process.

A-Frame launching is similar to HIAB type crane launching in that a docking or latching mechanism is utilised. The A-Frame allows a reasonable reach over the vessel or installations side.

The Fixed Deployment Cursor/Guide Wire Systems are particularly useful for moonpool deployment. It can allow operations to continue in relatively high sea states. However, it should be said that ROV's with Heavy Tether Management Systems (TMS) can be just as effective. Further, operating a Guide Wire system through a vessel's moonpool can cause difficulty in a "Dead Vehicle Recovery" situation. Rather than attempt to recover through the moonpool when a loss of power has been experienced alternative steps may be taken. These may involve the ROV umbilical being paid out and the vessel being moved off station. In this situation the ROV being in a "positively buoyant" mode will come to the surface, where a line is attached from an inflatable. The vehicle can then be retrieved on board. The umbilical must then be separated from the ROV and pulled back through the moonpool deployment system.

In some cases when vehicles are operated with no TMS or docking mechanisms in the launch crane an alternative method may be used.

Launch/Deployment can be carried out with a line other than the umbilical cable. When launching, a quick release hook is used that is tripped by a lanyard on deck. For retrieval some operators prefer to manoeuvre the vehicle on the surface to a point where the lift line can be attached from a long pole aboard ship.

Other operators prefer to marry a length of line to the umbilical which, when it has reached the winch, is used to bring the vehicle aboard. This procedure requires a second winch or windlass for the lift line.

7.6.5 UMBILICAL MANAGEMENT SYSTEMS

Umbilical Management Systems go very much hand in hand with Cage (Garage) Launch Systems.

Again, varying systems are available depending on which ROV is being utilised, the most common being:

a. Top Hat System
b. Side Entry Garage
c. Front Entry Garage

In the case of (a) a Dead Vehicle Recovery can be carried out relatively easily, whereas in (b) and (c) problems can be encountered.

Tether Management Systems (TMS) can be most useful in a number of areas. They can provide:

- Additional lighting
- Sonar
- Lifting capability
- Tool carrying carousels
- Winching capability

The Tether from the garage or TMS to the ROV is lighter and usually smaller than the main garage tether which reduces drag on the ROV allowing freedom of movement.

7.6.6 RANGE OF SIZE AND TYPES OF VEHICLE

Many ROV's have been developed for a variety of tasks. The most common in oilfield terms are as follows:

MINI ROV's	- Mini-Rover, Phantom, Sprint, RCV 225, UFO.
LIGHT INSP WORK ROV'S	- RCV 150, Recon, Scorpi.
MEDIUM WORK ROV'S	- Scorpio, Rigworker (and Rigworker Derivatives), Pioneer, Hydra
WORK ROV'S	- Trojan, Super Scorpio, Hysub
ADVANCED WORK ROV'S	- Triton, Challenger
DEDICATED PIPELINE ROV'S	- Solo

It should be said that the individual operators have up-graded or modified off-the-shelf ROV's to perform work normally outwith the standard vehicles capability. In the case of "SOLO" it was designed originally for platform inspection but has found greater success in pipeline survey.

7.6.6.1 SIZES - EXAMPLES

a. Mini-ROV's

Mini-Rover	:	26" x 18.5" x 12.5"
RCV 225	:	20" x 26" x 20"

b. Light Inspection ROV's

RCV 150	:	52" x 47" x 43"

c. Medium Work ROV's

Hydra	:	5.83' x 3.83' x 4.17'
Scorpio	:	7'3" x 5'8" x 5'3"

d. Work ROV's

Super Scorpio	:	7'6" x 4'5" x 4'8"

7 6 7 POWER AT THE VEHICLE

This is subject to the type of ROV and task(s) required. Historically, ROV's have had to devote most of their power to maintaining position and general station keeping, which has resulted in little ability to perform even the most basic tasks.

Advanced work systems such as CHALLENGER for example have 50 horsepower available at the vehicle for control with an additional 50 horsepower for the operation of a variety of tools. With some modification a further 50 horsepower could be made available.

EXAMPLES

Power available:

Scorpio	:	25 HP, 40 HP option
Rigworker	:	50 HP
Challenger	:	100 HP

7.6.8 MANIPULATORS

A variety of off-the-shelf manipulators are available, the most common in use are as follows:

a. Perry Five Function Rate Controlled
b. Kraft Five Function Master/Slave Arm
c. Kraft Nine Function Force Feedack Arm *
d. Slingsby Five Function Grabber/Claw Arm
e. Slingsby Nine Function Master/Slave Arm *

* c and e have been specifically built for an individual ROV operator.

EXAMPLES - (see following figures)

- TA9 Manipulator
- TA16 5-Function Manipulator/Grabber
- Manipulator and Grabber Envelopes (TA9 and 16)

It can be said that the size, facial profile and manoeuvrability of the ROV can drastically affect the performance of manipulators, in addition to pure pilot capability. A pilot may be efficient at flying or repairing the vehicle but not quite so efficient when operating manipulators and vice versa. Seldom is one man good at all facets of the operation, hence the reason for selecting the best possible team for the job.

7.6.9 SENSORY FEEDBACK

To date there has not been much call for sensory feedback, mainly due to the fact that ROV's were not considered reliable enough to conduct detailed inspection and NDT. In practice, about ninety percent of tasks do not require sensory feedback, consequently, it is not commercially viable for ROV operators to have such expensive items laying idle most of the time.

With ROV's becoming more reliable and generally more accepted, sensory feedback will most likely become common place within 2 years or so.

Already ROV's have proven their ability to conduct magnetic particle inspection and flooded member detection and utilised in conjunction with sensory feedback would prove most useful.

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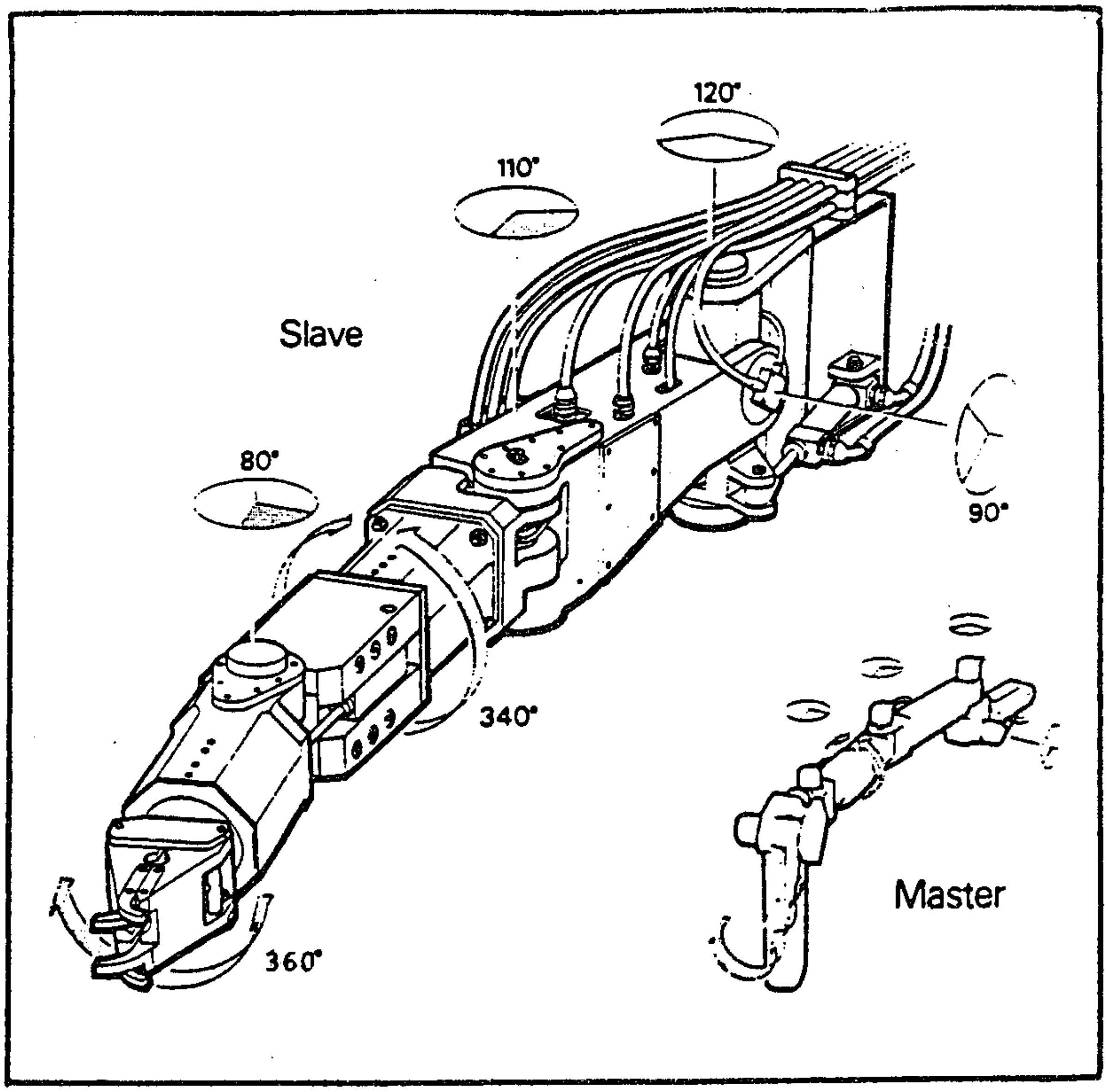
TA9 MANIPULATOR



TA9 MANIPULATOR: COMPONENT DATA

Degrees of Freedom	:	6 plus claw function
Control	:	Seven spatially corresponding master/slave servo-functions
Lift Capacity	:	445N (100 lbf)
Claw & Forearm Torque	:	100 N-m (75 lbf-ft)
Maximum Reach	:	1.3m
Weight of Slave Arm	:	36 kg in air (23.5 kg in water)
Weight of Installation	:	84 kg in air (56 kg in water)
Operating Oil Pressure	:	165 bar (2,400 psig)
Options	:	Vertical or Horizontal park Left Hand Version Shoulder 0.5m extend function Continuous Claw Rotation Electronic "Freeze" Function "Teach and Learn"

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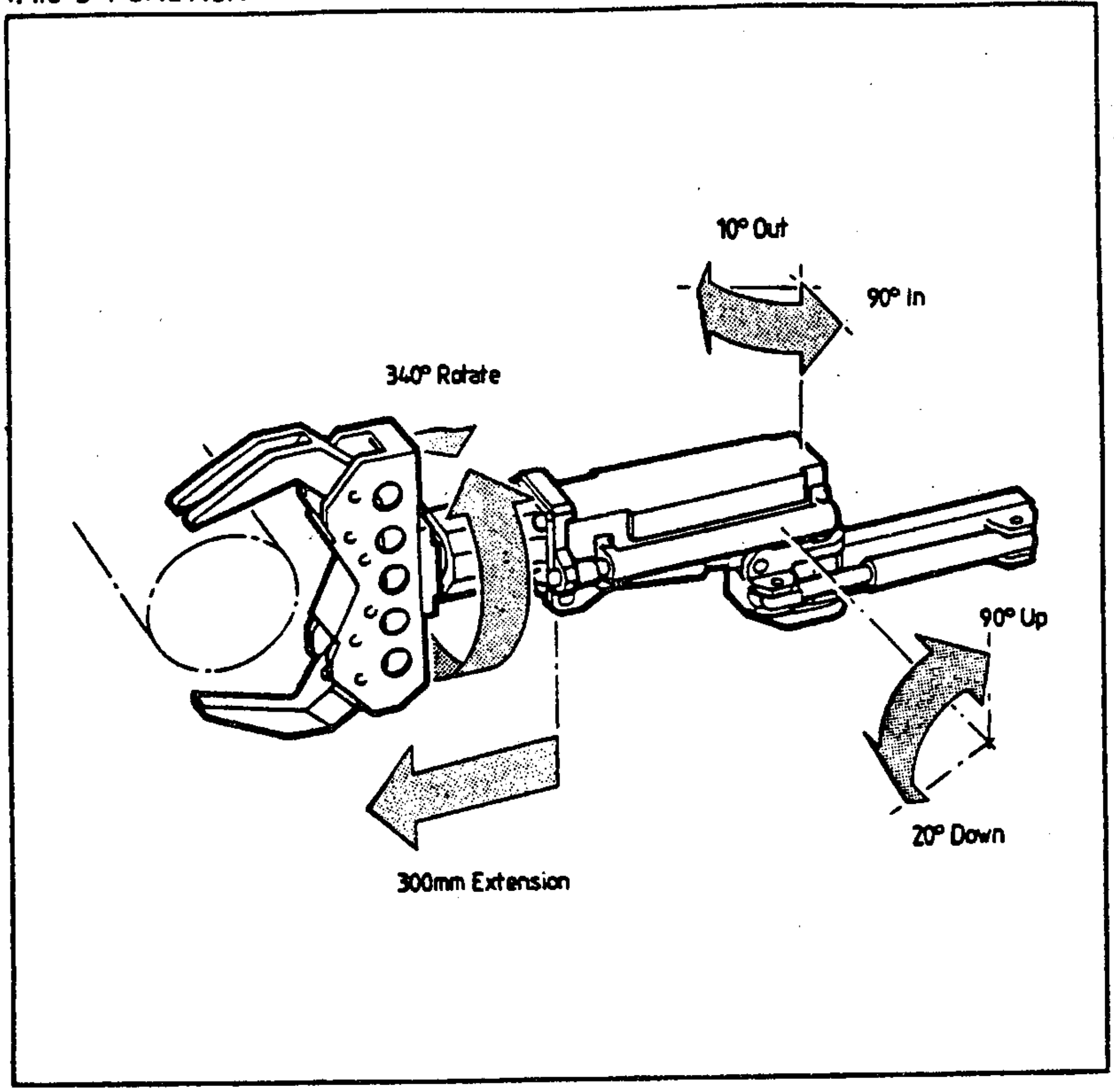
TA16 5-FUNCTION MANIPULATOR / GRABBER



5-FUNCTION MANIPULATOR: COMPONENT DATA

Degrees of freedom		:	5, Rate controlled.
Slew either		:	90° in, 10° out or 10° in, 90° out.
Up/Down		:	90°/20°.
Extend/Retract		:	300 mm.
Rotate		:	340° or continuous
Jaw Options	1)	:	6" Low Profile Jaw (std.).
	2)	:	9" Low Profile Jaw.
	3)	:	12" Grab Claw, opening 50mm min. 305mm max.
Control		:	Solenoid Valve.
Lift Capacity		:	100 kg (220 lbf) extended. 145 kg (320 lbf) retracted.
Claw Torque		:	95 N-m (72 lbf-ft).
Reach		:	1.06 m.
Weight		:	41 kg in air (32 kg in water).
Oil Pressure		:	165 bar (2,400 psig) max.
Mounting		:	Left or Right hand.

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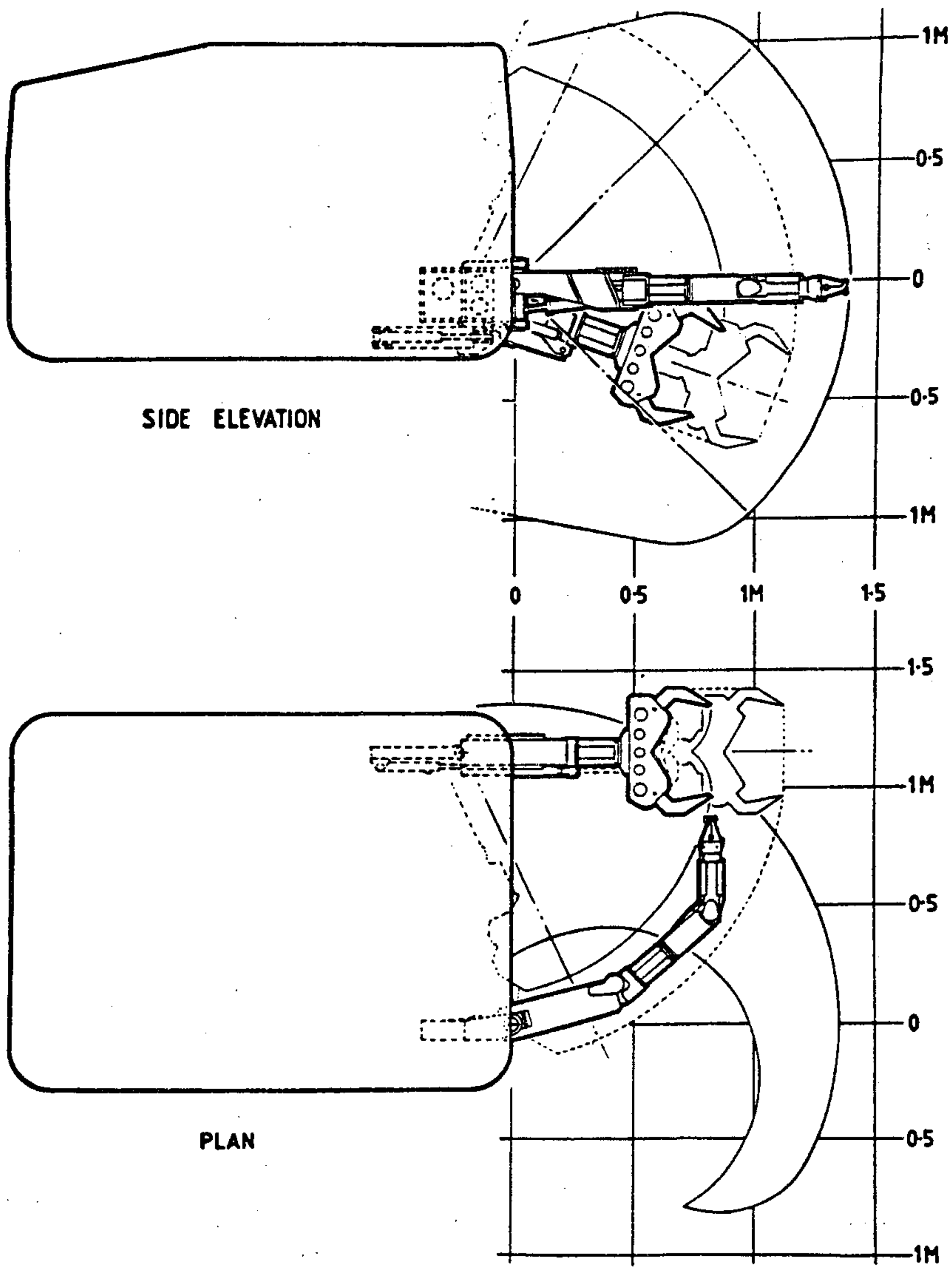

MANIPULATOR & GRABBER ENVELOPES (TA9 & 16)

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7.6.10 REMOTELY APPLIED INSPECTION SYSTEMS

7.6.10.1 VISUAL INSPECTION

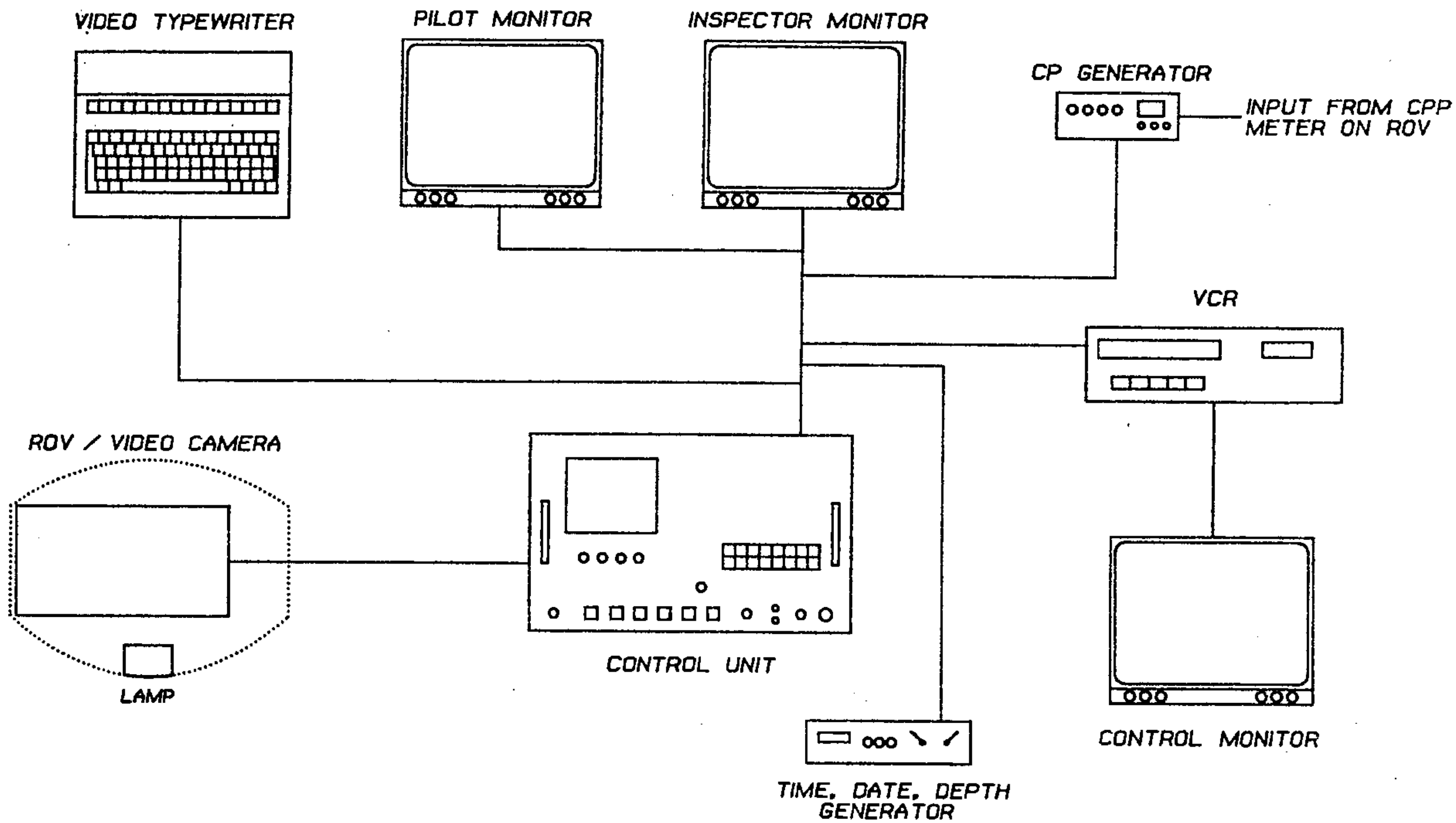
ROV's have traditionally been utilised to carry out general visual inspection utilising still photographic, CCTV and CP measurement techniques. Major advances have been made in recent years in the field of ROV inspection including the use of Robotics which have enabled some close visual inspection tasks to be carried out.

For details of current CCTV and photographic requirements for underwater inspection see Section 3 - Recording Methods.

An advanced ROV must be utilised to carry out close visual inspection. It would not be unusual to equip such an ROV with, a 7-function manipulator to deploy, for example, a Photosea NDT 4000 stills camera for high resolution, close-up weld and corrosion inspection and photogrammetic measurement. The manipulator could be mounted on a 360^{o} rotatable and extendable turntable to allow access to within a few inces of most nodal welds. The same manipulator may well be used to deploy a water blast capability for marine growth and protective coating removal.

This type of ROV would normally attach itself to the structure using suction devices. A high resolution split-head colour CCTV would be utilised for detailed inspection - there are several very good systems in todays market place. A schematic diagram of CCTV survey equipment is shown overleaf.

SCHEMATIC DIAGRAM OF CLOSE CIRCUIT TELEVISION SURVEY EQUIPMENT USING ROV



7.6.10.2 <u>CATHODIC PROTECTION POTENTIAL MEASUREMENT</u>

ROV deployed CP measurement equipment is normally one of the common types:

1. <u>Direct Contact Probe</u>

This system most commonly packages a half cell connected via a cable to a digital surface voltmeter. The unit is mounted on the ROV, the pilot positioning the vehicle so as to make the probe tip contact the inspection site.

For calibration of the contact probe unit, the following additional equipment will be required:

- 3 Calomel electrodes
- High impedance voltmeter (10M ohm)
- Zinc block with clamp and lead

2. <u>Proximity Cell</u>

A proximity system deploys only the half cell underwater, at the end of an electrically insulated lead. This is connected to a digital voltmeter, with the negative terminal connected by another lead to the structure. With this permanent single-point electrical contact, the half cell will complete the circuit while near, <u>but not in contact with</u>, the structure and give continuous cathodic potential readings.

Equipment suitable for taking proximity CP readings includes:

- Ag/AgCl proximity probes, connecting cables and high impedance voltmenter (10M ohm).

Contents

For the calibration of proximity cells, the following additional equipment will be required:

- 3 Calomel electrodes
- High impedance voltmeter (10M ohm)
- Zinc block with clamp lead (zinc 99.99% pure)

Prior to commencement of CP survey, the contact probe or proximity cell must be calibrated. An initial calibration must take place of a suitable calomel electrode, this shall involve the following:

(a) Check that electrodes are in good condition (total of three required), the electrode is filled with Potassium Chloride (KCl) solution, free crystals of KCl are visible and there are no air bubbles in the electrode.

(b) Label the electrodes 1, 2, and 3.

(c) Connect electrode 1 to the negative terminal of the voltmeter and electrode 2 to the positive terminal.

(d) Immerse the tip of the electrodes in a plastic bucket of clean seawater and record the reading on the voltmeter.

(e) Rinse electrode tips with clean fresh water.

(f) Repeat steps 3 - 5 with each possible electrode pair.

(g) Select electrode to be used in calibration of CP meter according to the procedure below.

Acceptable readings between pairs of electrodes are "-2mV to +2mV.

If all readings are in this range, any electrode may be used.

If one reading is out of range the electrode not included in the pair giving this reading shall be used.

If one reading is in range either of the two electrodes included in the pair giving this reading may be used.

If all readings are out of range either of the pair giving the least reading may be used.

Calibration of Direct Contact CP Meter

Calibrate the unit against a calomel electrode as follows:

(a) Ensure calomel electrodes have been properly calibrated.

(b) Soak contact CP meter in clean, fresh seawater (not fire mains) in a plastic bucket for 30 minutes prior to calibration.

(c) Connect the calomel electrode to the negative terminal of the voltmeter and immerse the electrode tip in the seawater.

(d) Connect the zinc block to the positive terminal of the voltmeter and immerse the zinc block in the bucket of seawater, ensuring only the zinc is submerged and not the clamp or the cable.

(e) Take the reading on the voltmeter. This should be in the range -1.00v to -1.05V.

(f) Disconnect the clamp from the zinc block.

(g) Measure the potential of the zinc using the contact half cell as a contact probe. The reading should be in the region -1.00V to -1.05V.

(h) Subtract the reading obtained for the calomel/zinc cell from that obtained for the half cell/zinc cell. The result should be between 0 and -10mV.

(i) Repeat procedures if readings fall outside this range.

(j) Replace the unit if inaccurate readings persist.

Calibration of Ag/AgCL Proximity Cell

Calibrate the unit against a calomel electrode as follows:

(a) Ensure the calomel electrodes have been properly calibrated.

(b) Soak the Ag/AgCl half cell in clean seawater in a plastic bucket for 30 minutes prior to calibration.

(c) Connect the negative terminal of the voltmeter to the Ag/AgCl measuring electrode.

(d) Connect the positive terminal of the voltmeter to the calomel electrode and immerse the electrode tip in the seawater.

(e) Take the reading on the voltmeter. Acceptable readings are in the range 0 to -10mV.

(f) Repeat the procedure if readings obtained are outwith this range.

(g) Using the procedure previously described measure the potential of the zinc block using the proximity cell. The reading should be in the region -1.00V to -1.05V.

7.6.10.3 CURRENT DENSITY

This technique can again be carried out by either diver or ROV although is most commonly carried out by ROV. The principle behind the technique is that the cathodic protection system must be able to supply a certain current per unit area of steel to prevent corrosion. In the Northern North Sea this is around 150mA/m^2. Using specialist probes to measure current density we can determine any areas where the CP system is not providing sufficient current density to prevent corrosion.

7.6.10.4 ULTRASONIC WALL THICKNESS MEASUREMENT AND FLOODED MEMBER DETECTION

Flooded member detection has been attempted underwater utilising several methods including ultrasonic, neutron backscatter and gamma radiographic techniques. Wall thickness measurement, however, has been restricted to the use of digital ultrasonic instruments in the main.

Research and development in recent years has led to the production of ROV mounted systems that carry out both of these functions using ultrasonic techniques. Proprietary systems are marketed by Baugh and Weedon (ROVPROBE) and Subspek Ltd.

In operation either a diver or an ROV applies the probe to the surface of the member to be tested. Once the probe has been positioned assessment of results is carried out by a surface operator who interprets the A-Scan wave form presented on a Cathode Ray Tube (CRT).

Difficulty can often be experienced by an ROV in accurately aligning the probe on the member to be tested.

Equipment currently available is generally suited for use on members up to 2.5 metres in diameter and with wall thickness in the range 10mm to 50mm. All hard marine fouling must normally be removed but the system is tolerant to a certain amount of soft marine growth. Thin coatings of protective paint on the tubular under test can be tolerated.

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7.6.10.5 CLEANING

Cleaning of steel tubulars or sheet pile surfaces and concrete, can adequately be accomplished by ROV's or remotely operated machines nowadays utilising one of the following techniques:

- high pressure water jet, typically 20,000 psi but up to 36,000 psi has been used.
- rotary hydraulic wire brushes
- rotating steel cutting heads

Most advanced ROV's need a significant portion of their power and manoeuvrability to clear marine growth and protective coating effectively. They normally utilise rotating hydraulic wire brushes or, typically, a 7-function manipulator to deploy high pressure water blasting equipment. The ROV would normally attach itself to the structure using suction devices and should be able to clean (and inspect) several brace welds before needing to relocate the vehicle. Water blasting systems are available for ROV use which deliver 36,000 psi at 2.5gpm or an optional 12,000 psi at 10gpm depending on what is required to be removed.

Equipment recently developed by Australian based Dawson Industries includes a cleaning vehicle which may be either ROV or diver deployed and a remotely operated, self-propelled vehicle capable of working in the splash zone and effectively cleaning corrosion product, hard marine fouling and, where required, protective coatings.

Both vehicles utilise a variety of innovative cutting heads which clean to a specified finish by altering the cutting head, the cutting head pressure and cleaning speeds.

7.6.10.6 MAGNETIC PARTICLE INSPECTION (MPI)

Several trials have been carried out to date utilising ROV's to carry out MPI. Results have been achieved using the current carrying coil technique and there are developments under way to test more innovative equipment. Only advanced vehicles have had any success to date.

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7.6.10.7 <u>OTHER NDT TECHNIQUES</u>

Eddy current and ACPD are NDT techniques that would be useful to apply underwater using either ROV's or Robotics. To date, there has been no commercial success in this area.

7.6.10.8 <u>GENERAL COMMENT</u>

Section 7.6 deals with the current capabilities and limitations of ROV's and examines the limitations of and the effects on underwater inspection systems when remotely deployed. Access, attitude, positioning, stand-off, set up constraints, deployment method constraints, cleaning, location and referencing limitations must all be taken into careful consideration when considering ROV use.

It is important to consider and select the correct system if it is available. Used efficiently, ROV's and Robotics can usually provide an economic alternative to carrying out underwater inspection using divers, especially in the saturation diving range.

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7.6.11 MANNED SUBMERSIBLES

7.6.11.1 AUTONOMOUS VEHICLES

Range

Subject to size, weight and power output, payload required etc.

The use of modern, lightweight construction materials would enhance range and perhaps make autonomous manned submersibles more viable.

Endurance

This is directly reliant on power storage, and dependent on the capacity of batteries, for example, Lead - Acid, Cadmium-Nickel which are very expensive, Silver-Zinc, Hydrogen-Nickel, etc. Other types have been developed or are under development.

As an example with a 2 knot current behind the submersible a dive duration of 8, 9 or 10 hours can be achieved.

Nuclear based packages will, of course, allow a massive increase in endurance although to date no such systems are in use commercially.

Payloads

As in range, payload is directly related to the type of submersible, size, weight and buoyancy, etc.

A typical payload would be in the order of about 1000lbs.

Diver Lock-out

Commercially there are few diver lock-out submersibles in use. The British Underwater Engineering Manned Sub LR5 is still in use for military submarine escape support.

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Endurance of Divers

Heating tends to pose restrictions on lock-out time. As an indication, 6 hours has been achieved, although not on a continuous basis.

Access to Structures

Access to structures can be difficult enough for small remote vehicles. A vessel as large as a conventional manned lock-out submarine would, therefore, have great difficulty, although it could be achieved.

Such craft have accessed structures in the past and then by operating in "Heavy Mode" have come to rest on horizontal members. This procedure may not be considered acceptable in the future.

Attachment to Structures

Historically, "WINDAK" type suction devices have been used, but have proven to be unreliable in practice. More up-to-date systems have been developed such as those fitted to the ROV Challenger for example which are far more efficient.

The larger manned submersible saw its demise in the late 1970s due to the advent of more effective and flexible remote systems and a wish to keep man out of the water. Deepwater developments may well see the return of more sophisticated manned submersibles in the next 5-10 years particularly to allow operations to be carried out under ice.

7.6.11.2 **MICROSUB (HARD ONE ATMOSPHERE SUITS)**

Several systems exist as follows:

- Wasp
- Jim
- Mantis
- Mantis-Duplus

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Wasp and Jim are vertically orientated whereas Mantis and Mantis-Duplus are horizontally arranged.

The Jim suit has tended to be more suited to bottom working than a mid-water situation. However, Jet-Jim now exists which is fitted with a thruster pack arrangement to facilitate mid water working.

Walk ways and attachment points usually have to be fitted to subsea equipment to accommodate the bottom walker such as Jim which is an obvious disadvantage.

The Mantis-Duplus which is horizontally arranged can be operated in the manned or unmanned mode which may be seen to be an advantage.

Manipulative Capability

There is a definite advantage in having the human eye at the worksite working directly in conjunction with the manipulator and its array of end effectors. Special adaptors may be required in advance as with remote systems. This reduces the ability to compromise at the work site which the diver has in his favour.

The Microsub did not gain full acceptance in oilfield terms due to an overriding wish to keep man out of the water. Some are still in service.

7.6.11.3 MISCELLANEOUS VEHICLES

1. **Seabed Crawler**

   Generally, seabed crawlers are used in conjunction with cable laying/burial and de-burial operation. By virtue of the fact that these machines operate on the seabed they are restricted to such use and do not free swim.

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A seabed crawler system has also been built for the inspection of a storm flood barrier, the "EASTERN SCHELDT" on the Coastline of Holland. The "PORTUNUS" named after a swimming crab was developed because of high currents experienced in that particular area. Manned diving was considered to be inefficient and conventional tethered ROV's were also limited.

The machine deploys a variety of equipment and sensors, eg:

- Cameras
- Sedimentation measuring systems - based on high frequency multichannel penetrating sonar.
- Obstacle Avoidance Sonar
- Master/Slave Manipulator
- Scanning Profiler
- Current Meter
- Transponder
- Gyro Compass

This system proved successful in the inspection of the seabed mattresses which are positioned around the barrier's upright columns. Although it is obviously restricted to this type of work the "Portunus" is a clear case of using the right equipment for the job.

2. Structure Crawlers

The general idea of the structure crawler is attractive in itself for several reasons, perhaps the most significant of which would be to take the effect of current out of the equation which normally affects conventional tethered ROV's.

To-date, there is no commercially available system which has seen any real field use. One or two of the units are under research and feasibility study.

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The system must still rely on either diver or ROV positioning. In the case of ROV's, a reasonably powerful and able machine would have to be utilised even though the crawler would have its own buoyancy. Anodes are likely to pose a problem for the movement of such systems.

3. **Towed Units**

The towed Ocean Rover and Ocean Surveyor systems have been very successful in high speed pipeline survey operations. The system has a towing speed of 0.5 - 4 knots and has controllable depth and lateral movement capability.

It is a light weight system which has been used not only for geophysical data acquisition but for fishing gear observation also.

A range of options can be fitted, as follows:

- Xenon Flasher
- Compass
- Speed Meter
- Depth Sensor
- Photo Strobe
- 35mm Stills Camera
- Lights
- Pan and Tilt
- SIT CCTV Camera
- Sidescan Sonar
- Sub Bottom Profiler
- Trench Profiler
- Scanning Sonar
- Echo Sounder Altimeter
- Responder
- Temperature Sensor
- Salinity Sensor
- Pinger

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4. Diver Support ROV's

Smaller ROV's have proved beyond any doubt to be extremely useful in supporting diving operations from a safety and productivity stand-point.

The RCV 225 and UFO Observation ROV's have been the most commonly used systems.

Several benefits can be enjoyed such as:

- The provision of extra lighting.

- Locating the job-site, thereby saving time and unnecessary strain on the diver as he makes his way over to the site, possibly carrying heavy tools.

- Provides the topside supervisor, engineer, or inspection controller with a greater understanding of what is actually happening, thus creating greater efficiency.

- Increased safety benefits.

The "DAVID" ROV is not a support ROV in the conventional sense. It is a diver support system that can be used as a work platform, hydraulic supply unit and for the provision of lighting etc.

The concept has only been used on a trial basis so far, however, in certain circumstances it may improve the efficiency of manned diving operations. Commercially, it is not in a diving contractor's best interest to cut time off projects unless the work is being conducted on a lump sum basis. It is also unlikely that the major oil companies will purchase and maintain such equipment themselves.

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7.6.12 OPERATIONAL CONSIDERATIONS

7.6.12.1 ENDURANCE

Varying systems require different levels of maintenance which obviously affect endurance. Dives of 100 hours or more are not uncommon.

7.6.12.2 HUMAN RISK

Having enough crew to handle the job is very important. Unfortunately in some cases, there is a temptation to minimise manning levels for commercial reasons but this may affect safety.

In some cases very high voltages are being dealt with. In addition, there is a need to utilise lift cranes and davits. Tired or pressurised crews can potentially be at great risk and safety procedures must be strictly followed.

7.6.12.3 MANNING LEVELS

These vary depending on job requirements or commercial aspects (as above), however, as an indication:

Observation ROV's - 2 men per 12 hour shift
Work ROV's - 3/4 men per 12 hour shift

7.6.12.4 REAL TIME DATA ACQUISITION

The ability to handle real time data can be very useful, allowing the opportunity to carry out remedial work quickly prior to the vessel leaving the site, thus saving money.

As an example, there are a range of survey sensors that produce real time data;

CP Probe, Dual Head Scanning Profiler, etc.
Surface navigation, easting, northing and kilometer post (KP) information, etc.

7.6.12.5 SPATIAL AWARENESS

It is very important to plan the dive in advance, taking all parameters into consideration. This would include, for example, ROV path, obstacles such as guide wires, anodes, valves, etc, amount of space at the worksite, the size of the ROV and whether it can turn round once on location or whether it will need to reverse. The use of sonar and video will assist, however, all the aforementioned points including of course bad visibility and current can cause great difficulty.

7.6.12.6 HUMAN CONTACT

This subject relates very much to spacial awareness. One point to remember is that, ultimately, a human being is taking the decision making necessary deviations, where required. Intelligent robots have not found their way into the oilfield yet as far as subsea activities are concerned.

7.6.12.7 DEXTERITY

Refer - MANIPULATORS

7.6.12.8 RISK OF SNAGGING

Refer - SPATIAL AWARENESS

There is a high risk of snagging for instance when working around a structure or subsea template, on components, anodes, or debris. The use of tether management systems (TMS) reduces the chance of snagging but not every ROV is fitted with a TMS. Operator experience has a bearing on this point also.

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7.6.12.9 ACCESS

Access has been a problem for many ROV's usually because it is rarely taken into consideration at the design stage of structures or templates. The tendency is to save on capital expenditure at the expense of future operational expenditure.

ROV's such as the ADVANCED CHALLENGER have been purposely designed to allow access into platforms and templates, having a very small and narrow frontal profile.

7.6.12.10 OPERATING RADIUS

Again this depends very much on whether a TMS is in use or not. Currents and drag can restrict even powerful ROV's. Having to tow a large amount of umbilical behind itself, an ROV can be hindered to about 100 metres, or less in some cases.

7.6.12.11 SIMULTANEOUS OPERATION OF ROV'S AND DIVERS

One very simple comment can be made on this subject - COMMUNICATION.

ROV's and divers have a proven effectiveness when working together. Pre-planning is the secret, which applies to all types of operation whether it is ROV or diver based.

Refer DIVER SUPPORT ROV's.

8. QUALITY ASSURANCE

8.1 INTRODUCTION

Quality Assurance can be defined as the utilisation of activities and functions concerned with the attainment of quality. It is based on the principle that prevention is better than cure.

In the past there has been a tendency for inspection programmes to be conducted in a somewhat haphazard or random manner. This has often led to the generation of excessive amounts of data and exposed a series of engineering deficiencies; namely:

- Lack of definition ie. what is important and what is not
- Insufficient onsite investigation when a defect has been found
- Lack of standardisation of response on finding a defect
- Lack of direction onsite in monitoring defects or anomalies

As the need for inspection increases, it is apparent that positive control is required to avoid these pitfalls. It is for this reason QA systems are an important aspect of underwater inspection. The implementation of QA systems can be described under the following three main headings:

- Controlling inspection activities and avoiding over or under inspection
- Ensuring that all information actually <u>needed</u> is recorded and valid
- Ensuring that methods and objectives are understood and executed

QA is essentially good common sense housekeeping. Reference should be made to the appropriate British Standard BS 5750 which describes in detail the various aspects of Quality Systems.

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8.2 QUALITY ASSURANCE SYSTEMS

8.2.1 REQUIREMENT FOR QA SYSTEMS

A quality assurance system must be planned and developed to take into account all aspects of a structure's life from actual development and design, fabrication, installation and commissioning through to in service inspection, repair and maintenance. At each stage it is essential to apply systematic QA principles to ensure safety and reliability and to make certain that set objectives and applied methods are achieving the desired results.

Although Quality Assurance relevant to underwater inspection repair and maintenance is of primary importance to the Inspection Controller and Pilot/Observer Inspector a brief overview of quality requirements for design, fabrication and installation will also be discussed.

8.2.1.1 DESIGN

Good quality control at the design stage is crucial since this is the first stage in the life of the structure. The design functions which must be controlled and maintained at this stage include:

- the provision (where necessary) of a design and development programme
- the provision of a code of design practice and procedures
- the preparation and maintenance of drawings, specification and procedures
- the considerations of statutory requirements, including those for health and safety.
- the evaluation of new material under appropriate environmental conditions
- the use of defect data feedback from previous designs, where appropriate

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8.2.1.2 FABRICATION

It is important to ensure that manufacturing operations are carried out under controlled conditions. Controlled conditions include documented work instructions defining the manner of manufacture or processing, suitable manufacturing equipment and any special working environment.

Mistakes at the fabrication stage can result in lengthy delays and increased costs. Equipment and personnel selected for the work should be capable of fabricating construction material in accordance with the design specification.

Standard of workmanship should be established to provide an objective basis for acceptance and rejection to achieve the quality required by the contract.

Work instructions and procedures should cover every phase of manufacture and assembly. They should identify each operation and establish the responsibility and suitability of the personnel controlling and performing the work.

On completion of fabrication it is often useful to perform an on-site baseline survey of the completed structure. This can then be compared with the design drawings so that any discrepancies can be identified and recorded prior to installation.

Special Note

If a good QA system has been set up at a structure's fabrication stage it should be relatively straight forward to set up a Construction Activity Monitoring System alongside it. Such a system would compile on an ongoing basis a full index for locating the original material and NDT certification. This would include an index for locating any concessions, repairs or temporary access windows and J-tube hole positions throughout the jacket structure.

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Several of these systems have been completed after fabrication some years into a jacket's service life, as a retrospective Material Documentation System.

The hard copy produced provides a very useful reference document for the structural engineer, metallurgist or underwater inspection engineer. A computerised system compatible with a computerised in-service inspection database can make inspection defect problem solving very much easier and, therefore, cost effective.

8.2.1.3 INSTALLATION AND COMMISSIONING

During installation it is important to prevent damage or deterioration of the structure. Stress limits should not be exceeded and environmental conditions must be favourable. It is absolutely paramount to ensure that the structure is installed in the correct location.

Hook-up to control lines and pipelines must be undertaken in accordance with the proper specifications and procedures.

8.2.1.4 IN-SERVICE INSPECTION REPAIR AND MAINTENANCE

The contents of the inspection programme will be dictated to a large extent by the following factors:

Certification Requirements	-	Certificate of Fitness (Requirements for Major Survey)
Design Criteria	-	identify areas such as low fatigue life welds, loading parameters etc.
In-House Policy	-	Operators engineering departments have differing attitudes towards inspection practices ie. use of particular NDT methods for example.
Inspection History	-	results of previous inspections must be taken into account primarily areas of repair, damage etc.

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Planning an inspection programme should begin by determining what kind of information is required for condition monitoring and analysis, and deciding what is the best method to gather this information.

Recording unnecessary or spurious information is time wasting both during the contract and when post season analysis is required. Therefore, over inspection should be avoided. Similarly, it is important not to under-inspect a component since this may result in re-mobilisation to obtain the required data. The inspection should be relevant and adequately fulfil the statutory requirements.

There must be a consistency of inspection methods applied and the recording of results. It is important to control the inspection quality to ensure that the information required is collected satisfactorily and is valid.

It is important to ensure that the methods and objectives of the inspection programme are understood and executed in accordance with the given procedures. Similarly, repair and maintenance work must always be carried out to original design specification procedures.

8.2.2. <u>UNDERWATER INSPECTION QA DOCUMENTATION SYSTEMS</u>

There are several elements which go together to form the basis of a good inspection documentation system. It is not possible to standardise these elements due to clients individual requirements and availability of information such as design criteria, drawings and historical data. The same principles should apply, however, and if, for example, the technical specification and inspection procedures are set up correctly, confusion and ambiguity can be avoided.

The adoption and correct utilisation of an anomaly based inspection philosophy can significantly simplify the overall documentation system.

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8.2.2.1 TECHNICAL SPECIFICATION

The technical specification sets the standard for all aspects of the offshore inspection programme. It should define precisely the various levels of inspection to be carried out for each operation, eg:

- General gross damage survey
- Weld inspection
- Marine growth survey
- Cathodic protection survey
- Debris survey
- Scour survey

and so on

Inspection locations and sample points must be clearly defined. For example, are marine growth measurements on a bracing to be taken at both ends and mid-span, on the top or bottom face, on the inboard or outboard face?

Each specific task in a technical specification should make reference to a procedure or technique for carrying out the work. Since the technical specification and procedures complement each other it is very important that they are in absolute agreement with one another.

The technical specification is usually dictated by the clients engineering department and any enhancement must be subject to close consultation with the client.

It has been found that a loose technical specification is a poor basis for an efficient, cost effective offshore programme.

The general specification would also detail personnel requirements and qualifications and interim and final report formats for example.

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8.2.2.2 INSPECTION PROCEDURES

Inspection procedures are rules for the conduct of underwater inspection tasks. They specify personnel qualification and equipment standards as well as the sequence of activities particular to each task. It is of paramount importance that the Inspection Procedures are in absolute agreement with the terms of the Technical Specification.

Each procedure will describe a specific technique and is used as a reference document in the field. The procedure should be a "stand-alone" document and should contain an outline of:

- Purpose of procedure
- Personnel qualification required
- Equipment and materials required
- Preparation required including equipment calibration
- Method of operation of the procedure
- Outline of the method of data collection and the recording of results.

By the application of procedures, inspection tasks are standardised. Procedures should also always be applied when carrying out repair or remedial work. Procedures should always be clearly written, concise, and unambiguous.

8.2.2.3 TECHNICAL SYSTEM AUDITS

In order to assure that an underwater QA documentation system is in place and being adhered to, an audit of a contractor's compliance may be requested from time to time.

Such an audit is often required in lieu of any permanent Quality Control Representation being present during an underwater inspection programme.

To increase efficiency an audit is normally carried out according to a strict set of procedures. Audit procedures are, in fact, yes/no check lists which confirm or not a contractor's compliance with, for example:

- each inspection procedure being used
- presence, calibration and quantity of equipment being utilised
- onsite personnel qualifications

8.2.2.4 <u>AUDITING/DATA VALIDATION</u>

Once the inspection data has been collated it is essential to establish the validity of the data. Quantitative data should be compared with known acceptance limits to establish whether it is anomalous or not. Checks should be made to ensure that all the requested information has been collected. It may be that photography of an anode was requested in the specification and has been omitted. Cross checks between completed datasheets and the specification should highlight any oversights.

It is also important to ensure that all the relevant information for an attribute has been recorded. For example, where corrosion has been discovered by diver the information normally recorded would be location, % coverage and maximum and average depth (mm). It is important to pick up mistakes and omissions at an early stage so that faults can be rectified.

Where an anomaly does exist it is extremely important that all relevant information is collected using the appropriate paperwork (datasheets, anomaly reports etc). This may involve photographic and/or video inspection techniques. Where photography and video is used it is important that correct idents are used. Structural component identification should be referenced with respect to platform drawings. Video and photo logs should be produced giving details of the subject matter, dates, film numbers etc. Video and photographic film numbering systems should be unique so that there is no duplication. The numbering system should be such that platform, diving spread and year of inspection can be identified.

As the majority of inspection data is recorded onto datasheets it is important to ensure that they are correctly filled out.

Where photographs or video is required cross checks can be made between entries in the datasheets and the individual logs and indexes to ensure agreement of subject matter.

8.2.2.5 DOCUMENTATION CONTROL SYSTEM

By its nature, an underwater inspection programme will involve the capture and recording of a vast amount of information and data. The medium of recording will primarily consist of datasheets, photographs and video tape. It is therefore extremely important to exercise some form of control and logging of this data. It is essential to keep an accurate record of job progress. It is therefore useful to split the technical workscope into more manageable packages of work (eg. all welds, all risers etc). This is normally achieved by the use of Task Codes or Job Numbers. Common datasheets can then be grouped together making work progress monitoring simpler.

Use of indexes for completed videos, photographs, datasheets and anomaly reports is recommended as it acts as a quick reference to determine the contents and whereabouts of the appropriate documentation. If on completion, datasheets and accompanying anomaly reports, photographs and video tapes are sent ashore a transmittal form should be produced stating contents, date sent ashore, department sent to etc. A copy of this should be kept offshore.

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In addition to the inspection data, the documentation required to carry out the inspection must be documented. Workscope, technical specification, procedures, platform drawings etc should be readily accessible. Changes or additions to the workscope may become necessary as the inspection programme progresses (possibly due to the discovery of anomalies). Specific tasks can be easily added with the issue of job cards. However in the case of alterations to the engineering criteria, a definitive document must be issued, which in some cases may result in a new workscope and/or specification. In this case, the introduction must state that the new documentation supersedes all previous issues.

8.3 EFFECT OF PERSONNEL STRUCTURES ON QA

BS 5882 (1980 States):

Good management contributes to the achievement of quality through thorough analysis of the task to be performed, the identification of the skills required, the selection and training of appropriate personnel, the use of appropriate equipment, the creation of a satisfactory environment in which activity can be performed and a recognition of the responsibility of the individual who is to perform the task.

Section 2.1.4 states:

2.1.4 The authority and duties of persons and organisations responsible for activities affecting quality shall be delineated in writing.

The persons and organisations performing the quality assurance functions of:

(a) ensuring that an appropriate quality assurance programme is established and effectively executed, and

(b) verifying that activities have been correctly performed,

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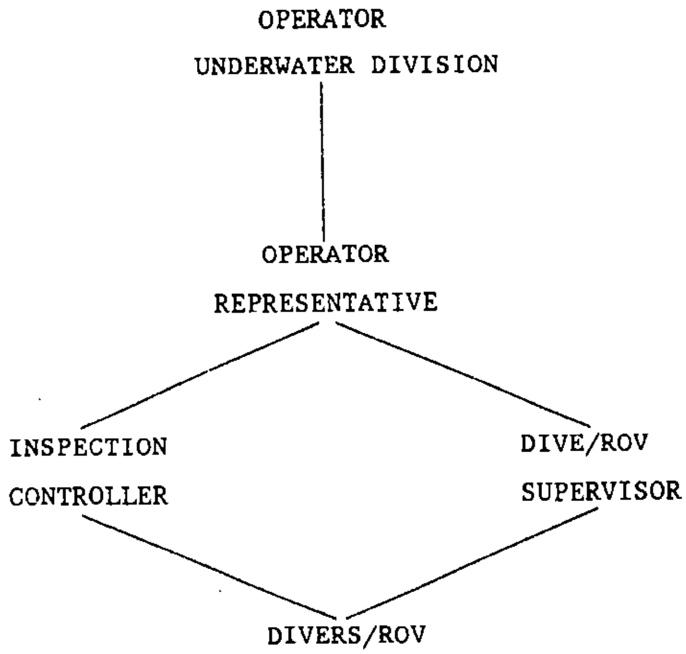
shall have sufficient authority and organisational freedom to identify quality problems; to initiate, recommend, or provide solutions and to verify implementation of solutions and, where necessary, to control further processing, delivery, or installation of a non-conforming item. Such persons and organisations performing quality assurance functions shall report to a management level such that this required authority and organisational freedom, including sufficient independence from cost and schedule considerations, are provided.

All personnel involved in the underwater inspection programme must be suitably qualified for their particular task and be fully aware of inspection objectives and requirements. The personnel structure is such that the Operator maintains control to ensure consistent performance, and correct execution of the programme. A typical organigram is illustrated below.



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This structure will assist in maintaining the line of management, while giving full technical support at all levels to ensure control and implementation of quality assurance. Report communication channels must be open between each level to ensure the free flow of information pertinent to the inspection programme. The Inspection Controller is directly responsible for on-site quality control of inspection activities. This is a crucial link since he must ensure that involved diving personnel are fully aware and understand the requirements of each specific task of the inspection programme.

He reports directly to the Client's Representative on job progress, defects encountered, technical problems etc who in turn relays this information directly to the Operator's engineers. The importance of good communication techniques cannot be over emphasised. Work instruction to diving personnel must be unambiguous and clear and may necessitate the need for written instructions, group meetings to discuss particular points of importance or one-to-one verbal discussions.

At all times, close liaisons between individuals should be ongoing to ensure that the common goal is the effective and efficient execution of the inspection programme.

8.4 QA REQUIREMENTS FOR EQUIPMENT

Equipment used during inspection tasks must be maintained and calibrated to ensure that its performance is of an acceptable standard, as laid out by inspection procedures. This applies to photographic, video, and all NDT equipment.

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It may be necessary to carry out exclusive calibration checks on a piece of equipment before and after usage. These checks must be carried out according to specified procedures and must prove valid before use. Any equipment faults or defects encountered must be identified immediately in order to prevent its further usage since errors or inferior quality results will be obtained.

Log charts should be kept in order to keep a record of the equipments battery capability at any given time. It is of paramount importance that all underwater inspection equipment is intrinsically safe. Any equipment defects which could be potentially dangerous <u>must</u> be identified immediately and brought to the notice of the diving supervisor and the client's representative.

9. DATA RECORDING AND PROCESSING

9.1 INTRODUCTION

9.1.1 OVERVIEW

One of the major roles carried out by the Inspection Controller is that of recording data and its processing. The ability to record all the relevant data and subsequent processing will reflect on the success and integrity of the operators inspection programme. The degree of success will further be influenced by the initial detail and quality of that data.

The Inspection Controller must be fully conversant with the inspection techniques employed and the various methods of recording the data gathered. This places the emphasis on the Inspection Controller being able to communicate effectively with the source of information whether it is a Diver or an ROV and to pass this information on in a concise and accurate manner.

This section will outline the various methods available for recording and processing data and the presentation of same to the client or other interested parties.

9.1.2 NECESSARY SKILLS AND QUALITIES OF AN INSPECTION CONTROLLER

Due to the nature of the work the skills and knowledge needed by the Inspection Controller require that he:

- has a working knowledge of the inspection equipment used
- is conversant with how a diving or ROV operation is carried out
- is conversant with the purpose of the inspection and why it is being carried out

Contents

- must recognise what is acceptable data and verify it is correct
- is aware of the constraints placed on the diver by his environment
- is able to communicate effectively and coherently
- can make an estimation of task time and be able to forward plan.

Other qualities he may need to display are:

- diplomacy
- authority
- intuition (especially when planning)

9.1.3 ABILITIES AND LIMITATIONS OF INSPECTOR AND TECHNIQUE

The Inspection Controller must be able to identify each systems capabilities and limitations in order to fully exploit each to its maximum. Detailed below are some of the abilities and limitations of the various systems in use.

ROV (in common working use):

Abilities	Limitations
B/W Video	Breakdowns/temperamental
Colour video	Confined spaces
Still photography	No eyeball contact
Cathodic potentials	Cannot interpret
Unlimited dive duration (relative to diving)	Operator dependent, ie, skill
Cheap (relative to saturation diving)	Splash zone
Good Inspection Controller control	Platform penetration
	Not versatile
	Limited detailed inspection capability

Air Diving:

Abilities	Limitations
Can interpret	Depth
Eyeball contact	Duration
Versatile	Diver dependent
Confined spaces	Range of operation
Good communication	Safety considerations
All inspection techniques currently employed	

Contents

Saturation Diving:

Abilities	Limitations
Depth and duration good relative to air diving	Communication at depth
Can interpret	Diver dependent
Eyeball contact	No physical contact (in sat)
Versatile	Expense, planning is critical
All inspection techniques currently employed	Slower than air diving due to depth
	Safety considerations

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9.1.4 **FAMILIARISATION WITH THE WORKSITE - FABRICATION DRAWINGS, GENERAL ARRANGEMENTS, PREVIOUS INSPECTION FINDINGS**

It is essential that the Inspection Controller is totally conversant with the worksite in relation to the inspection tasks required. It is quite possible that the diving or ROV contractor has never worked on that particular structure and they and even the Client's Representative will be relying on the Inspection Controller for worksite familiarisation. The Inspection Controller should, therefore, be aware of:

(1) All fabrication drawings and general arrangements. Isometrics are particularly easy to interpret by the inspection personnel and an adequate supply of these should be available for distribution.

(2) Orientation of the worksite in relation to the operations being carried out. These should be communicated to the inspection personnel and other interested parties so that everyone is 'talking the same language'. This will involve making personnel aware of platform North, inboard, outboard, 12 o'clock positions, node side, member side etc. The Inspection Controller must obviously know <u>the exact location of every facet of the inspection</u>.

In communicating this information to personnel the correct terminology should be used to avoid ambiguity. This will necessitate using the Client's structure reference system.

To be fully prepared for the inspection, previous inspection findings should be reviewed. In this way the Inspection Controller will be aware of what the Inspector is likely to find and may provide information as to defects or information being specifically sought after. This information should remain confidential and should not be communicated to the Inspector prior to inspection. However, it can be used to prompt the Inspector into more detailed observation or inspection in a specific area, but only after the full scope of that particular facet has been achieved.

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Other relevant information that can be obtained from these drawings or previous reports may indicate possible hazards and hindrances in operating and deploying equipment. Although primarily this is the Diving Supervisor/Clients Representative's responsibility it is also essential information for the Inspection Controller.

Above all the Inspection Controller must have a clear picture in his own mind as to what the Inspector is doing, where this is taking place and an idea as to what he might find.

9.2 CLIENTS REQUIREMENTS

9.2.1 INTRODUCTION

Before commencement of the inspection programme the clients' requirements will have been identified in the Scope of Work and Technical Specification. The scope of work and technical specification will frequently be inextricably linked and may be referred to as the Work Specification.

9.2.2 SCOPE OF WORK

The purpose of the Scope of Work is to precisely identify where the work is to be done during the next inspection programme. This can be simply presented as a complete Task Code Listing, as a written statement or in a "tick box format". The exact format will depend on the client.

Ideally the format of the Scope of Work should not change from year to year. To accomplish this its framework needs to be flexible. Examples of "Scope of Work" follow.

Contents

9.2.2.1 **EXAMPLE 1 SCOPE OF WORK**

This form specifies items required during the Underwater Inspection of the designated platform. Full description of the requirements are given in the Technical Specification.

Underwater Survey Specification for Platform

1. Primary Weld Inspection

   Required

   Weld No 1: ....

   Weld No 2: ....

   Weld No 3: ....

   Not Required

2. Secondary Weld Inspection

   Required on Weld No(s) ....

   Not Required

3. Scour

   Full Survey

   Spot Check

   Not Required

4. Cathodic Potential

   Full Survey

   Spot Check on Leg ....

   Not Required

5. Debris Survey and Removal of Contacting and Hazardous Items

   Required

   Not Required

6. Riser Survey

   Required on risers ......

   Not Required

7. Marine Growth Survey

   Required in zones ......

   Not Required

8. Marine Growth Cleaning

   Required over depth interval ...... to ...... feet

   Not Required

9.2.2.2 EXAMPLE 2 SCOPE OF WORK

Welded Joint Inspection

All joints described in this section are to receive full close visual inspection as detailed in the Technical Specification.

NOTE: Only the two welds under Task Code 29A-01 shall be inspected by MPI as primary requirement. For all other welds, MPI shall be a secondary inspection step if required within the terms of the weld inspection anomaly procedure.

Platform 29 A
Task Code 29A-01

B63/JJA4
B95/JJA4
B93/JJA4

Platform 29B
Task Code 29B-01

A91/LLB4
A92/LLB3
A966/LB3

9.2.2.3 **EXAMPLE 3 SCOPE OF WORK**

The Workscope summaries presented in Table 1 are intended to provide an overview of the 1987 inspection and work requirements.

Table 1

OIL AND GAS LTD

ALPHA FIELD

1987 UNDERWATER INSPECTION WORKSCOPE SUMMARY

PLATFORM	MARINE GROWTH SURVEY	SACRIFICIAL ANODE SURVEY	CATHODIC PROTECTION SURVEY	SCOUR SURVEY	WELD INSPECTION	RISER SURVEY
Alpha Field 29-A Platform	Type 2	Type 3	Type 3	Type 2	Type 1	Type 2

9.2.3 TASK CODE LISTING

The use of Task Code Systems is a well established philosophy. The provision of a Task Code System enables each inspection task to be identified in a concise, shorthand manner for record and reporting purposes and simplifies progress monitoring of the inspection programme. The level of operational reporting will be determined by the degree of refinement of the Task Numbering System.

The prime requirements of the Task Code system are that it should be logical and capable of development to convey all the required information.

Logic requirements will be largely satisfied if each task is allotted a group number in a sequence following that already established in the Technical Specification and Workscope.

For purposes of illustration a Task Code Listing System along the following lines, would be typical:

Task	Task Code Group
General Swimround	100
Weld Inspection	200
Marine Growth Survey	300
and so on.	

For a multi-platform programme these group numbers may be prefixed by the platform's identifying initials, eg. BD100, BP100, etc.

Alternative adaption can be made to identify tasks to be carried out by air diver, saturation diver or ROV:

A100, A200, etc.
S100, S200, etc.
R100, R200, etc.

Contents

Whatever system is used, the task group, location, method of intervention or other relevant information is conveyed by the first digit and prefix (if any). Individual tasks within the group will then be identified by the remaining digits. Thus the Task Group BD201 - BD299 can accommodate 99 weld inspections on Platform BD. The system may require modification if this is insufficient capacity, ie. if more than 99 features require inspection a four-digit Task Groups (1000,2000, etc) would be used, but it may also be possible to group several individual tasks together under one Task Code number to maintain the three-digit system.

9.2.4 COMPONENT ORIENTATION RULES

The client will establish ground rules for establishing clock notation conventions, direction of view etc. at the outset of the programme. This information would normally be specified in the technical specification and must be strictly observed throughout the inspection programme to ensure consistency.

Items requiring such rules are:

Platform Legs
Bracings (horizontal/vertical/horizontal diagonal/vertical diagonal)
Conductors/guides
Piles/sleeves
Caissons
Risers
Welds

9.2.5 MEMBER AND COMPONENT REFERENCE DRAWINGS

Member and component reference drawings will be supplied by the client and will ensure continuity of reporting against previous years records.

Contents

The complexity of the system will vary directly with that of the structure. A typical system for, say, an eight-leg jacket with four frame levels, would comprise alpha-numeric grid and level references as follows:

Grid Lines:

Long sides	: A, B
End and intermediate rows	: 1, 2, 3, 4
Horizontal Frame Levels	: C, D, E, F
Legs	: L

Thus LA4 represents the Leg at the junction of Side A and Row 4, member 304 will be fourth Member on Row 3, Member E28 will be a Member at level E and so on.

Another common method to identify members and nodes is to divide the structure into levels and each level is then divided into a box matrix (see diagram overpage). The code for any member or node is then a unique four digit alpha-numeric.

9.2.6 WORKBOOK

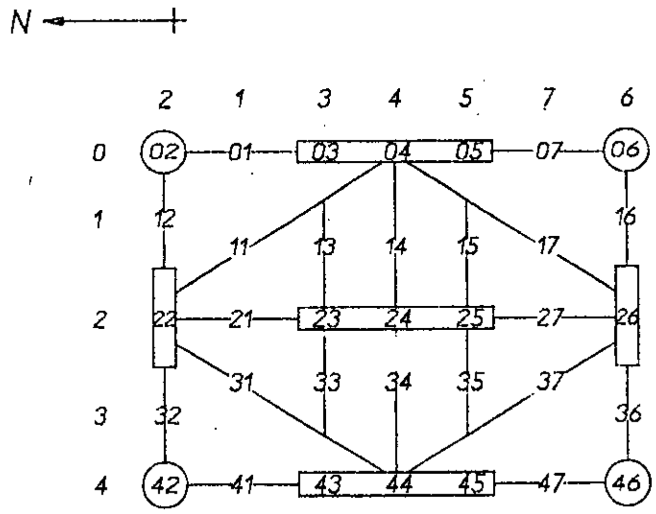
The workbook is a data format for reporting on the completed work. This will normally take the form of a book compiled from blank datasheets which relate to the various inspection tasks detailed in the Scope of Work and Technical Specification.

The format for the workbook will be dependant upon the client. In its most simplified form the workbook will be divided into five sections as follows.

9.2.6.1 WORKSCOPE AND TECHNICAL SPECIFICATION

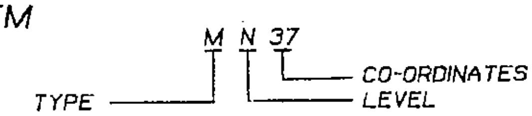
This contains the scope of work, technical specification and operational specification.

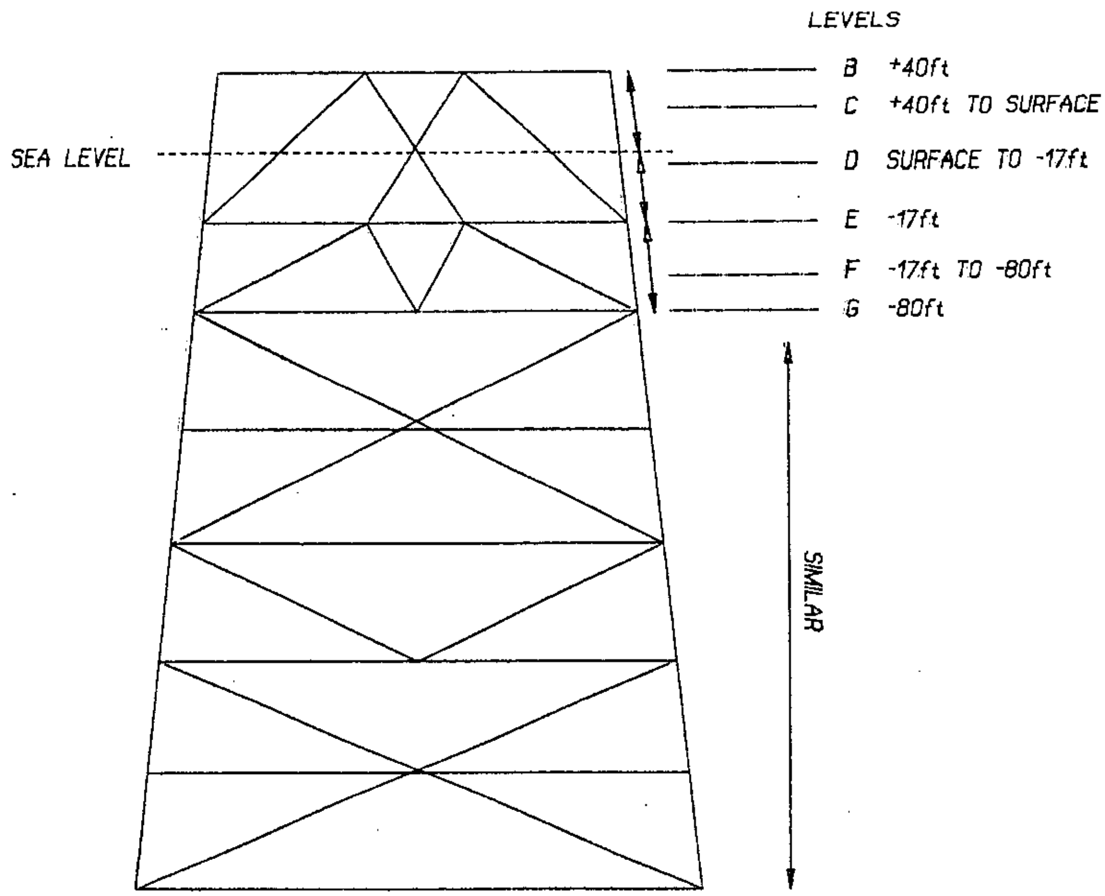
PLATFORM CO-ORDINATION SYSTEM



CO-ORDINATE SYSTEM

- M Member
- N Node
- C Conductors
- F Diagonal Members
- R Risers
- B Riser Brackets
- S Risers (Sea Suctions Outfall drains etc.)
- P Pile Sleeves





REF.ORCA.DP053

Contents

9.2.6.2 FIELD AND PLATFORM DATA

All the data relevant to the field such as platforms and pipelines will be listed together with structural drawings illustrating all facets of the platforms, risers, caissons, conductors and cathodic protection systems. Environmental information would be detailed for each platform in the form of water depth, tides, currents and seabed conditions.

9.2.6.3 ANOMALY REPORT AND ADDITIONAL INSPECTION PROGRAMME

This would detail the client's philosophy and the criteria of non-conformance together with the step by step actions and checks to be followed should an item be outside the stated criteria of non-conformance.

9.2.6.4 DATASHEETS

This section would contain all the datasheets as required by the Workscope and Technical Specification.

9.2.6.5 DATASHEETS/LOG SHEETS

Blank examples of the main pro-forma sheets to be used for recording inspection data. Typical examples would be:

- Photolog
- Photo index
- Video log
- Video index
- Weld CVI/MPI datasheet
- Anomaly report sheet

9.3 ANOMALY REPORTING METHOD

In practice, all items contained in the Workscope are inspected and the fact of their inspection must be recorded and reported. With the anomaly reporting method a system operates whereby only items inspected which fall outside acceptance criteria are reported in detail. This may be a CP value which falls outside an acceptable range, etc. The non-acceptance criteria are termed the "criteria of non-conformance", a typical listing of non-conformance values are shown in Section 9.4 against possible anomalies.

In section 9.4 typical inspection fields have been listed with possible pertaining anomalies. For simplification the criteria are coded, as are the components to which the non-conformance apply. The possible anomalies need not be listed for each survey field. A single list of anomalies can be prepared which covers all inspection fields.

If items are found to lie outside the criteria of non-conformance during the inspection, then these are deemed to be anomalous. To highlight these areas for reporting, an anomaly sheet is generated on which all pertinent information to this anomaly is recorded.

On finding an anomaly the Offshore Inspection Controller follows the designated further checks and actions. The checks are possible connecting occurrences which may have caused or have been caused by the anomaly found, which themselves may also be anomalous, ie. physical damage on a mid-water member may have been caused by a large item of debris which has fallen to the seabed. These items are required to be checked. It is at the Offshore Inspection Controllers discretion as to whether further anomaly sheets need to be generated. Typical checks are listed in Section 9.5. On each anomaly sheet a box is given where each pertinent check should be identified as having been carried out.

The actions detail the relevant further inspection tasks that are required and the information which needs to be collected by the Offshore Inspection Controller relating to the anomaly found. See also Section 9.5 for a list of typical actions relating to each anomaly.

The results and readings from the additional checks are set out in tabular form (if suitable) or in some other fashion, actually on the anomaly sheet. In this way, all relevant information is contained on the one sheet allowing for full engineering interpretation. The actual format will depend on the client.

Photocopies of all anomaly sheets should be presented to the Client's Representative as soon as all the relevant information has been collated including photos and videos. However, this does not obviate the Inspection Controller's responsibility to report all anomalies to the Client's Representative as soon as is practicable after they are found.

If an anomaly is deemed to be critical then a photocopy of the completed sheet along with the photographs and video should be forwarded to the Client's Onshore Inspection Management as soon as possible. This can then be passed on to the engineering department for full appraisal.

When anomaly sheets are generated then these would be numbered consecutively for each jacket. The numbering may take the following form:

BD/87/01

Platform / Year / Anomaly Sheet No.

The Anomaly Sheet No. would start at 1 and increase consecutively for each platform as each anomaly is found.

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For each anomaly some form of photographic or video label may be required. This would be similar to the anomaly coding and can have the following format:

Platform /	Year /	Part of Structure (member D22)	/ Structural Component (Clamp)	/ Anomaly Type (lack of integrity)	/ Depth (m)

This, along with any reference tape and clock position labels would be the only identification markings on photographs.

A full breakdown of the method of photographic and video labelling, is contained in the relevant sections 3.2.3 an 3.3.2.

9.4 CRITERIA OF NON-CONFORMANCE

For each inspection field the "criteria of non-conformance" would be determined by the client's engineering department. The following tables list typical criteria of non-conformance.

INSPECTION FIELD	POSSIBLE ANOMALIES	ANOMALY CODE	CRITERIA OF NON-CONFORMANCE (C.N.C.)
GENERAL VISUAL INSPECTION	COATING DAMAGE DEBRIS PHYSICAL DAMAGE	CD DB PD	ANY METALLIC/HAZARDOUS ANY
WELD INSPECTION	CORROSION (WELDS)	CR	GREATER THAN 2mm DEEP
CP SURVEY	CATHODIC POTENTIAL	CP	OUTSIDE -850mV AND -1150mV
ANODE SURVEY	ANODE WASTAGE	AW	SEVERE, >75%
RISER SURVEY	LEAK AT BOLTED FLANGE	LK	ANY

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9.5 FURTHER INSPECTION ACTIONS AND CHECKS

On finding an anomaly as detailed in section 9.4 the Inspection Controller would follow the further actions and checks as specified by the client and detailed in the technical specification. The following tables list typical examples of the actions and checks that could be called for by the client.

ANOMALY CODE	ACTIONS	CHECKS
AW	RECORD ANODE IDENTIFICATION AND POSITION	CR, CP DB, LI
CP	TAKE ADDITIONAL CPs TO ESTABLISH EXTENT OF ANOMALOUS AREA	AW, CR, DB
CR	MEASURE CORRODED AREA, % COVER IN AREA, MAX AND AV DEPTH AND DIAMETER OF PITS IN AREA	AW, CR, CP, DB
DB	RECORD TYPE, POSITION AND DIMENSIONS, SKETCH	AW, CD CP, DB
LK	RECORD FLANGE IDENTIFICATION AND LOCATION, SKETCH ESTIMATE RATE OF LOSS	PD,LI,DB CR, SD
WT	RECORD ELEMENT AND LOCATION TAKE ADDITIONAL WT READINGS TO ASSESS AREA OF ANOMALY	CR, PD

Contents

9.6 RECORDING OF DATA

9.6.1 WHY A RECORD - ESSENTIALS OF A GOOD RECORD

An inspection record is a description of conditions observed during the inspection. The record is the essence of the inspection.

In addition to the recorded data on the datasheets, photographs and video recordings are the only tangible evidence that inspection has taken place.

Certain basic elements are essential to the make-up of a good inspection record. These are:

Sufficient information
Organised presentation
Clarity of expression
Legibility
Sketches or diagrams
Standardisation of Terminology

Lack of sufficient information and diagrams are probably the most common failings of otherwise good records. Photographs and videos (usually specified but initiative counts in this case) convey information in less space than either drawn or written material. Diagrams are also useful and instructive in cases where ideas or concepts are being discussed or described.

Contents

9.6.2 THE DESIGN OF DATA AND LOG SHEETS

The report that will be generated at the end of the inspection process depends greatly on the quality and quantity of data recorded at the time of inspection. The data sheets as such should act as a prompt so that no facet of the inspection is missed. A logical layout further improves the Inspection Controllers task for carrying out the inspection. Many Operators now use some form of computerisation and datasheets are often formatted with computerisation of data in mind. The datasheet would then be used as a computer input sheet.

To reduce the amount of paperwork to be completed by the Inspection Controller, datasheets should be designed to incorporate as many inspection tasks on the one sheet. An example is the recording of close visual and magnetic particle inspection results on one data sheet. By having all the data on the one sheet the Inspection Controller is able to cross check the MPI results with the CVI findings. By reducing the paper work the Inspection Controller is able to devote more time to actually carrying out the inspection and organising the programme. The essential information contained on most datasheets will include:

Date
Dive Company
Client
Dive No.
Diver's Name
Element Reference No.
Title
Page No. ... of ... sheets
Key Diagram - Location
Drawing of Element
Inspection Equipment Used
Calibration
Comments Space
Inspection Controller's Name

9.6.2.1 LOG SHEETS

Log sheets are used to provide a record of events/tasks/features as they occur. The recording of this data provides an easy reference system by which subject matter/equipment status can be ascertained. Typical log sheets together with information to be recorded are detailed below:

Photographic Logs - film no., frame no., subject, f-stop, shutter speed, stand-off distance, camera, lens, strobe, dive no., diver/ROV.

Video Logs - camera, recorder, video tape, video no., counter/timer no., subject, dive no., diver/ROV.

Equipment Calibration Logs - pre/post dive, date

Equipment Charging Logs - hours on charge, data, hours used, serial no.

Chemical Logs - date mixed, films processed

9.6.2.2 TYPICAL EXAMPLES OF DATASHEETS AND LOG SHEETS

Examples are included for the following:

1. Video Log
2. Photographic Log
3. E6 Chemical Processing Log
4. CVI and MPI Datasheet
5. Cathodic Potential Survey Datasheet
6. Scour, Marine Growth, and Identified Weld Datasheet
7. Riser Inspection Datasheet

SAMCO		ALPHA FIELD 1987
VIDEO LOG		FILM NO. /87/
DATE :	DIVE NO :	TASK GROUP :

TASK CODE	COUNTER		DESCRIPTION / COMMENTS
	FROM	TO	

Contents

SAMCO		ALPHA FIELD 1987
PHOTO LOG		FILM NO. /87/
DATE :	DIVE NO :	TASK GROUP :

TASK CODE	COUNTER		DESCRIPTION / COMMENTS
	FROM	TO	

Contents

E6 CHEMICAL LOG

(i) New 1st and colour developer after 4 rolls of 36 frames/35mm
(ii) New full batch after 8 rolls of 36 frame/35mm

NEW FULL BATCH	1ST AND COL. DEV.	NO. OF ROLLS	DATE

Contents

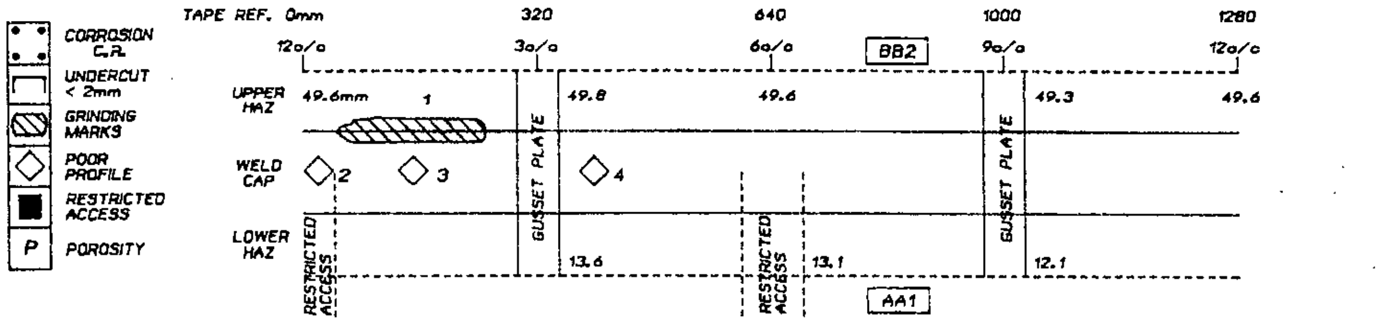
PLATFORM	IDENTIFIED WELD: AA1/BB2	START DATE 10/8/87	YEAR	DATASHEET No.
XX	EL.: -5.40m (LEVEL 'E')	FINISH DATE 11/8/87	1987	1 OF 1

INSPECTION	DIVE No.	DATE	INSP. COORD.
C.V.I.	68	10/8/87	A.OTHER
M.P.I.	73	11/8/87	B.A.OTHER
G.R.			
N.D.T.			

VIDEO			PHOTOGRAPHY		
TAPE No.	FROM	TO	FILM No.	TYPE	FRAME No.
N/A			N/A		
			TYPE: M - MOSAIC MPI - MPI		

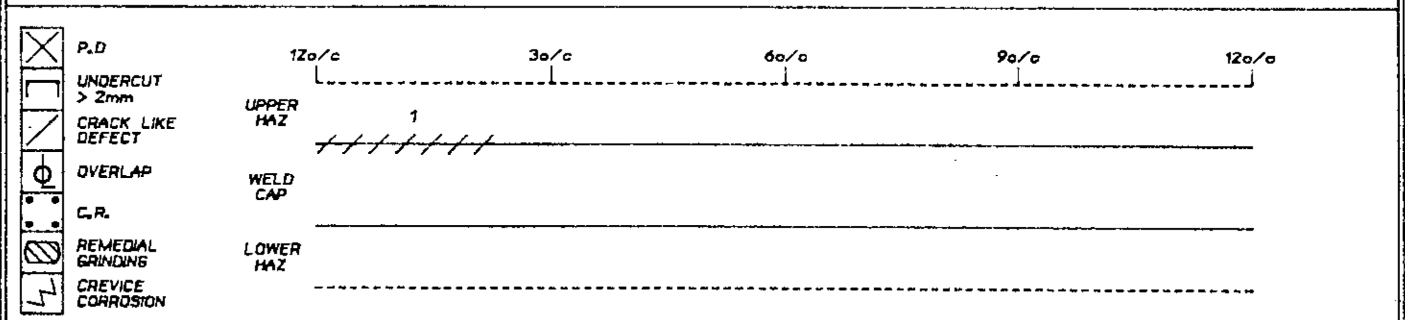
CP READINGS			
CALIBRATION ON Zn:			
12o/c	3o/c	6o/c	9o/c
910	900	890	860

CLOSE VISUAL INSPECTION REPORT



FEAT. No.	FEAT. TYPE	CLOSE VISUAL INSPECTION REPORT DESCRIPTION	DIST. FROM 12o/c (mm)	MAX DEPTH (mm)	FEAT. No.	FEAT. TYPE	CLOSE VISUAL INSPECTION REPORT DESCRIPTION	DIST. FROM 12o/c (mm)	MAX DEPTH (mm)
1.	GR	GRINDING IN BB2 TOE	90 TO 250	2					
2.		CRATER IN WELD CAP	55	3					
3.		CRATER IN WELD CAP	160	3					
4.		SLAG INCLUSION	340	3					

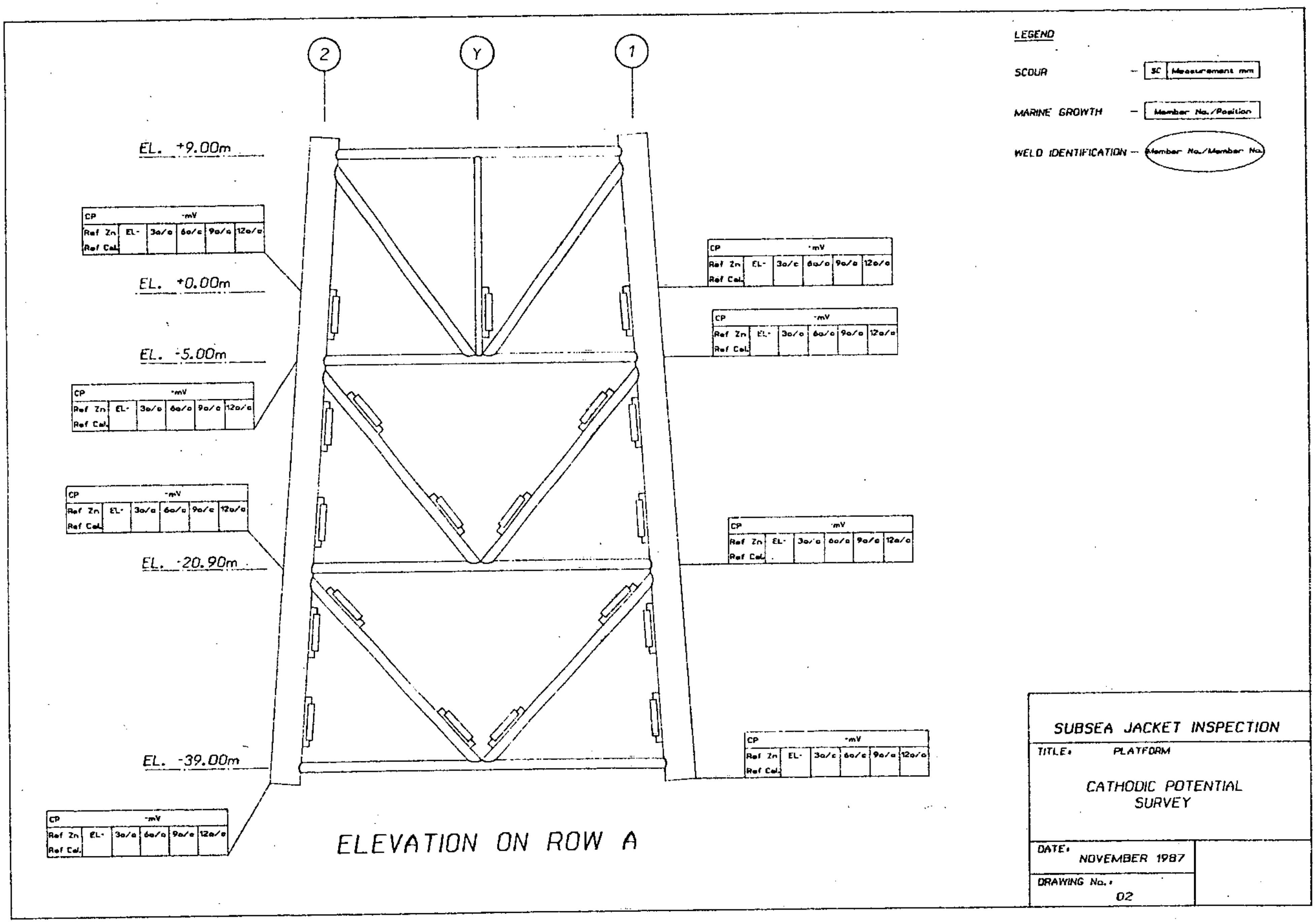
MPI / ANOMALY REPORT



FEAT. No.	FEAT. TYPE	ANOMALY REPORT DESCRIPTION	DIST. FROM 12o/c (mm)	MAX DEPTH (mm)
		N/A		

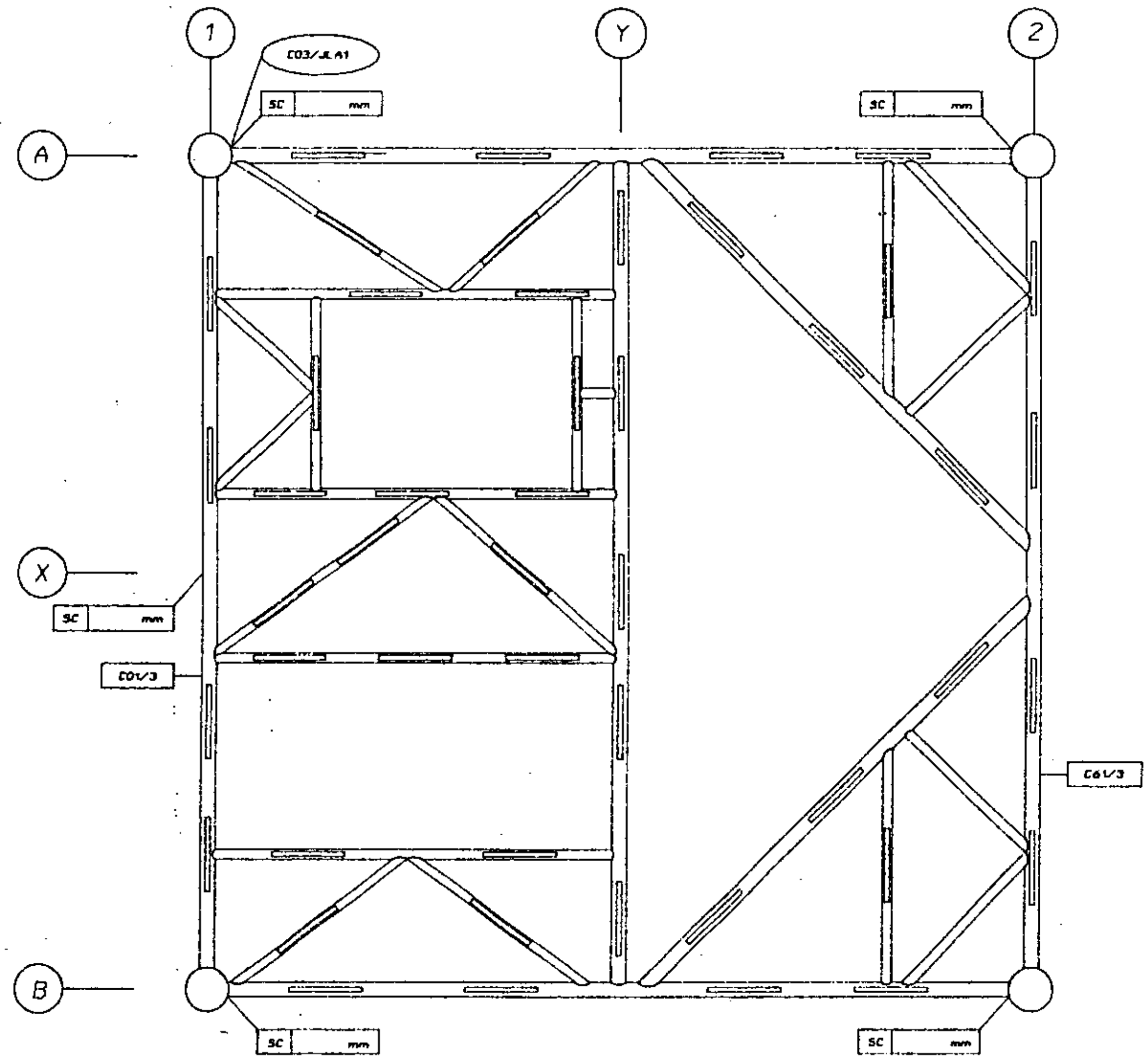
FEAT. No.	FEAT. TYPE	MPI UNDERTAKEN Y/N	CURRENT (AMPS)	DEFECT INDICATIONS Y/N	DIST. FROM 12o/c (mm)
		Y	750 X 2	Y	
1.	CK	DETAILS: INTERMITTENT CRACKLINE INDICATION IN LEG BB2 TOE. INDICATION REMOVED AFTER GRINDING TO DEPTH OF 1mm.			10 TO 170

Contents



LEGEND
SCOUR
SC
Measurement mm
MARINE GROWTH
Member No./Position
WELD IDENTIFICATION
Member No./Member No.
2
Y
1
EL. +9.00m
EL. +0.00m
EL. -5.00m
EL. -20.90m
EL. -39.00m
CP
-mV
Ref Zn
Ref Cal.
EL-
30/o
60/o
90/o
120/o
ELEVATION ON ROW A
SUBSEA JACKET INSPECTION
TITLE: PLATFORM
CATHODIC POTENTIAL SURVEY
DATE: NOVEMBER 1987
DRAWING No.: 02

Contents



PLAN ON LEVEL 1

EL. -39.00m

LEGEND

SCOUR — SC | Measurement mm

MARINE GROWTH — Member No./Position

WELD IDENTIFICATION — (Member No./Member No.)

SUBSEA JACKET INSPECTION

TITLE: PLATFORM

SCOUR SURVEY

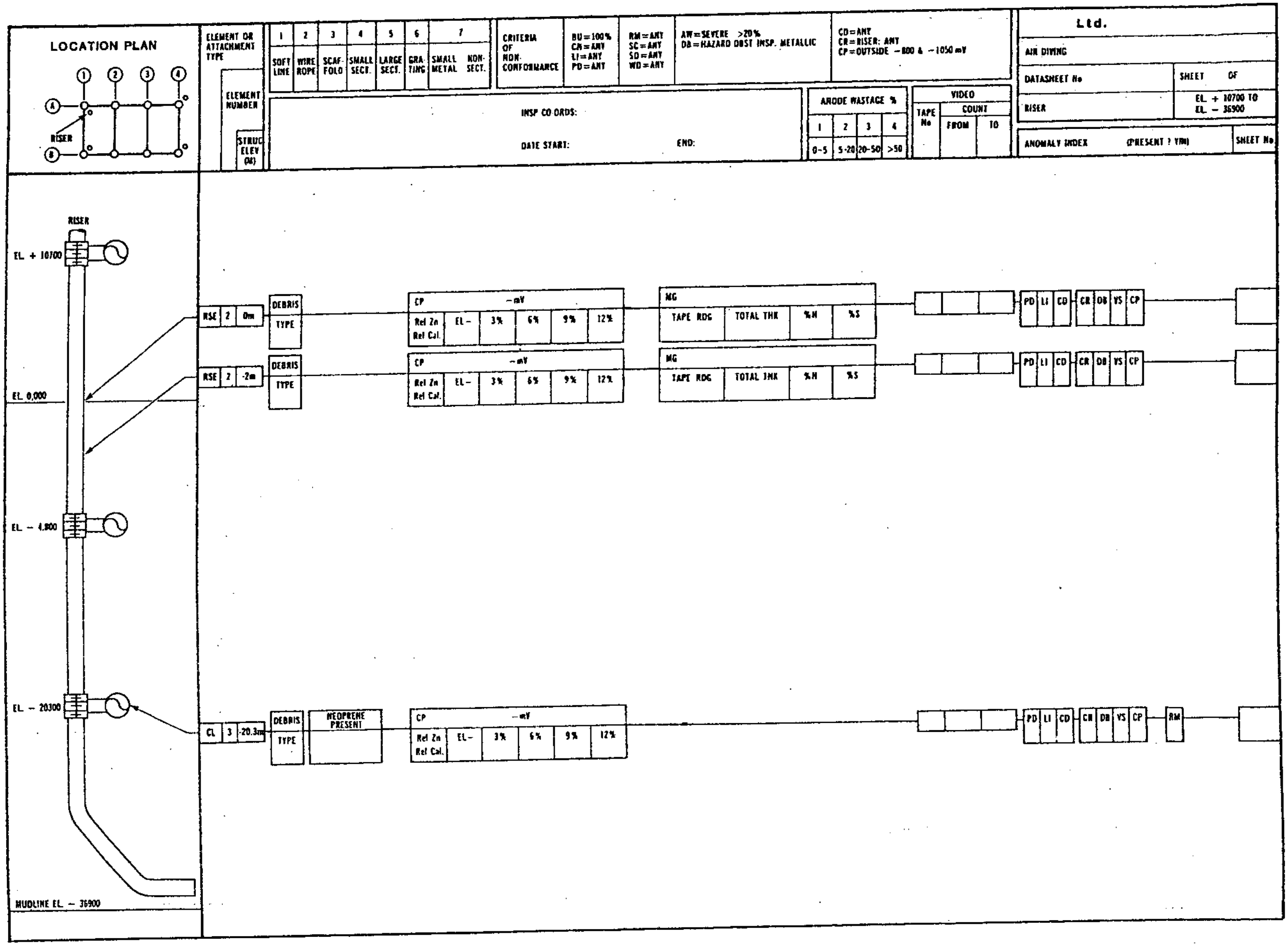
MARINE GROWTH SURVEY

IDENTIFIED WELDS SURVEY

DATE: NOVEMBER 1987

DRAWING No.: 01

Contents



LOCATION PLAN
RISER
ELEMENT OR ATTACHMENT TYPE
ELEMENT NUMBER
STRUC ELEV (M)
1 SOFT LINE
2 WIRE ROPE
3 SCAF-FOLD
4 SMALL SECT.
5 LARGE SECT.
6 GRA-TING
7 SMALL METAL NON-SECT.
CRITERIA OF NON-CONFORMANCE
BU=100% CN=ANY LI=ANY PD=ANY
RM=ANY SC=ANY SD=ANY WD=ANY
AW=SEVERE >20% DB=HAZARD OBST INSP. METALLIC
CD=ANY CR=RISER: ANY CP=OUTSIDE -800 & -1050 mV
Ltd.
AIR DIVING
DATASHEET No
SHEET OF
RISER
EL + 10700 TO EL - 36900
INSP CO ORDS:
DATE START:
END:
ANODE WASTAGE %
1 2 3 4
0-5 5-20 20-50 >50
VIDEO
TAPE No
COUNT
FROM TO
ANOMALY INDEX (PRESENT ? Y/N)
SHEET No
EL + 10700
EL 0,000
EL - 4,800
EL - 20300
MUDLINE EL - 36900
RSE 2 0m
RSE 2 -2m
CL 3 -20.3m
DEBRIS TYPE
NEOPRENE PRESENT
CP -mV
Ref Zn Ref Cal.
EL-
3% 6% 9% 12%
MG
TAPE RDG
TOTAL THK
%H
%S
PD LI CD
CR DB YS CP
RM

Contents

9.6.3 COMPLETION OF DATASHEETS AND LOGS

There will be a datasheet and log provided for every aspect of the inspection. Datasheets will vary in format from company to company, but the essential information mentioned here should apply to all of them. These notes may also be used to construct a datasheet for an inspection which is missing from the workbook such as a riser inspection.

9.6.3.1 WELD INSPECTION DATASHEETS

These will normally require the most information to be supplied and will be looked at in detail. The information may be required on one or several sheets for any one weld.

The datasheet should first be checked for accuracy with the existing situation:

- Check the key plan which shows the position of the node/weld and the level on which it is on.

- Check the node plan for correct configuration and ensure that all members shown are correctly labelled.

- Check the large weld diagram for correct configuration and ensure that each member is correctly labelled.

The information required on the sheet should be filled in; sheets, sheet number, weld/node reference checked, standard elevation, data recorder, dive number, diver and date. Use a highlight pen to show on the large weld diagram, which weld is being inspected.

When a magnetic particle inspection is being reported, the following information should be included:

Demag: eg. Pre-No, Post-Yes
Amps : eg. 400A, 3 turns, coil
Flux : eg. 30 Oe. min., at 12, 3, 6 and 9 o'clock
Type of Flux indicator used (Burmah Castrol Type 1, Brass Finish)

On most modern datasheets a coding system is used. A particular attribute may be coded in the following way (check in applicable procedures).

eg.

Code	Attribute
CK	Crack
CL	Cold lap
UC	Undercut
CR	Corrosion
GR	Grinding
etc.	

All information should be be marked on the large weld diagram using the codes or symbols specified. Do not clutter the diagram and highlight important information.

Comments - a concise description in the comments section will be needed to accompany the appropriate code. Standard terminology should be used; this is outlined below:

Contents

Crack type defects - the defects can be described as follows:

Visual	continuous
	intermittent
MPI	continuous
	intermittent

Any branching should also be noted.

Lap type defects should be described as continuous or intermittent.

Corrosion pitting should be typically reported as:

General/Localised

slight	0-25%
moderate	25-75%
severe	75%-100%

Examples of the type of statement that should be made in the comments section are given below, together with the appropriate code:

Code	Comments
CR	General pitting in both HAZ's of weld
CK	Visual continuous branching crack in toe of weld MB16

Dimensions - all dimensions should be given in SI units, and in most cases this will mean metres and millimetres. Various attributes will require different dimensional descriptions, for example, a pit will require a diameter and a depth and should be written:

20 dia. x 3 deep

An area of grinding may require a length, width and depth and should be written:

200 long x 40 wide x 2 deep.

Clock Positions - Orientation for clock positions will be as outlined in the specification. Clock positions should be quoted in whole hours.

9.6.3.2 DIAGRAMS

Diagrams are extremely useful and instructive in cases where ideas or concepts are being discussed or described. A good diagram should be drawn in black on white. Colour cannot be photocopied on standard machines and as photocopies will be needed various types of shading can be used. The following guidelines should be applied when drawing a diagram:

- Use straight lines wherever possible (use a ruler!).

- Title - a complete title should appear at the top of the page.

- Labelling - all components should be fully labelled using correct terminology.

- Scale - a diagram need not be drawn to scale but an indication of the size should be given using a scale.

- Measurements - measurements taken should be shown on the diagram using straight lines ending in an arrow at the precise beginning and end of the measurement. Include the measurement in <u>millimetres only</u> at the mid-point of the line.

- Key - a key should be included and boxed in if symbols have been used.

- Orientation - give an indication of orientation, ie. platform North, in-board, etc.

- Location - give an indication of the location of the subject.

- Keep the diagram or drawing as simple as possible and show relevant detail only.

- Complete the diagram by including Inspection Controller's name and the date.

9.6.3.3 <u>VIDEO LOGS</u>

An accurate video record sheet (log) will be completed for each video tape and be included inside the video tape box. The video record sheet provides detailed information as to the tape content and acts as a tape index enabling specific footage to be found quickly. A sample video log sheet is included in section, 9.6.2.2.

The information generally required on the video record sheet is as follows:

Project	The overall project title, eg. Typical North Sea Platform 1987 Riser Inspection.
Date	The date the video was taken.
Contractor	The Diving Contractor, eg. TSOL.
Dive Spread	eg. TNSP
Dive Number	eg. Dive Number 284
Tape Number	eg. TNSP/87/02
Operator/Vehicle	eg. Diver, hand-held

Contents

Real Time	In hours and minutes, this information is the time shown on the video.
Counter Number	Shown on the VCR, this will commence at 000 and must be accurately noted to enable specific detail to be located quickly. Record type of video machine.
Subject	The subject in view at that particular counter number.

9.6.3.4 **PHOTOGRAPHIC LOGS**

Photographic Logs are essential and should be composed exposure by exposure as to subject, film and camera parameters, location, distance and orientation. Very often as in weld close-up photographs the sequence is not immediately obvious from the results but must always be easy to establish from the film log. The film log should also record the date, divers name or vehicle/pilot for ROV work, film type and camera/lens combination.

A cross-reference to the roll number/frame number is to be recorded on the relevant inspection datasheet.

All exposed film will be removed from the camera immediately on recovery and processed for viewing within 24 hours.

Transparencies should be mounted in slides or viewpacks and correctly labelled according to the Client's specification.

In addition, a master log sheet will be required to record the number of rolls and titles so far produced by the spread. A photographic record sheet is included in section 9.6.2.2.

Contents

9.6.3.5 CHARGING LOGS

Much of the flash failure during underwater photography can be put down to irregular and insufficient charging. It is recommended that as soon as a strobe/flash is back onboard it is immediately placed on charge and topped up. Extreme care should be taken not to overcharge the unit.

For this reason it is essential that a charging log is filled in continuously as re-charging takes place. A 16 hour charge is required to fully charge an Oceanic 2003 strobe (this is typical for most charging units in use - check equipment supplied as charging units vary). This should give around 300 flashes per charge on full power. After a dive a simple calculation will give the approximate time needed for recharging.

9.6.3.6 PROCESSING CHEMICAL LOGS

A processing chemical log maintains an up to date record of the number of films developed and the remaining chemical life. Using this information the chemicals should be replaced on a regular basis so that the quality of films developed does not decrease.

A processing chemical log for E6 processing is included in section 9.6.2.2.

Contents

9.6.3.7 CROSS REFERENCING

Information which is separate but relating to the same subject should be cross referenced for completeness and to prevent information going astray. In most cases this applies to information such as photographs, videos, their associated log sheets and how they relate to the datasheets. Photographs and videos will have a reference number from a system specified at the beginning of the inspection. This number should appear on the photograph or video, on the relevant log sheets and, most important of all, on the datasheets. If it does not appear on the datasheets then it will not be known that this photographic or video information exists and thus may be passed over.

Cross referencing of this sort also applies to any other relevant information such as samples, previous inspections, etc.

9.6.3.8 DATA SECURITY AND CONFIDENTIALITY

All data collated by the Inspection Controller is the property of the operating oil company who are paying for the inspection. It is also confidential and should not be passed into unauthorised hands. A primary reason for this is that when collated into a report it is then used to satisfy the Certifiers of the platform that this is in a safe condition and can continue to operate.

The divulgence of potentially damaging information, such as a serious defect, might affect a structures' Certificate of Fitness. Consequently, all recorded data and inspection information should be kept secure and confidential.

9.6.3.9 DATA DESPATCH

Completed datasheets will usually be passed on to the Client's Representative for verification, copying for the vessel or platform records, and despatch to shore. This will normally be through the inter-operating company mail system for daily despatch by helicopter. All data must be accompanied by a transmittal form.

Contents

Data which needs urgent despatch will be sent by facsimile transmission. If possible the Controller should on-pass all datasheets relating to one facet of the inspection in one package so that nothing will be mislaid.

Progress charts should be maintained offshore which reflect the current state of the inspection programme. As work is completed and dispatched a note should be made of this on the progress chart together with date and method used to send the material ashore.

9.7 DATA REPORTING AND PRESENTATION

9.7.1 DAILY PROGRESS REPORT TELEX/OPERATIONS REPORTING

The specific content, length and level of detail will depend on the client. Typically the telex is used to record diver/ROV activity over a 24 hour period. In addition the telex can be used to record vessel movements.

The Inspection Controller would typically be involved with the recording of in-water diver activity. This would be carried out using in-water diver activity sheets. The Client's Representative would compile this information as required for insertion into the agreed telex format. Typical telex codes could be split into:

1. Non-diving activities including delays
2. Diving activities
3. Diver activities
4. DSV activities

9.7.1.1 NON-DIVING ACTIVITIES

Typical codes would include:

Code	Description
WOD	Dive System Operations
MOB	Mobilisation
WOW	Waiting on Weather

9.7.1.2 DIVING ACTIVITIES

Typical codes would include:

Code	Description
BEG	Start of Dive
MOV	Diver Movements
TND	Tide Not Dived

9.7.1.3 DIVER ACTIVITIES

Typical codes would include:

Code	Description
RIG	Rigging
CVI	Close Visual Inspection
MGR	Marine Growth Removal

9.7.1.4 DSV ACTIVITIES

Typical codes would include:

Code	Description
MF	Made Fast (moorings)
AU	Anchors Up

9.7.1.5 TELEX FORMAT

```
TO        :  A. OTHER, OIL LTD
CC        :  ONSHORE CO-ORDINATOR, OIL LTD
FROM      :  REPS NAME, VESSEL NAME
DATE      :  13TH OCTOBER 1987
TELEX NO:    005
```

AA) LOG OF EVENTS 0001-2400 12TH OCTOBER 1987

0001 - 1200	WOW	WIND 25 KTS
1200 - 1205	WOD	PREPARING TO DIVE
1205 - 1230	ADV	CP SURVEY

ETC.

BB) EVENT BREAKDOWN AND COMPLETION

EVENT CODE	JOB NO.	TODAY HRS	TODAY MINS
WOW	29-C	12	00
WOD	29-C	00	05
ADV	29-C	00	25

CC) JOB PROGRESS

JOB NO.	TASK	% COMPLETION	EST. TIME TO COMPLETE (MAN DIVES)
29-C	INSP	35	42

DD) DSV MOVEMENTS

1550	LG	29-C
1730	MF	29-B

EE) CONSUMABLES

CONSUMABLES	USED	REMAINING	REQUIRED
SLIDE FILM	3	25	0
GRIT	10 BAGS	45	0

FF) PERSONNEL MOVEMENTS

NAME	GRADE	COMPANY	TRANSFER (T) MOB (M), DEMOB (D)

GG) EQUIPMENT MOVEMENTS

TYPE	COMPANY	TRANSFER (T) MOB (M), DEMOB (D)

HH) CLIENTS COMMENTS

SLIDE FILM USED FOR TOPSIDE MOORING DETAILS REQUIRED ON PLATFORM 29B.

REGARDS
REPS. NAME

9.7.1.6 MONITORING INSPECTION PROGRESS

As the Inspection Controller is responsible for planning the inspection programme it is important that he monitors how the inspection progresses. Essentially this means keeping a close record of what has and has not been completed, and a system for achieving this developed prior to the programme commencing. This should be agreed so that both the offshore and onshore controller keep the same records. In this way planning can take place with confidence and without duplication especially when a variety of diving spreads are inspecting the same structure.

Typically, for a weld inspection programme, a master chart should be produced listing the welds by priority and/or location, providing space for checking off:

- Cleaning
- Close Visual Inspection
- Magnetic Particle Inspection
- Remedial Grinding
- Photography
- Comments
- Completion Date

Different types of inspection require different charts. These should be kept as simple as possible, and above all the information on them kept up to date. It would be useful to cross reference these with the onshore controllers' copy at certain time intervals. It is possible that onshore monitoring of inspection progress will utilise a computer and thus versatile print-outs of work remaining, work accomplished etc can be forwarded for cross referencing offshore.

9.7.2 REPORTING

The granting of a structure's Certificate of Fitness requires that the Certifying Authority is presented with a report detailing the condition of the structure. The report would be collated using the data recorded during the inspection programme on the datasheets. In normal circumstances this would be carried out at the end of the programme. Unusual findings may dictate that interim reports are generated.

This would be at the client's request unless required under the contract as a matter of course. In addition, operational reports may be generated during and at the end of the inspection programme, these reports would normally be for internal circulation only.

All reports should be treated as confidential and access limited to authorised personnel only.

Presentation of the final report is extremely important. The report will be viewed by internal departments and possibly by external organisations such as the Certifying Authority and partner companies. The text should be set out in a clear and concise manner with full use of tables, diagrams, charts and graphs where applicable. Photographs where used should be correctly labelled, well composed and exposed. All cross referencing used in the report should be checked for accuracy and amended accordingly.

9.7.2.1 OPERATIONAL TASK BREAKDOWN

Operational task breakdowns are essential for providing information on costs, task completion times, divers efficiency, planning etc. The breakdowns are produced by keeping a careful record of activities and times and are usually included in the client's representative daily telex. It is quite likely that the Inspection Controller will be requested to help in recording this information. In most cases this information will be coded for inclusion in the telex and onshore analysis which might include computing.

Codings typically used are shown below. The exact time in hours and numerals would be entered beside each code; the diving supervisors's log book will provide much of this information as will the vessel's log. Some may have to be recorded continuously by the Inspection Controller.

Various inspection activities, ie. weld inspection, riser inspection, etc are also coded for telex inclusion, usually with a job number. Sample sheets of these breakdowns and their subsequent use to generate pie charts are included in this section to illustrate this analysis.

WOD - Preparing to dive or changeout between dives.

WOT - Manoeuvring or transiting to a worksite.

WOP - Waiting on platform (awaiting clearance to dive - an end to scaffolding or the unloading of tubulars, radio silence etc)

WOC - Waiting on cargo where cargo is being transferred to the diving vessel.

WOW - Waiting on weather.

WOED - Waiting on Diver/ROV equipment.

WOEV - Waiting on vessel repair.

WOV - Waiting upon vessel, awaiting the end of non-diving activities by the vessel.

EVENT TIME BREAKDOWN REPORT

ESSEL/PLATFORM : DSV DIVEBOAT
YPE OF SPREAD : AIR DIVING
PREAD ID. : 1
PERATOR : SAMCO LTD
ONTRACTOR : OIL INDEPENDENT INC.
EPORT PERIOD - FROM : 01/06/85 TO : 31/08/85

EVENT CODE	TIME HOURS	MINUTES	%AGE OF TOTAL	DESCRIPTION
ADV	164	9	7.42	AIR RANGE DIVING
TND	80	37	3.64	TIDE NOT DIVED
WOD	4	15	0.19	DIVE SYSTEMS OPERATIONS
WOT	0	19	0.01	DSV POSITIONING AND TRANSIT
WOC	24	40	1.11	WAITING ON CREW CHANGE
WOP	0	25	0.01	WAITING ON PLATFORM
WOV	24	20	1.10	REPAIRS TO DSV
WOSW	1840	3	83.33	WAITING ON SLACK WATER
WOW	69	12	3.12	WAITING ON WEATHER

OTAL REPORTED TIME = 2208 HOURS 0 MINUTES.

Table 1

Contents

Sub-event/Job code breakdown

All events

VESSEL/PLATFORM : DSV DIVEBOAT
TYPE OF SPREAD : AIR DIVING
SPREAD ID. : 1
OPERATOR : SAMCO LTD
CONTRACTOR : OIL INDEPENDENT INC.
REPORT PERIOD - FROM : 01/06/85 TO : 31/08/85

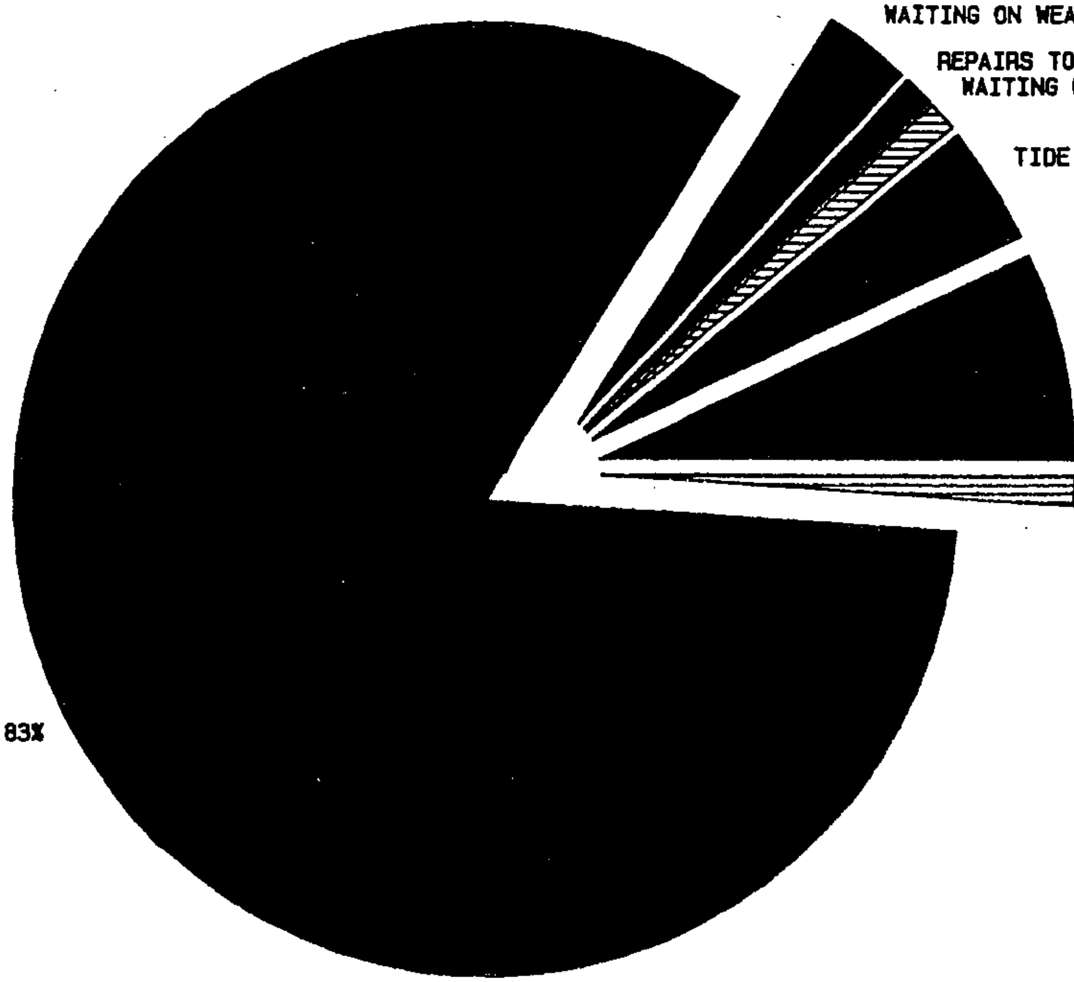
EVENT DESCRIPTION	JOB CODE/ SUB-EVENT	TIME HOURS	MINS	%AGE TOTAL	DESCRIPTION
WAITING ON SLACK WATER	23AQ	284	35	12.88	INST AQ - WAIT ON SLACK WATER
	23AT	200	1	9.05	PLATF'M AT-WAIT ON SLACK WATER
	18AP	121	46	5.50	RIG AP - WAIT ON SLACK WATER
	18BP	120	47	5.46	RIG BP - WAIT ON SLACK WATER
	27FD	102	59	4.66	RIG FD - WAIT ON SLACK WATER
	16BD	78	54	3.56	PLATF'M - WAIT ON WEATHER
WAITING ON WEATHER	23AC	37	29	1.68	PLATF'M - WAIT ON WEATHER
	18AD	14	52	0.67	INDE AD - WAITING ON WEATHER
	23AT	9	0	0.40	INST AT - WAIT ON WEATHER
	23AQ	6	30	0.29	INDE AQ - WAITING ON WEATHER
	18BP	0	41	0.03	INDE BP - WAITING ON WEATHER
	18BD	0	40	0.03	INDE BD - WAITING ON WEATHER

TOTAL REPORTED TIME = 2208 HOURS 0 MINUTES.

Table 4

Vessel/Platform : DSV DIVEBOAT
Type of spread : AIR DIVING
Spread ID. : 1

Event type : ALL EVENTS
Report period : 01/06/85 To 31/08/85
Total reported time = 2208 Hours 0 Minutes.



Contents

DATE : 31/10/85

EVENT TIME BREAKDOWN REPORT

GENERAL DOWNTIME

VESSEL/PLATFORM : DSV DIVEBOAT
TYPE OF SPREAD : AIR DIVING
SPREAD ID. : 1
OPERATOR : SAMCO LTD
CONTRACTOR : OIL INDEPENDENT INC.
REPORT PERIOD - FROM : 01/06/85 TO : 31/08/85

EVENT CODE	TIME HOURS	TIME MINUTES	%AGE OF TOTAL	DESCRIPTION
WOSW	1840	3	96.37	WAITING ON SLACK WATER
WOW	69	12	3.62	WAITING ON WEATHER

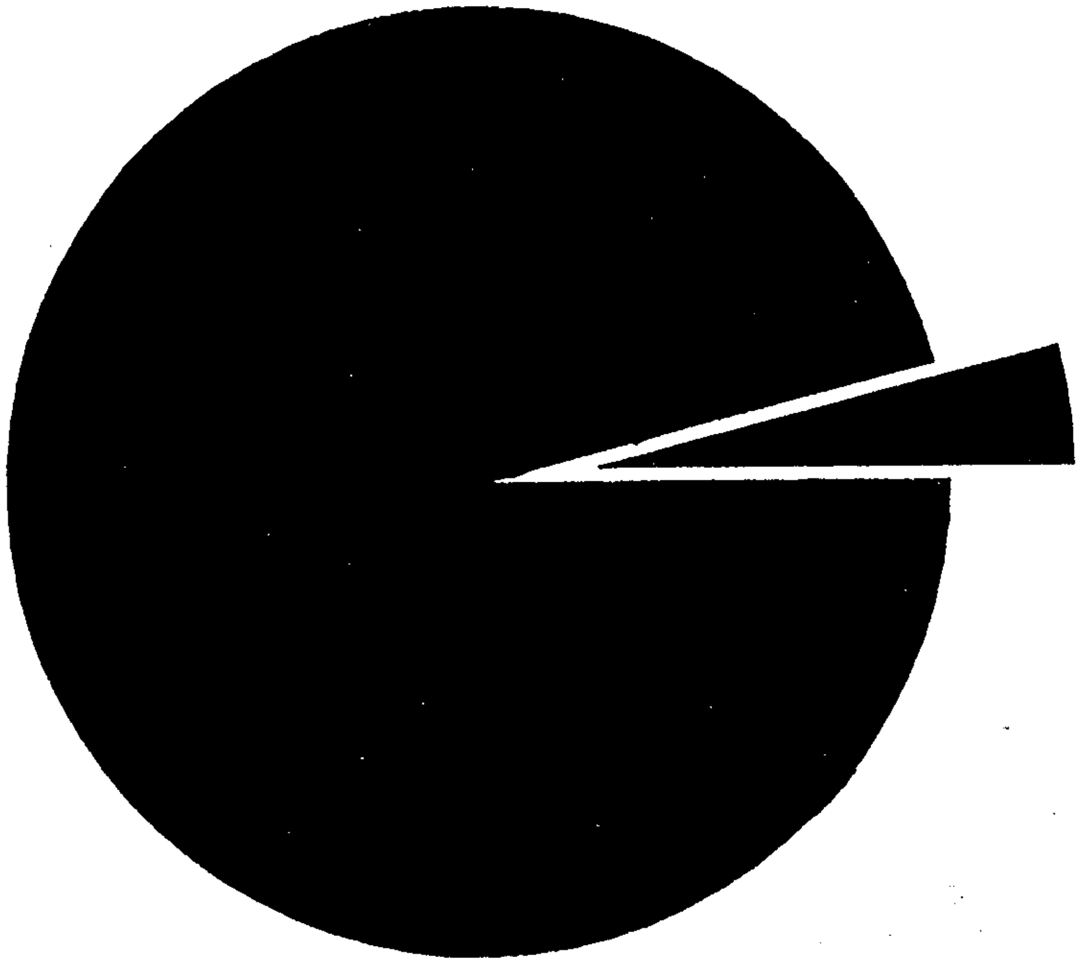
TOTAL REPORTED TIME = 1909 HOURS 15 MINUTES.

Table 3

Contents

Vessel/Platform : DSV DIVEBOAT
Type of spread : AIR DIVING
Spread ID. : 1

Event type : GENERAL DOWNTIME
Report period : 01/06/85 To 31/08/85
Total reported time = 1909 Hours 15 Minutes.



Contents

9.7.3 REPORT WRITING

The format for report production will be dictated by the client's requirements. Where no format is established a report should typically have the following components:

Title *
Signing-off Sheet
Table of Contents *
Introduction *
Summary *
Results *
Conclusions
Recommendations
References
Glossary
Appendices

* The items marked with an asterisk are normally essential.

9.7.3.1 TITLE

This should be as short and as descriptive as possible. It is usually presented as a frontispiece with the title, the name of the writer, the date and the project.

9.7.3.2 TABLE OF CONTENTS

This should show the pattern of the report at a glance. It should give the main headings and sub-headings. It should be on a separate page.

9.7.3.3 INTRODUCTION

This is to tell the reader the purpose of the report. It should explain briefly the background of the report.

It may serve to define the subject or your term of reference. For example you might say "This report deals with the Structural Loading of the Platform. It does not deal with the Cathodic Protection for the Platform".

The introduction is the appropriate place for any definition you might want to use. For example you might say "for the purpose of this report the term manager is defined as anyone who objectively directs men and materials".

For a task completion report it should be based on three things. The first paragraph or section should state the objective. The second paragraph should deal with the workscope and any addition. The third paragraph deals with the action taken and how and why it may have differed from the workscope.

Each section should be sub-paragraphed if necessary, but leaving only 1 line space within a section. Between 2 sections, 2 line spaces should be left.

9.7.3.4 SUMMARY

This is not merely a summary of the conclusions and recommendations. It is a highly condensed precis of the whole report. It may save a busy reader reading the whole report.

It should indicate:

(i) The extent of the report
(ii) The findings of the writer
(iii) If appropriate, proposed action

9.7.3.5 WORK DESCRIPTION

If this is short it can be included in the introduction or the results as appropriate. But, if the report is very technical or complex it is better to treat them separately.

Contents

9.7.3.6 RESULTS

This is the main body of the report and contains all the relevant information and discussion from which conclusions will be drawn.

The inspection results can be presented in many formats, typical formats for cathodic potential and marine growth are included.

Be as brief as possible, but do not sacrifice clarity and essential information for the sake of brevity. The report must be clear, concise and accurate. Do not make oblique references to tables and diagrams. Be specific and reference any photographs or video tapes. Always give dimensions where they are relevant.

Summary of Results

It may be necessary in a large report to write a summary of results.

9.7.3.7 CONCLUSIONS

Conclusions are not always asked for, for example, interim reports may not contain conclusions. Again, the subject of the report may not require you to draw conclusions. (Such a subject could be an annual review, or a progress report).

Having gathered and organised your facts you should find that conclusions follow logically.

However you may be obliged to state opinions based on the facts. Do not be afraid to do so - as long as you indicate that they are opinions.

You may also decide "that no conclusions are justified from the facts". You may for instance realise that further investigations may be necessary before you can come to a conclusion, and that this investigation is beyond the scope of your activities.

Contents

The important thing to remember is that your conclusions must be supported by facts in the report. By reading the report the reader should clearly see how you arrived at your conclusions.

Conclusions are best given in listed form eg. (a) (b) (c).

9.7.3.8 RECOMMENDATIONS

Not always specified by the client but if required should follow these lines.

Recommendations usually have an ingredient of opinion in them. See that they are derived from the conclusions. Be critical of your recommendations to make sure they are both practicable and practical, and are within the province of the report. As with conclusions, it is best if these are given in listed form.

(It may be appropriate to draw conclusions and make recommendations at various stages of the report, in which case it is usual to gather them all together at the end of the report under some such heading as "Summary of Conclusions and Recommendations". If you do this, it also helps the reader if you place in parenthesis after each item the number of the paragraph where you made the conclusions or recommendation in the first place).

9.7.3.9 REFERENCES

The references should list all material which is relevant to the report and has been drawn upon to provide additional background data or support.

9.7.3.10 GLOSSARY

The glossary should list technical or special words, with definitions as used in the report.

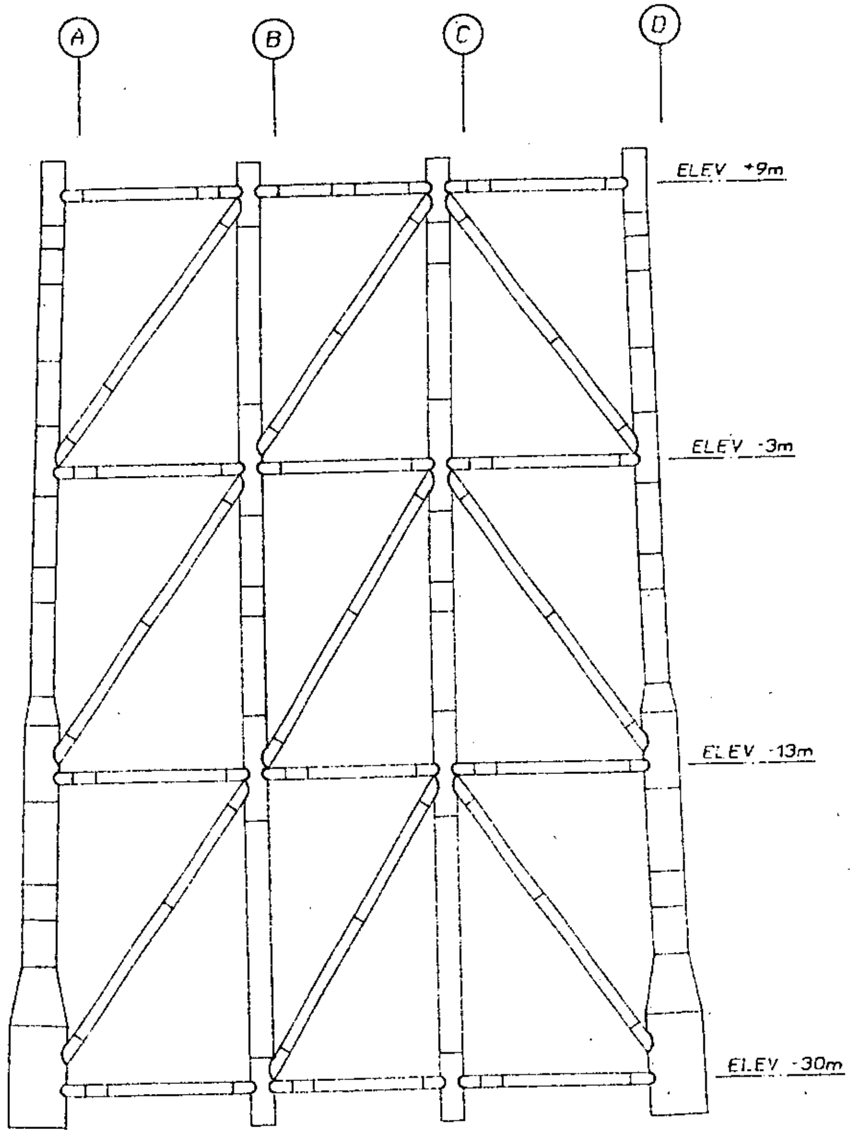
Contents

9.7.3.11 APPENDICES

The appendices should contain matter which is auxiliary to the main body of the report.

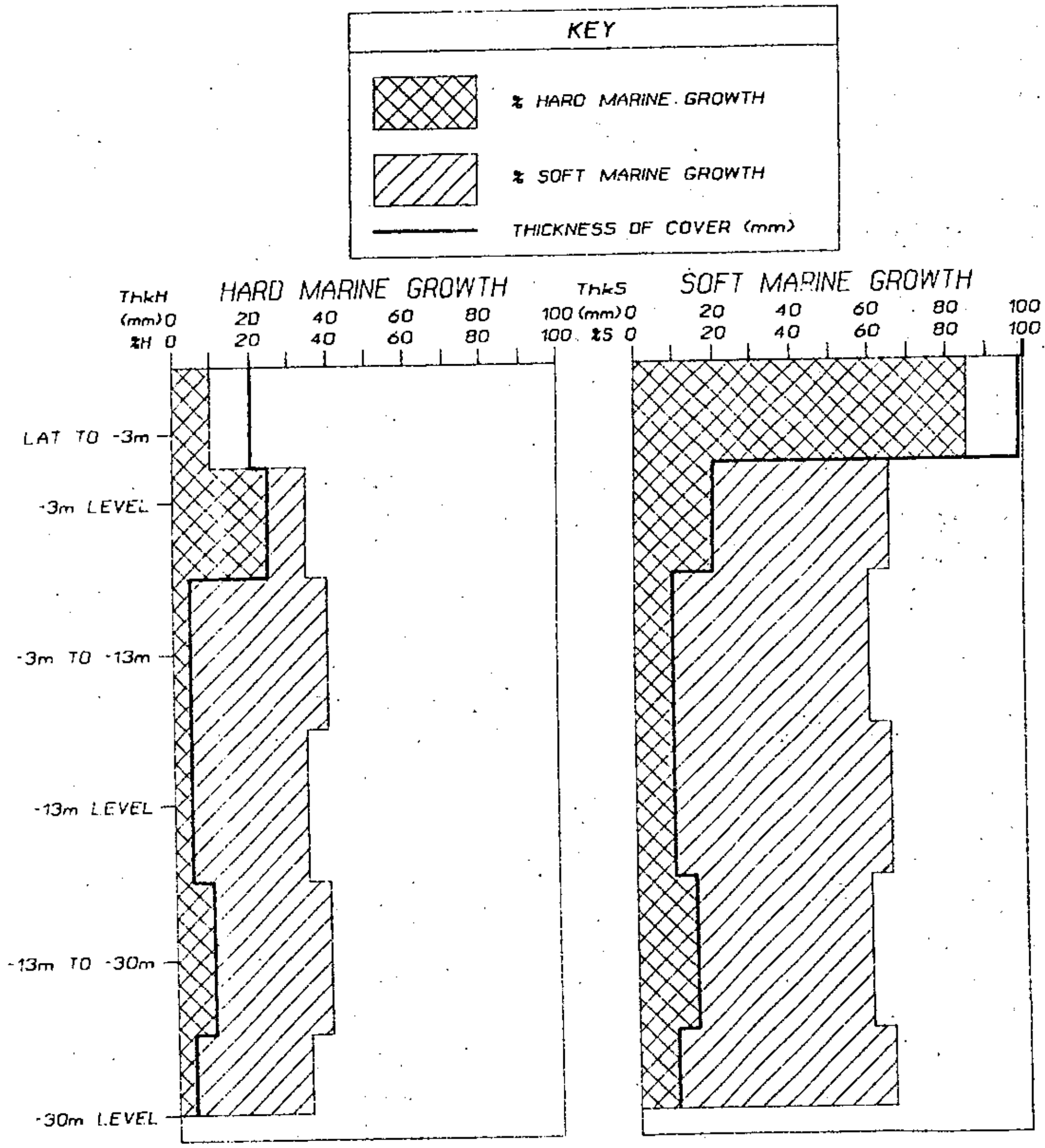
eg. copy of workscope
raw data sheets
sketches
calculations
printout

Contents



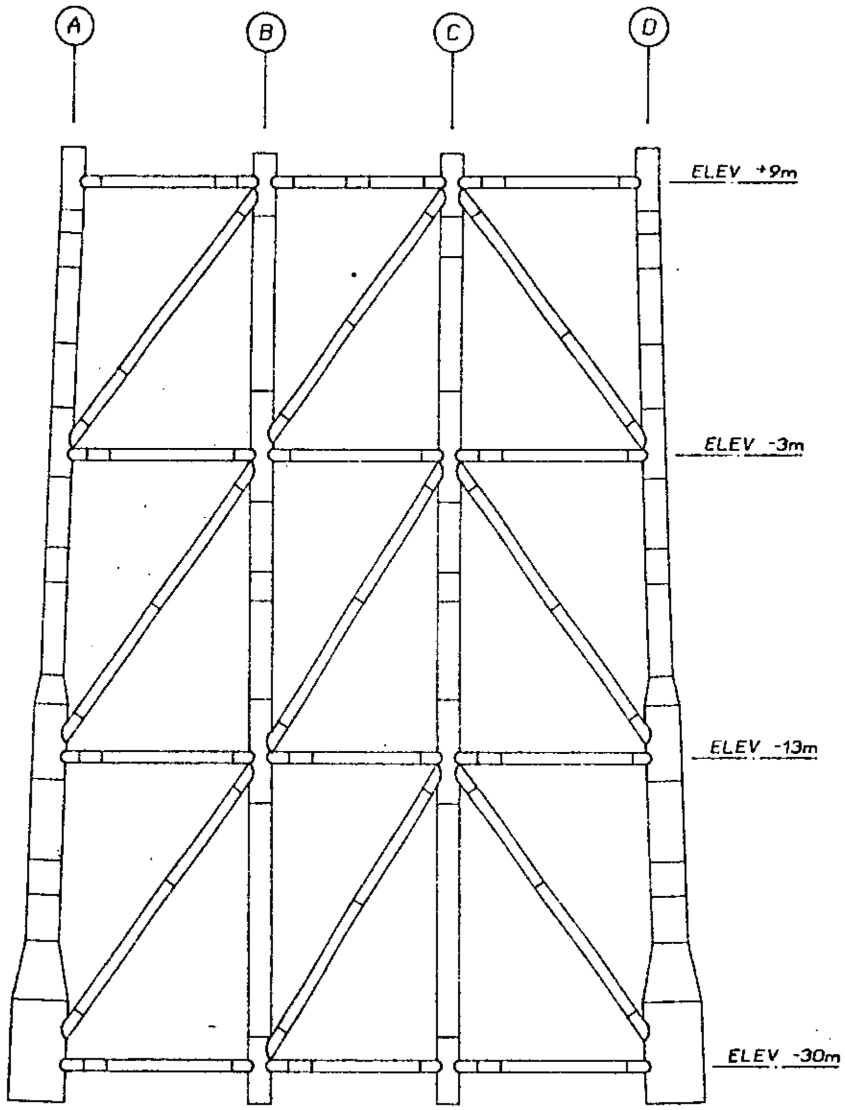
ELEVATION ON FRAME 1

MARINE GROWTH - PLATFORM



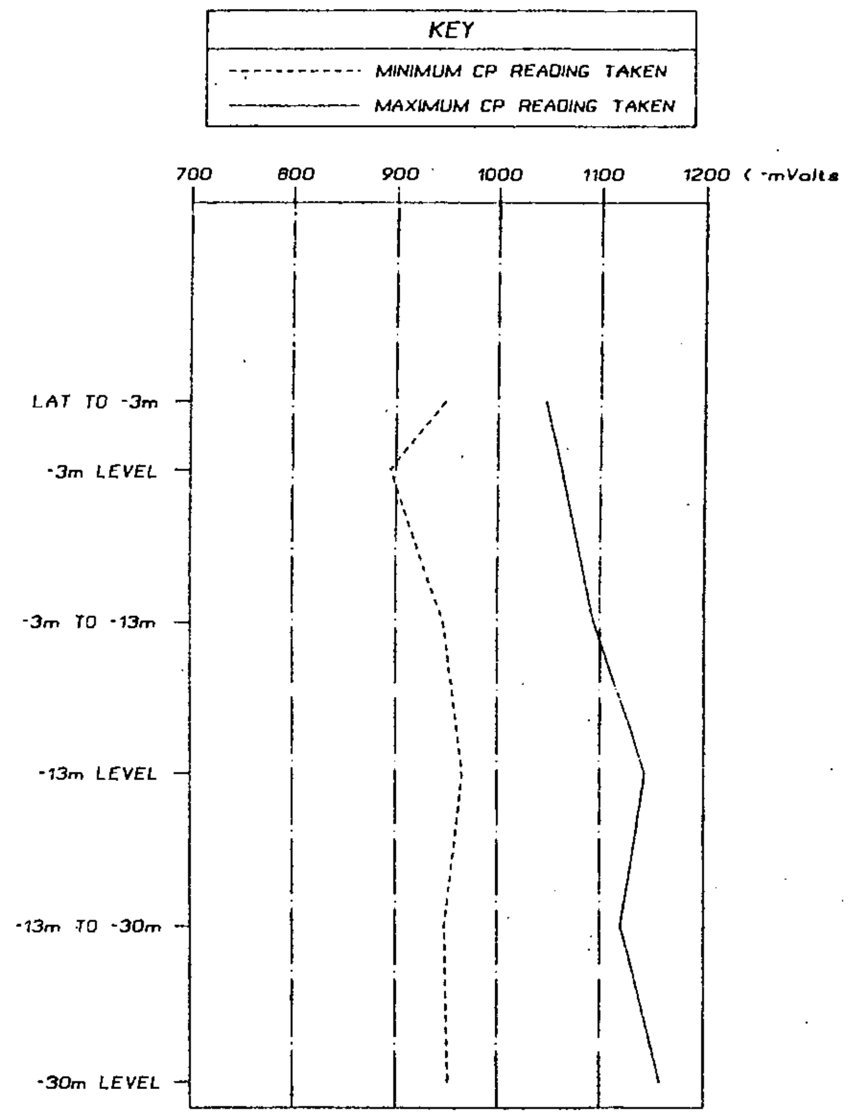
% COVER AND THICKNESS SHOWN AS AVERAGE FOR EACH HORIZONTAL LAYER OR FOR MEMBERS BETWEEN LAYERS.

Contents



ELEVATION ON FRAME 1

CATHODIC POTENTIAL - PLATFORM



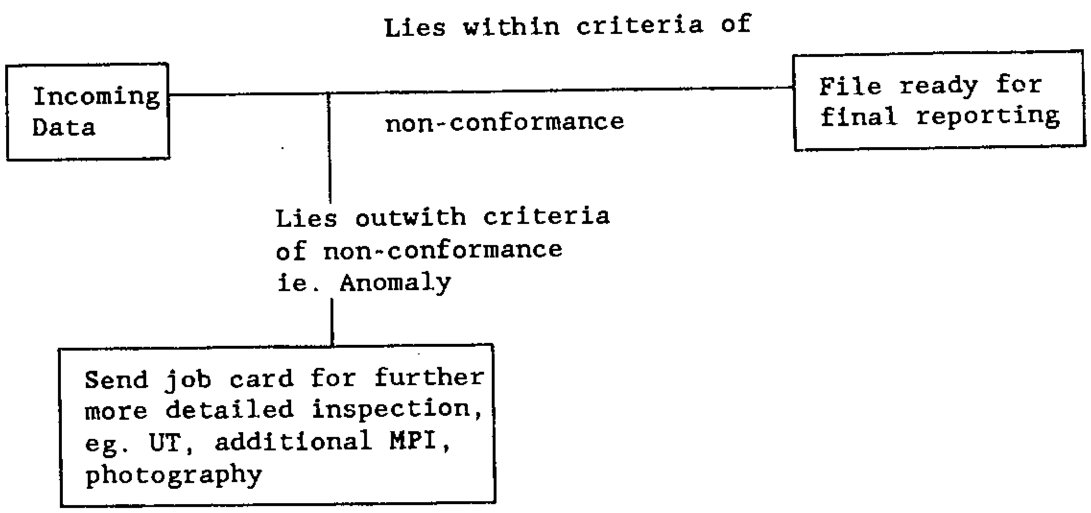
VALUES PLOTTED ARE MAXIMUM & MINIMUM READINGS TAKEN AT HORIZONTAL LEVELS & ON MEMBERS BETWEEN LEVELS.

9.8 DATA PROCESSING

Data is processed as it comes ashore to provide information for immediate and long term action.

9.8.1 IMMEDIATE ACTION

Typically the data will be scrutinised and sorted into two basic categories, routine, or that which lies within specific limits/criteria of non-conformance, and anomalies or that which lies outwith the specified limits/criteria of non-conformance.



(i) Carry out repair if feasible
(ii) Carry out temporary repair
(iii) Monitor if applicable
(iv) Impose restrictions if necessary

9.8.2 LONG-TERM ACTION

The system outlined for immediate action is useful in that if planning and decisions are made swiftly resources which are on site can be utilised eg DSV or other diving spread. Long term action will be necessary in any event. This can provide:

(i) Scope of work, procedures and any necessary fabrication for a repair

Contents

(ii) Analysis of data to highlight other areas liable to damage or failure.

(iii) Level and frequency of inspection monitoring after repair

(iv) Modification of inspection techniques

(v) Modification of inspection programme

(vi) Preventative maintenance from trend analysis

9.8.3 DATA MANAGEMENT SYSTEMS - IDEALISED

Data management systems have the potential to define the workscope, produce the workbooks, store data, carry out analysis and produce reports all in the one package.

9.8.3.1 WORKSCOPE PRODUCTION

The workscope is based on the 5 year Inspection Programme plus additional work from previously reported anomalies. The system should be flexible enough to incorporate new inspection techniques and procedures. By outputting the workscope the system would identify the work to be carried out on each component.

9.8.3.2 WORKBOOK PRODUCTION

Once the workscope has been defined the system could output blank data sheets, log sheets, anomaly details, inspection procedures, drawings and work monitoring sheets as a complete package.

9.8.3.3 DATA STORAGE

The system should be flexible enough to store all inspection repair, maintenance data using either on-line or off-line input.

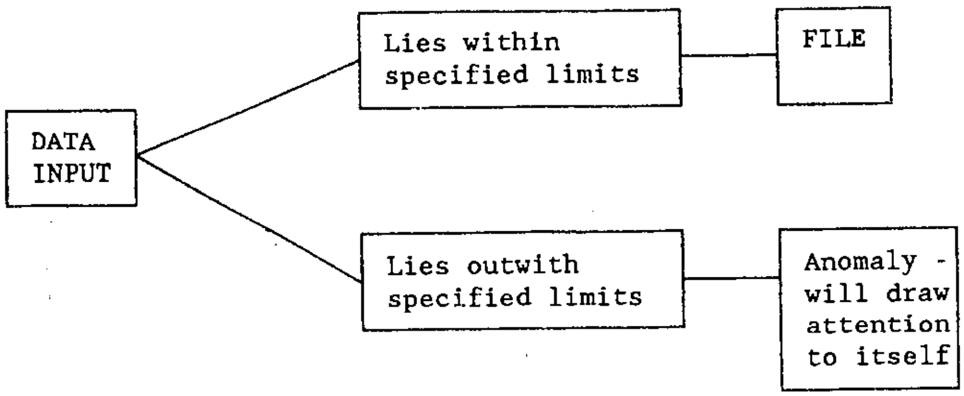
Contents

9.8.3.4 REPORTING AND ANALYSIS

The system should be capable of printing the completed data sheets etc set-up during the workbooks production. This facility could include the up-dating of drawings as required. Using the input data a report writer/and or various analysis packages could produce reports.

9.8.4 DATA MANAGEMENT SYSTEMS - PRACTICAL

At present typical data management systems are used to provide the information required for instigation of immediate or long term action. This is initiated by a system of flagging. This means that any data entered will lie in two categories as shown below.



In computing terms a flag is an additional piece of information added to a data item which gives information about the data item itself.

This occurs through a flag event which is a condition occurring in a program which causes a flag to be set.

The condition would be the specified limits or criteria of non-conformance.

Contents

Databases - a database is simply a file of data. It is a computerised file of data so structured that appropriate applications draw from the file and update it but do not themselves constrain the file design or its contents; a file which is not designed to satisfy a specific, limited application.

In order for the data base to work efficiently in terms of offshore inspection data, the Inspection Controllers datasheet and the database input should be as similar as possible. The database may have design constraints put on it by its need to act as an input document. If loading is to be carried out by inexperienced operators the database should be:

(i) as user friendly as possible
(ii) have only one point of entry
(iii) have a network allowing access to all areas within the database.

Trend Analysis

Computerised data storage in a database system allows trend analysis to take place far more easily than using a manual system.

For example CP values over an entire platform face can be analysed for trend using:

(i) Colour representation on diagrams - allows instant trends to be visualised.
(ii) Actual values can be compressed onto one diagram.

(iii) Histograms and other graphical and statistical manipulation of the data can show averages and ranges.

10. INSPECTION PLANNING AND BRIEFING

10.1 INSPECTION PHILOSOPHY AND STATUTORY REQUIREMENTS

10.1.1 PHILOSOPHY

Inspection and maintenance of offshore oil and gas installations is primarily carried out to ensure the safety of the onboard operatives.

This has become an increasingly important factor since the service life of early structures, which was considered to be virtually infinite in the calm inshore waters where they were employed, has been found to be drastically reduced by the extremely harsh conditions of areas such as the North Sea.

The purpose of inspection is to detect and catalogue defects arising during the platform's life and hence allow the assessment of the criticality of these defects. The extent of any remedial works carried out will be dependent on the severity of the defects found and the expected economic life of the reservoir.

Engineering analysis of programme results determines the extent and frequency of inspection required for each part of a structure, enables economic preventive or remedial maintenance to be carried out, and allows material and design specifications for new structures to be improved.

10.1.2. STATUTORY REGULATIONS

Because of the extraordinary deterioration experienced in some offshore structures and a number of catastrophic failures, governments have produced legislation seeking to ensure that structures are safe and fit to operate.

The British Offshore Installations (Construction and Survey) Regulations 1974 lay down in broad terms the minimum standards for the design and construction of structures to be used in UK waters, and require each to have a Certificate of Fitness valid for up to five years.

This Certificate is issued subject to survey by certain Certifying Authorities approved by the Secretary of State: Lloyds Register of Shipping; The American Bureau of Shipping; Bureau Veritas; Det Norske Veritas; Germanischer Lloyd; and the Offshore Certification Bureau.

Where no Certificate of Fitness is in force, or before installation, or when renewal of a Certificate is sought, a major survey is required. Where a Certificate is in force, annual surveys, may be accepted in lieu of a subsequent major survey. The first annual survey is to be performed not less than nine and not more than eighteen months after the date of issue of the Certificate of Fitness. Thereafter, similar surveys shall be carried out not less than nine nor more than fifteen months of each anniversary of the date of issue.

Any structural damage, major alterations to or deterioration likely to impair the safety, strength and stability of an installation must be reported to the Certifying Authority, who can request further survey or can invalidate the Certificate of Fitness, thereby prohibiting further operations depending on the severity.

Parts of the Regulations and other enactments extend such requirements to floating vessels associated with offshore production, particularly when personnel are accommodated aboard ("flotels", semi-submersible drilling rigs, etc).

The Submarine Pipelines Safety Regulations 1982 require a pipeline to be designed, constructed, operated and maintained to ensure, as far as is reasonably practical, that every part of it is protected from damage where necessary, no part is a danger to any person, and that the position of the pipeline does not change.

Pipeline owners are required to prepare and carry out an inspection scheme providing systematic examination of all parts of the pipeline, at intervals not exceeding 12 months, detailing any damage or defects, position changes, extent of exposure or burial, seabed condition and amount of marine growth.

Similar laws and regulations have been enacted by other maritime governments, particularly Norway, where they are formulated jointly by the Petroleum Directorate and Det Norske Veritas. They specify inspection and maintenance standards and methods precisely and rigidly enforce them.

10.1.2.1 CERTIFYING AUTHORITIES' REQUIREMENTS

The approval of the Certifying Authorities by the Secretary of State springs largely from their prior existence as independent and respected Surveyors and Insurers of ships.

Because of the unpredictable effects of weather on underwater inspection, availability problems with techniques, equipment and trained and qualified personnel; most Authorities' Inspectors, who are invariably Chartered Engineers, are prepared to allow Operators some latitude in the extent and standards of surveys. However, the appointed Surveyor has unlimited powers in the ordering of tests and surveys as he sees fit, to ensure compliance with the regulations.

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Although flexible, surveyors do expect Operators to complete a sufficient amount of approved inspection in any one year to comply with the Annual Surveys Ruling and also to accumulate findings on a progressive basis towards the nulling of the requirement of a major survey, should this be the route chosen by the operator company. Typically surveys will comprise of:

- Close visual, video and magnetic particle inspection or re-inspection of a representative number of welds.
- A general corrosion survey, including cathodic potential readings, and protection system assessment, (anodes, electrodes).
- A seabed condition and scour survey around the structure.
- A physical damage/structural integrity survey.
- A debris survey.
- A marine growth survey.
- A full survey of marine export risers, conductors and caissons and their supports and protection systems.

10.1.2.2 MULTI-YEAR INSPECTION PROGRAMMES

The need for systematic re-inspection of various structural components and the impossibility of inspecting all parts of large structures every year have led to the adoption of multi-year programmes, as provided for in the Regulations.

10.2 PERSONNEL STRUCTURE

10.2.1 INDIVIDUAL BODIES

10.2.1.1 THE CERTIFYING AUTHORITY SURVEYOR

It is the responsibility of the Owner of the Installation to obtain the Certificate of Fitness which allows commencement and continued operation of an installation.

It is the concession owner's responsibility to maintain safety and revenue from the field.

The Certifying Authority Surveyor is an Independent Assessor of inspection reports and results and is required to be satisfied that the measures taken by the Operator Company are adequate and effective, before issuing a Certificate of Fitness.

In the employment of a Surveyor, who's task it is to verify that an installation conforms to, "The Offshore Installations (Construction and Survey) Regulations 1974", which have to be satisfied to obtain a Certificate of Fitness, an Operator may only choose from the D.O.E. list of approved Certifying Authorities. An Operator Company is free to choose any of those approved.

The Surveyor will make periodic visits to the installation and to any diving vessel used on that installation, to satisfy himself that survey work is being carried out in a correct and efficient manner to recognised standards.

10.2.1.2 OPERATOR COMPANY ENGINEERING DEPARTMENTS

Operator companies normally have their own Engineering Departments whose task it is to develop survey workscopes to ensure sufficient and correct information has been gathered to allow the trouble free granting of the Certificate of Fitness.

Their role is one of assessing incoming data and instigating further survey work or remedial works, in lieu of the Surveyor making his recommendations. However, the regulations require that the Surveyor be kept informed of all developments and remedial works resulting from survey activities.

In this way, the Surveyor's role becomes one of Overseer and Grantor of final approval.

In developing schedules for annual surveys, Operator Company Engineering Departments will often draw up specifications and procedures to which the survey should be carried out by contract companies. These are often submitted to the Surveyor for approval so that work of known quality is being achieved.

10.2.1.3 <u>OFFSHORE CLIENT REPRESENTATIVE</u>

An Operator Company requires a person to be intimately involved with the offshore operation to ensure his interests are being looked after. This covers all aspects of the job such as safety, conduct of the vessel, compliance to procedures and specifications and liaison with other field activities.

In his role, the Offshore Representative is in total control of the progress and activities of any diving survey work. He is generally answerable to an onshore Staff Engineer of the Operator Company and is the focal point for all onshore to offshore and all offshore communications to installations, other vessels etc.

In certain circumstances, such as when a Diving or ROV Contractor is working on a lump sum basis, the Offshore Representative will not be able to dictate activities but will act as an Observer, ensuring that a client's specifications are met. Should he feel they are not being met, then he will have powers of intervention.

10.2.1.4 <u>SURVEY CONTRACTORS</u>

Because of the specialist nature of equipment and personnel required for survey, Operators employ contract companies to undertake the work under the Operator's guidance and control. This is especially so in underwater survey work because of the high capital cost of equipment and the seasonal nature of the work.

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The Survey Company employed by an Operator Company will be able to provide the specialist equipment and necessary skilled manpower required to complete a specific survey task.

The Offshore Team will comprise of a Superintendent or Senior Supervisor who will be answerable to the Offshore Representative and will have overall control over the Survey Team and represent the Survey Company in any offshore discussions.

Reporting to the Superintendent there will be a Supervisor for each shift and then the personnel conducting the survey (dive or ROV team).

10.2.1.5 UNDERWATER INSPECTION CONTROLLER

The Inspection Controller may be employed by the survey contractor or may be independently employed by a specialist contractor. His role is to efficiently manage the inspection programme, reporting to all concerned the progress of the job, plan dives, brief divers, record data and report anomalous findings to the Offshore Representative. He requires an understanding of the structural response of a platform, the methods and physics of diving and a common sense and responsible attitude to his work.

10.2.1.6 PLATFORM OFFSHORE INSTALLATION MANAGER (OIM)

The OIM is an Operator Company staff man in charge and responsible for all activities within 500m of an offshore installation. In this respect, the Offshore Representative is directly answerable to an OIM, if a survey vessel is operating within an installations' 500m zone, for all operational requirements.

10.2.1.7 VESSEL MASTER AND VESSEL CREW

The vessel Master has overall responsibility for his vessel and the safety of all those onboard.

He can, therefore, terminate operations should he feel that either is in jeopardy - including a diver.

In a platform's emergency situation, the vessel would be at the disposal of the OIM, but the vessel master's first concern would be for the safety of those onboard.

In many instances the vessel crew have no direct involvement in survey activities except for occasional equipment rigging, crane operation etc. Their tasks normally include vessel maintenance and mooring.

10.2.2 HEIRARCHY

On a platform and for operations within 500m of a platform, the ultimate authority is the OIM (Offshore Installation Manager). The company Diving or Marine Representative is responsible to him for all aspects of the diving. The Diving Superintendent is responsible for the dive crew and overall running of the spread. The Diving Supervisors are legally responsible for the running and safety of individual dives. Dive crew members are directly responsible to their Supervisor and Superintendent.

Dependent on employing company the Inspection Controllers may be directly responsible to either the clients Diving Representative or the Diving Superintendent.

No instructions concerning the conduct of diving activities may be given by the Inspection Controller to any member of the dive crew. All Controller's requirements during the inspection are requests. Supervisors may be questioned pertinently on their inability or refusal to fulfil the Controller's requirements, but not coerced.

10.3 PLANNING

10.3.1. OFFSHORE ORGANISATION

10.3.1.1 PERSONNEL AND EQUIPMENT: ABILITIES AND RESPONSIBILITIES

The responsibilities for carrying out certain tasks and caring for certain equipment, eg. inspection instruments, cameras, etc, should be established from the beginning. This is particularly important where divers have been used to their own company's data recorders looking after equipment. Unless the equipment belongs to the Operator, the contractor will have to make adequate provision for its maintenance.

10.3.1.2 DATA RECORDING WORKSTATIONS AND FACILITIES

Inspection data is usually recorded in the dive control shack, which is a busy, crowded and often grubby place. In theory it is the sole domain of the Diving Supervisor, and due note should be taken of this.

A suitable place for the Controller to work and to leave paperwork undisturbed should be arranged from the outset with the dive crew.

It should be clearly established that the point of the diving is to obtain high quality inspection data and that the supervisor should endeavour to prevent any disturbance or hindrance to this.

10.3.1.3 DATA AND SAMPLE PRESENTATION AND PROTECTION

Any data recorded or samples collected must be protected and preserved from the moment they are taken, or else the dive may be nullified.

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Data should always be copied and cross-referenced unless in the possession of a Controller. Every sample or piece of data must be clearly labelled with date, location, member, etc. so that it cannot be misconstrued.

10.3.1.4 DATA VERIFICATION

Data verification is an important factor in quality assurance. A possibly spurious reading or description must be recognised by the controller at its inception and re-checked. Such checking will continue as results are collated for transmission, but verification on the spot is less time consuming.

10.3.1.5 PERFORMANCE ASSESSMENT

Controllers should try to build up some kind of assessment of each diver's and each shift's performance. This will allow better scheduling and more efficient work.

If a diver is found to be inadequate for the job, this is best conveyed - if necessary - to the Supervisor confidentially, Controllers must be sure of their grounds for complaint.

10.3.1.6 FURTHER INSPECTION PROGRAMMING

Inspection results will give rise to further instructions from onshore, especially when Q.A. systems are in operation.

Controllers should try to be aware of the likely ramifications of results, to discuss objectives and actions with onshore staff, and to relate future instructions logically to previous activities.

Some systems make this easy, but there is no substitute for the keeping of Controller's logs and personal notebooks.

10.3.1.7 DIVE CONTROL

The safety and conduct of the dives are the legal responsibility of the Supervisor. He must decide when sea and weather conditions or any other situation prevent diving.

In doing this he must take his company's standing instructions into account.

10.3.1.8 CONTROLLER AND DIVER CHANGEOVERS

Controllers may change shifts at times different from those of the divers, and inspection tasks may continue throughout several dives. Whatever the occasion, every effort should be made to secure continuity of the workscope.

Controllers should arrive before their shift starts, and provide coherent handover notes or instructions to their successors at their shifts' end. They should also familiarise themselves with the general progress of the inspection programme as it develops, especially when returning from leave.

10.3.2 PRE-PROGRAMME PLANNING

10.3.2.1 BASELINE SURVEYS

A baseline survey is one which establishes the exact condition of a structure at a given point in time, against which all further changes can be compared and their extent and severity ascertained.

The term baseline has been applied to that survey carried out prior to the float-out and installation of a structure. This is a very valuable exercise because it establishes the actual finished form of a structure after fabrication.

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However, correctly, the term baseline is applied to the initial survey performed just after installation, when the greatest stresses and potential damage have occurred to the structure.

An exhaustive baseline survey is extremely important, as from it all the subsequent inspection programmes are formulated.

10.3.2.2 SPREAD MOBILISATION

When an inspection spread is mobilised all equipment should be thoroughly checked to ensure that the correct amount of the right equipment has been supplied and that it is all in good working order.

Charging schedules for items such as bathycorrometers and wall thickness meters should be established so that charge status of the pieces of equipment is known when they are put in the water.

10.3.3 DIVE PLANNING

The planning of dives offshore by Inspection Controllers is performed very much intuitively. Experience largely determines what weighting is given to the various factors involved. These may be examined as follows:

10.3.3.1 TASK PRIORITY, ACCESS AND DURATION

Task priority will often be set initially by the onshore engineering department. Thereafter the most complex tasks are best tackled first, particularly where data sent ashore may result in further inspection being authorised, as delays caused to the relocation of dive stations or by return to a previous site can be very time consuming.

Access to worksites is usually easy for DSVs, as installation staff are well informed of their high day rate. This in itself may cause access difficulties for air dive spreads, either vessel or platform mounted, since no work can be done which would endanger saturation divers below. Moreover, air diving is not always given precedence over other platform functions.

Whenever possible Controllers should try to make an estimate of the duration of any task, as this will allow better scheduling, prevent undue disruption of platform routine and obtain maximum co-operation from staff.

Scheduling is also important regarding quality control, since data can become messy if a task is completed in several stints at different times by different divers. This is particularly relevant to vessel-mounted air diving systems where access is variable.

10.3.3.2 EQUIPMENT

Although the diving contract may stipulate the presence of all equipment necessary to carry out every inspection task, in practice some items may not be available on time from the manufacturer, some may be missing because of bad control by the contractor, and some may require some preparation time offshore.

The Controller must take these conditions into account when planning dives; the need for forward planning is obvious.

10.3.3.3 MULTI DIVER OPERATIONS

Most commonly one task per dive period is performed, using one or two divers. Sometimes two separate tasks may be undertaken using a diver each. Every precaution must be taken to ensure that the divers do not endanger each other with tools or equipment and that each can be adequately supervised from the surface. This is primarily the responsibility of the diving supervisor.

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Controllers should try not to schedule more than one inspection task at the same time, since they cannot be properly covered regarding data recording and control.

10.3.3.4 DIVER QUALIFICATIONS AND TRAINING

Diving contracts stipulate the number of divers with given qualifications to be provided at any time. In practice numbers are often short, and controllers will have to take this into account when scheduling tasks.

Providing the Operator is in agreement, certain allowances may be made: moderately skilled and experienced divers may be used for many tasks if they are carefully briefed and monitored, while the appropriately qualified divers may be reserved for weld inspections and MPI.

This will also allow divers to gain valuable experience which is becoming mandatory for receiving certain qualifications. Care must be taken, however, to ensure time is not wasted.

10.3.3.5 DECOMPRESSION SCHEDULES

Decompression schedules differ between diving companies. Some disapprove of surface decompression: in-water decompression may delay diver changeovers. Most companies have rules regarding "free time" during decompression, before which no diver changeout is allowed, depending on the number of unoccupied chambers available.

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Controllers must be conversant with each company's schedules and rules, and plan to minimise waiting time. Where this is inevitable, preparatory deck work, maintenance, etc. may be carried out, providing there are enough dive crew members.

Saturation decompression is a complex procedure carried out to the complete dive system or sections of it, for the purpose of changing working depth or bringing men to the surface. It is costly and time consuming. Some dive companies will not allow upward excursions from the bell depth (equivalent to decompression). Controllers must therefore be extremely careful to schedule tasks working from shallow to deep, or as guided by the Superintendent and Diving Representative, and to ensure completion of all tasks at any depth before moving to another.

10.3.3.6 DIVE ROTAS AND WORKSHIFTS

Each Supervisor will establish a rota to give each diver an equal chance to dive throughout his time offshore, since all men may not be used during each shift. Though Supervisors are usually prepared to reorganise where necessary, Controllers should avoid this if possible to keep friction to a minimum.

Unlike other jobs carried out on platforms, diving usually does not stop for meals, and is a very busy activity during the 12 hour or tidal shifts. Most divers and supervisors are very co-operative about stretching into the next shift where necessary to finish a task, but this should never become the norm. Divers are entitled to go off shift, to eat, relax and sleep like anyone else. Overrunning will only shorten their off-time, cause friction and diminish co-operation. Careful task scheduling will avoid this.

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10.3.3.7 CONTINGENCY PLANS

Controllers should endeavour always to have a clear plan of action for their shift, or a series of shifts, and also a backup plan or plans of action in case inspection does not proceed as expected.

Not having a back-up task when a certain diver is employed and the primary inspection equipment fails, can result in wasted dive time especially when interfacing with other critical tasks.

Being prepared in this manner necessitates having to hand all the required paperwork, briefing aids and equipment for alternative activities.

10.3.4 DIVE BRIEFING

Briefing of the dive crew by the Controller is one of the most important aspects of his work offshore. He cannot expect his wishes and methods of working to be automatically understood by others.

10.3.4.1. BEGINNING OF CONTRACT BRIEFING

Good briefing starts here, either by the Controllers alone or together with the Diving Representative.

After introductions, basic topics to be covered are:

- the reasons for inspection - new divers may be present.
- the type of inspection results expected.
- the programme workscope.
- responsibilities.

10.3.4.2 PRE-DIVE BRIEFING

The success of a dive is often proportional to the content of the pre-dive briefing. Not only should the diver be conversant with his task, but so should the Dive Supervisor and any deck crew who are required to lower equipment. Marine crew should also be briefed so that any necessary vessel moves can be incorporated and the Officer of the Watch knows where the diver is likely to be should an emergency occur.

What, why, when, where and how are the questions of the diver that should be satisfied.

The explanation of his task should be presented in such a manner so that it is not confusing, ambiguous or conflicting. However, it should also be concise with key points raised so that it is known which task has the highest priority and requires greatest input.

In underwater inspection, tasks are often repetitive between sites and are standard tasks well known to the diver. The difficulty is often positioning the diver at the correct site. To ensure that this is done, well labelled, easily understood diagrams are essential and previous photographs of what he is likely to find or models are invaluable.

Equipment requirements should also be explained so that these can be carried to the site or deployed in the most efficient manner.

The diver should always be encouraged to fully explain his findings at the worksite. A disinterested diver may not bother to report findings which to him are of no consequence, but may be essential to the survey being carried out.

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Terminology should be established and standardised.

Occasionally dive contractors may require written instructions to be issued, and there may be a few standing orders by the Controllers. These should be absolutely accurate and clear as to their application and scope.

10.3.5 TASK MONITORING

It is the duty of the Inspection Controller to keep all informed of the progress of the job. Planning of vessel movements, onshore financial constraints, saturation living depths etc, are a few of the constraint conditions which can be affected.

10.3.5.1 SHIFT BRIEFING

Offshore Representatives should be informed by the Inspection Controller at the beginning of a shift of the situation to date as he understands it and the intended work for the shift. A progress report during the shift and an end of shift work achieved debrief is also necessary. In this way, full knowledge of progress is ensured and problem areas can be highlighted.

10.3.5.2 WORKSCOPE COMPLETION

Diagrams of work completed are useful for showing to the Company Representative and Diving Supervisors.

Check charts in dive control which have to be ticked off or coloured in as tasks are completed, are invaluable for showing progress and preventing items of the workscope being missed.

In all cases, a separate master file of the workscope or a task code listing, is to be kept with any additional workscope items added as the job progresses.

This is to be updated continuously to allow identification of job completion and progression.

10.3.5.3 QUALITY ASSURANCE (QA)

Q.A., correctly implemented, is a complete, closed-circuit system of criteria creation, condition monitoring, engineering analysis and maintenance.

Offshore Q.A. depends upon the accurate assessment of task content, correct inspection technique, data validation and comparison with established criteria, and unambiguous recording.

Subsidiary feedback circuits within the system may direct Inspection Controllers to pursue further tasks limited in application and extent.

"Clean" data acquired by this means can be subjected to onshore analysis and further inspection or appropriate maintenance authorised.

Q.A. in conjunction with Operations Analysis will allow tasks to be assembled in order of priority and residual parts of a workscope to be transferred to subsequent inspection programmes without loss of identity.

10.4 CONTRACTUAL ASPECTS

10.4.1 CONTRACT TYPE

Contracts are characterised by two factors: duration and price.

Contracts are normally either fixed price or day rate. Fixed price contracts usually require an agreed amount of work to be performed at fixed cost.

A day rate contract runs until the specified work is completed or until the operator terminates the programme.

Fixed price contracts are favoured from a cost-control aspect by Operators, and are most readily taken up when competition between contractors is keen. They can, however, have serious implications on both the operator and the contractor. Either way the economics of fixed price contracting is often questioned by both parties. Open ended day rate contracts are, therefore, generally favoured at present by both operators and contractors.

Day rates paid by the Operators may be applied to either the entire spread or separately to resources itemised in the contract: vessel including crew; additional vessel equipment (navigation/positioning equipment); basic diving system; additional diving equipment (extra chambers, compressors, etc); individual items of job-related equipment and plant (hydrojet systems, photographic gear, inspection instruments etc); individual personnel (divers, supervisors, superintendent, technicians, representatives, controllers). Some consumables may be provided "free" by either side; most are billed at cost plus percentage by the contractor.

Whether a contract is fixed price or open ended, inspection quality can suffer unless good QA/QC principles are adopted. Operations analysis and reporting is essential to ensure the most cost effective approach is taken in the long term.

10.4.2 SPREAD CHOICE

Inspection programme contracts are invariably awarded to principal diving and vehicle contractors to operate individual spreads at particular installations.

Three major types of spread are available: remotely operated vehicle, air diving and mixed gas/saturation diving. All may be platform or vessel based.

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ROVs offer a number of attractive advantages to Operators: the spreads are compact, easily deployed and require little disruption of platform or vessel services. They use fewer personnel than diving spreads, and health and safety risks are virtually nil. Many ROVs can operate in sea conditions where divers cannot. Though system costs are high, day rates are relatively low.

The major disadvantages of ROVs are their inability so far to perform close visual inspections and NDT. They are, however, able to inspect large areas of a structure in complete safety, carrying out cathodic potential and wall thickness readings, debris, scour and gross physical damage surveys.

Air diving systems are plant and personnel intensive, and occupy large areas. Though day rates are relatively low, these are offset by the disruption to platform operations and catering. Air diving is very weather sensitive and limited by law to -50m maximum depth. As diving safety regulations become more stringent and decompression times longer, the proportion of productive work-time is reduced.

However, air diving is the only current method of carrying out close visual inspection and complex manipulative work down to about -30m, above which mixed gas/saturation diving becomes tricky.

Mixed gas/saturation systems are indispensable for all operations requiring visual acuity and manipulative tasks below -50m. They are also increasingly used economically in place of air diving up to -30m, since their inevitable presence for deep work and high day rates guarantee them access to platforms, when they are able to work speedily without the need for decompression, and with less weather down time.

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Operators' underwater inspection departments take these utilisation factors into account when planning the inspection workscopes and optimising contracts for available spreads. The conventional approach at present is to perform the maximum amount of general inspection early in the summer season by means of ROV; to use platform or vessel mounted air diving spreads on an open-ended basis to perform as much inspection as possible down to about -40m; to use a DSV as soon as weather conditions economically permit for all work below -50m and, with careful scheduling, up to approximately -30m.

This approach will be modified by any construction or maintenance work which must be done: DSV or air spreads may profitably be used while awaiting delivery of structural components; or conversely may need to be augmented by ROVs or other spreads because of workload.

10.4.3 INSPECTION TECHNIQUES

Operators are continuously seeking more efficient and objective means of performing underwater inspection. Incorporation of new techniques into programmes is however a very slow process. There is a general reluctance to allocate time offshore to relatively untried techniques; equipment may be costly and in short supply; and the necessary trained personnel may not be available. Operators continue to rely on the well tried methods of visual inspection, magnetic particle inspection, and digital and 'A'-scan ultrasonics for wall thickness measurement and flaw detection.

10.4.4 EQUIPMENT AND PERSONNEL SPECIFICATION

Inspection contracts invariably specify the types and amount of equipment to be provided by the contractor for performing inspection tasks. This is because different makes of the same nominal equipment have been found to differ in performance and reliability, and programmes cannot be held up waiting for replacements.

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Even quite simple inspection tasks require a good deal of experience to obtain consistent and reliable results and some equipment needs trained operators. Contracts, therefore, specify the training and experience levels (and numbers) of underwater inspectors to be provided by the contractor. Some latitude in these is allowed in practice because of the difficulties in obtaining suitable inspector divers, and the workscope may inevitably become modified.

Currently CSWIP inspection qualifications are the most commonly required in UK waters, and DnV in the Norwegian sector. These have in fact recently by agreement become interchangeable.
Some Operators, hold their own indexes of approved qualified diver inspectors who are allowed to work on their installations.

Other qualifications are Lloyds and ASNT (American Society for Non-Destructive Testing).

10.4.5 EQUIPMENT AND CONSUMABLE INVENTORIES

It will be the Company Representative's duty to inform the Onshore Representative or Engineer, of equipment status with regard to its chargeability to a contract. However, Inspection Controllers are often the most familiar with operations and should report to the Superintendent/Representative any equipment failures that come to their notice. In this way, critical equipment for future tasks can be replaced to maintain a ready inventory of equipment and consumables. This will allow the exact status of items such as MPI units, to be known in order that they will not run out.

11. OBSERVATION, DESCRIPTION, INTERROGATION AND COMMUNICATION SYSTEMS

11.1 INTRODUCTION

The quality of subsea inspection depends greatly on the ability of the diver inspector/ROV observer to report what he finds at the point of inspection. To further improve the quality of this data, the data recorder/inspection controller can elicit the maximum information by intelligent questioning. A knowledge of the structure, the inspection method being used, type of defect expected and the professional ability of the inspector can also benefit the data gathering process. This section serves to discuss and highlight the methods available and how their use can improve the quality of the data gathered.

11.2 COMMUNICATION SYSTEMS

Subsea inspection is carried out either by a diver at the point of inspection on the end of an umbilical or by an ROV. The process of communicating with the diver depends greatly on the system and the breathing medium used by the diver. The distortion of sound due to the helium environment requires time and practice to to get used to. Due regard must be made for this and the use of standard terminology, standard phrases and the phonetic alphabet by all parties will eliminate or reduce the risk of confusion.

11.2.1 OPERATIONAL CONSIDERATIONS

It is the Inspection Controller's responsibility to ensure that the quality of the communications is satisfactory for the task in hand. Generally speaking it does not take long to correct bad air diving comms by changing out comms boxes, batteries etc so good quality can be achieved quite quickly. With saturation diving the problem areas can be more diverse and lead to correspondingly longer repair times. Once the quality of comms is reckoned to be deteriorating, provision should be made to have the system checked during bell turn arounds.

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Most comms systems utilize a press-to-talk facility. The Inspection Controller must be aware of the fact that whilst the press to talk facility is being used the diver cannot talk to the surface. All communications should be kept short. This will enable the diver to question points as they arise and not have to ask for everything to be repeated. The diver will also maintain a steady breathing pattern and be able to communicate with the supervisor on matters of safety.

Comms are available which utilize the "round robin" system which enables both parties to talk at the same time.

The Inspection Controller may need to use radio telephoning when communicating between:

vessel to platform
vessel to vessel
vessel to shore

Two systems are used for RT communications. A "simplex" arrangement whereby only one party can transmit at any one time and a "duplex" arrangement where both parties can talk at the same time.

The three frequency ranges used are:

(1) Long range high frequency (HF) world wide service. (In UK - through Portishead Radio).

(2) Medium frequency (MF) which has a range of about 200 miles.

(3) Very high frequency (VHF) which has a range limited to little more than the line of sight between aerials and 35-40 miles between coastal shipping and coastal radio stations. It is the system most used by offshore installations. UHF is occasionally used in place of VHF to avoid interference in busy areas. UHF is suitable for walkie-talkies.

11.2.1.1 <u>VHF Call Procedure</u>

Make sure that you know:

- how to operate the radio/telephone.
- to whom you are speaking.
- on what frequency to transmit.
- and be prepared for any possible questions.

(1) Turn on your receiver to Channel 16 and listen before calling. If the channel is engaged wait until it is free.

(2) Transmit the name or Call Sign of the station that you are calling (up to three times only).

(3) Transmit the words, 'This is', and then:

(4) Transmit the name or Call Sign of your own station (up to three times only).

(5) When contact is established:

- transmit your own name or Call Sign once.
- nominate your working channel/frequency and ensure that the other station has that particular channel facility.
- transfer to your chosen working frequency.
  NOTE: Do not use channel 16 for working dialogue.
- transmit, 'How do you hear me? Over'.
- wait for response, 'I hear you loud and clear/weak but clear/loud but distorted', etc.
- deliver message.

(6) If you require an answer or continuation with the conversation, end your transmission with, 'Over'. If you do not require an answer or continuation of the conversation use, 'Out'.

(7) Use the phonetic alphabet for spelling difficult or unusual words.

(8) Use prowords (procedure words) wherever possible.

(9) On completion of transmission return the radio channel selector to '16'.

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11.2.1.2 VHF Operating Technique

Always give precedence to distress or urgent calls.

Do not jam channels with unnecessary conversation.

Avoid interrupting.

Avoid swearing.

Try not to say 'er' or 'um' between phrases.

Speak steadily and at a medium speed.

Speak only slightly louder than normal conversation.

Always keep your mouth close to the microphone.

Pitch your voice slightly higher than usual.

There are a variety of short phrases or words that make conversation easier. These are called PROCEDURE WORDS OR PROWORDS.

Contents

PROWORDS (Procedure Words)

PROWORD	Use of Meaning
MAYDAY (3 times)	The distress signal; used when threatened by grave or imminent danger; a request for immediate assistance. (Remember your call sign and position are of vital importance and should follow the proword 'Mayday').
PAN (3 times)	The urgency signal; used for a message concerning the safety of a ship or of a person. If you require medical assistance ask your coast radio station for Medico Service and you will be connected to the casualty department of a local hospital (no charge).
SÉCURITÉ (SAY CURE EETAY) (3 times)	The safety signal; mostly important navigational or metereological warnings. (Usually originate ashore).
Acknowledge	Have you received and understood this message?
Affirmative	'Yes' or 'Permission granted'.
All after	To identify part of a message.
All before	Used in conjunction with other words.
Break	Separation between address/text/signature of a spoken telegram.
Confirm	My version is .... is that correct?
Correct	You are correct.
Correction	Cancels the word or phrase just sent or indicated.
Go ahead	Proceed with your message

PROWORD	Use or Meaning
How do you read?	Can you understand what I am saying?
I read back	In response to 'Read back'; the message already sent then follows
I say again	When conditions are bad it is used by the sender to emphasise the important areas, or when a repetition is requested.
I spell	Used when spelling out a word or abbreviation.
Negative	'No' or 'Permission not granted'.
Net message	Message for all stations.
*Out	Transmission over and no reply expected.
*Over	Transmission over but a reply is expected.
Read back	Please repeat back the whole message.
Roger	Message received and understood.
Say again	Used by receiver when requiring the whole message to be repeated.
Seelonce	All stations maintain a radio silence and await direction.
Seelonce fini	Silence is lifted.
Wait	The station requires to consider the reply to transmission. 'Wait' followed by a number indicates the time (in minutes) required to consider.

*NOTE: The combination 'Over and Out' is contradictory and should never be used.

Contents

11.2.1.4 **STANDARDISATION OF TERMINOLOGY**

The correct terminology must be used in all inspection. This will encompass all aspects such as structural components, reference systems, weld inspection terminology etc.

11.2.1.5 **UNITS OF MEASUREMENT**

All units of measurement will be in SI units unless specified otherwise by the client. The International System of Units (SI) is in use throughout the scientific and industrial world.

The SI is based on seven units:

1. The metre (m) is the unit of length.
2. The kilogram (kg) is the unit of mass.
3. The second (s) is the unit of time.
4. The ampere (A) is the unit of electric current.
5. The kelvin (K) is the unit of thermodynamic temperature.
6. The mole (mol) is the unit of the amount of substance.
7. The candela (cd) is the unit of luminous intensity.

Other SI units are called derived units, formed by combining base units according to their corresponding physical properties. Some of these are described below:

Note: all symbols are written in lower case roman type, without full points and without any plural form (never hs for hours). The exception to this rule is when the symbol is taken from a proper name, ie. W for Watt. Symbols written in italics are physical quantities, ie. g = gravitational acceleration.

Contents

When a unit for a physical quantity is divided by a unit for another physical quantity, an oblique line (solidus) may be used, or the denominator may be expressed to the appropriate negative power, for example, m/s or ms^{-1}.

Quantity	SI Unit	Symbol
Area	square metre	m^2
Volume	cubic metre	m^3
Velocity, Speed	metre per second	m/s or ms^{-1}
Acceleration	metre per second squared	m/s^2 or ms^{-2}
Moment of force	newton metre	Nm
Mass per unit length	kilogram per metre	kg/m
Density	kilogram per cubic metre	kg/m^3

The following derived units have special names and symbols:

Quantity	Name	Symbol	Expressed in terms of: Other SI units	Expressed in terms of: SI base units
Activity (of a radio-active source)	bequerel	Bq		s^{-1}
Quantity of electricity (electric charge)	coulomb	C		A^3
Electrical capacitance	farad	F	C/V	$s^4A^2(m^2kg)$
Inductance	henry	H	Wb/A	$m^2kg/(s^2A^2)$
Frequency	hertz	Hz		s^{-1}
Energy, work, quantity of heat	joule	J	Nm	m^2kg/s^2
Luminous flux	lumen	lm		cd sr
Illuminance	lux	lx	lm/m^2	$cd\ sr/m^2$
Force	newton	N		$m\ kg/s^2$
Electrical resistance	ohm		V/A	$m^2kg/(s^nA^2)$
Pressure	pascal	Pa	N/m^2	$kg/(ms^2)$
Electrical conductance	siemens	S	A/V	$s^3A^2kg)$
Magnetic flux density	tesla	T	Wb/m^2	$kg/(s^2A)$
Electrical potential difference	volt	V	W/A	$m^2kg/(s^nA)$
Power	watt	W	J/s	m^2kg/s^n
Magnetic flux	weber	Wb	Vs	$m^2kg/(S^2A)$

Contents

There are other units, not themselves SI units, which are often used in conjunction with them.

minute(min)(of time)	degree(°)(of angle or temp.)
hour(h)	minute(′)(of angle)
day(d)	second(″)(of angle)
litre(l)	tonne(t)
bar(b)	nautical mile(nm)
atmosphere absolute(ata)	

Prefixes

In SI there is only one unit for each physical quantity, eg. the metre for length. If a unit seems too large or small, a multiple should be used, called a prefix.

Prefix	Symbol	Factor by which unit is multiplied	
mega	M	1 000 000	$= 10^{6}$
kilo	k	1 000	$= 10^{3}$
hecto	h	100	$= 10^{2}$
deca	da	10	$= 10^{1}$
deci	d	0.1	$= 10^{-1}$
centi	c	0.01	$= 10^{-2}$
milli	m	0.001	$= 10^{-3}$
micro	μ	0.000 001	$= 10^{-6}$

There are some symbols which might be ambiguous. The symbol for litre is l. This is often confused with the numeral 1. The symbol for the metric tonne is t, which is often used for imperial tons. In such cases confusion can be avoided by spelling out the whole word, litre or tonne.

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11.2.1.6 **PHONETIC ALPHABET**

The phonetic alphabet should be used for spelling difficult or unusual words.

PHONETIC ALPHABET

A	Alpha	ALFAH	N	November	NOVEMBER
B	Bravo	BRAVVOH	O	Oscar	OSSCAR
C	Charlie	CHARLEE	P	Papa	PAHPAH
D	Delta	DELLTAH	Q	Quebec	KEHBEK
E	Echo	ECKOH	R	Romeo	ROWMEOH
F	Foxtrot	FOKSTROT	S	Sierra	SEEAIRRAH
G	Golf	GOLF	T	Tango	TANGO
H	Hotel	HOHTELL	U	Uniform	YOUNEEFORM
I	India	INDEEAH	V	Victor	VIKTAH
J	Juliet	JEWLEEETT	W	Whiskey	WISSKEY
K	Kilo	KEYLOH	X	X-ray	ECKSRAY
L	Lima	LEEMAH	Y	Yankee	YANGKEY
M	Mike	MIKE	Z	Zulu	ZOOLOO

NUMERALS
Apart from Call Signs and Grid References all figures should be preceded by the word 'Figures'

0	ZEERO	5	FIVER
1	WUN	6	SICKSER
2	TOO	7	SEHVEN
3	THUH-REE	8	ATE
4	FOW-ER	9	NINER

11.2.1.7 ALTERNATIVE SYSTEMS

Alternative lines of communications are telex, telephone and facsimile transmission. All three provide a secure form of communication and should be used whenever sensitive information needs to be discussed. Facsimile transmission is extremely useful for the speedy transfer of diagrams or text.

The Inspection Controller should have the ability to produce a precis of a report including a diagram for insertion into a telex. The report would be used for the initial evaluation of defects, from which further inspection could be identified.

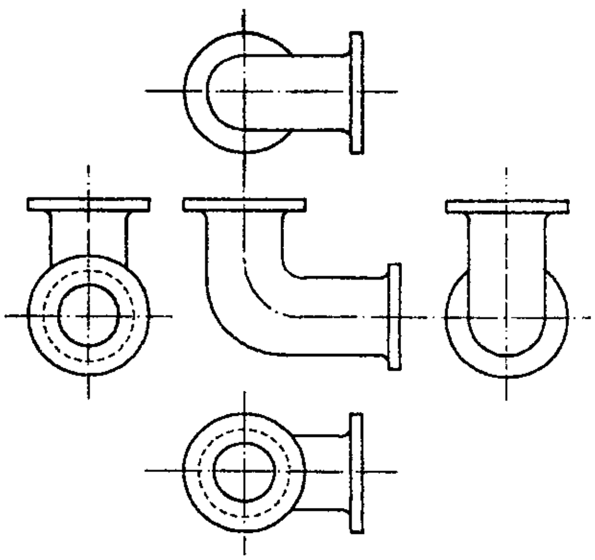
11.3 ENGINEERING DRAWINGS

Engineering drawings are produced in many projection formats. The formats as defined in BS.308 and BS.1192 are axonometric, cabinet, cavalier, dimetric, first angle, isometric, oblique, orthogonal, orthographic, plarometric, third angle, and trimetric.

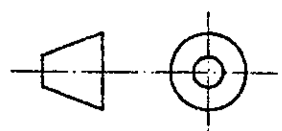
Two systems of projection, first angle (European) and third angle (American) are approved internationally and are regarded as being of equal status. These together with isometric projection will be the most commonly found formats.

11.3.1 FIRST ANGLE

In first angle projection each view shows what would be seen by looking on the far side of an adjacent view.



PIPE BEND, FIRST ANGLE PROJECTION



DISTINCTIVE SYMBOL FOR FIRST ANGLE PROJECTION

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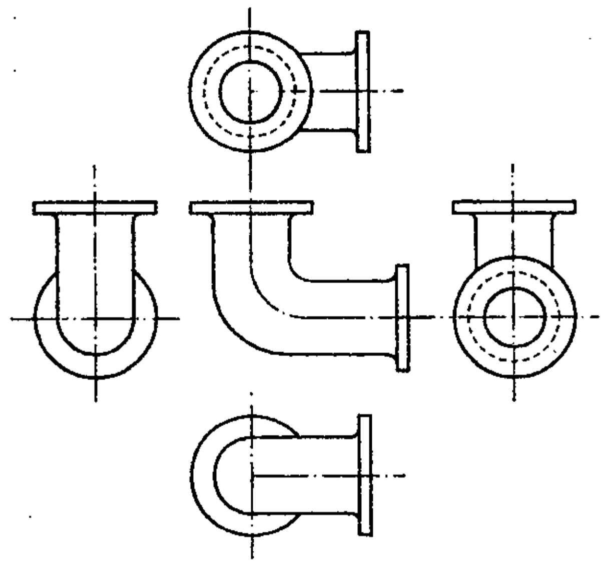
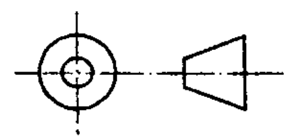
11.3.2 THIRD ANGLE

In third angle projection, each view shows what would be seen by looking on the near side of an adjacent view.





DISTINCTIVE SYMBOL FOR THIRD ANGLE PROJECTION

PIPE BEND, THIRD ANGLE PROJECTION

11.3.3 ISOMETRIC

In isometric projection, each of the three co-ordinate axes is inclined at the same angle to be projection plane. The projection of the Z axes vertical, and the projection of the X and Y axes are at 30° above the horizontal.

Contents

11.3.4 DRAWING PRODUCTION/INTERPRETATION

Drawings should be complete for their respective purposes either by themselves or with regard to the information they impart when read in conjunction with other relevant information.

A drawing conveys information graphically and annotation on drawings should be kept to the minimum necessary to meet its intended purpose.

11.3.4.1 TITLING

Titles should be concise but should accurately identify the contents of each sheet. The terminology used in titling should be consistent.

11.3.4.2 NUMBERING

A drawing number can indicate the location of a drawing in a sequence in order to facilitate filing and referencing. It can also be extended to aid the search for data, by the use of codes.

11.3.4.3 KEY DIAGRAM

The key diagram will indicate on the drawing the part of the project covered by that particular drawing sheet.

11.3.4.4 REVISION OF DRAWINGS

A short description of each revision should be provided under consecutive revision letters, within a space adjacent to the title panel. The date of revision should also be recorded.

Contents

11.3.4.5 TITLE AND INFORMATION PANEL

Each drawing should have a title and information panel. The title panel will normally occupy the lower right hand corner of the drawing with the information panel adjacent to it.

The title panel should contain essential information required for the identification and interpretation of drawings, as follows:

a) Project Title
b) Drawing Number
c) Drawing Title
d) Description of Projection or Projection Symbol
e) Scale
f) Date of drawing
g) Office of origin
h) Office project number
i) Identity of persons carrying out the draughting

11.3.4.6 LINES

Lines of differing thickness are used to facilitate the reading of a drawing. The following table shows the types of line used, their application, thickness and proportion.

TYPES OF LINE

EXAMPLE	TYPE OF LINE	LINE WIDTH (mm)	EXAMPLE OF APPLICATION
A	CONTINUOUS (THICK)	0.7	VISIBLE OUTLINES AND EDGES
B	CONTINUOUS (THIN)	0.3	FICTITOUS OUTLINES & EDGES DIMENSION & LEADER LINES HATCHING OUTLINE OF ADJACENT PARTS OUTLINES OF REVOLVED SECTIONS
C	CONTINUOUS IRREGULAR (THIN)	0.3	LIMITS OF PARTIAL VIEWS OR SECTIONS WHEN THE LINE IS NOT AN AXIS
D	SHORT DASHES (THIN)	0.3	HIDDEN OUTLINES AND EDGES
E	CHAIN (THIN)	0.3	CENTRE LINES EXTREME POSITIONS OF MOVEABLE PARTS
F	CHAIN (THICK AT ENDS & AT CHANGES OF DIRECTION, THIN ELSEWHERE)	0.7 0.3	CUTTING PLANES
G	CHAIN (THICK)	0.7	INDICATION OF SURFACES WHICH HAVE TO MEET SPECIAL REQUIREMENTS

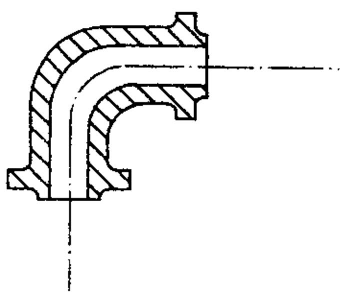
Contents

11.3.4.7 LETTERING

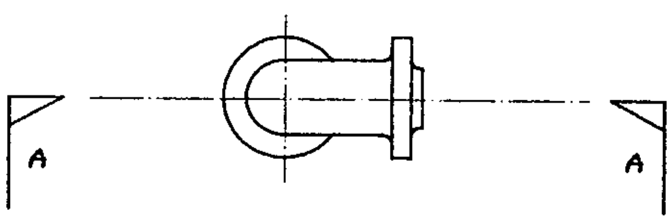
Characters should be uniform and either produced by hand, stencil or machine. The style of lettering should be uniform and capital letters are preferred to lower case. Lower case letters may be used where they are part of a standard symbol, code or abbreviation.

11.3.4.8 SECTIONING

Where sectioning is shown on a drawing, the cutting plane should be indicated by long chain lines, thickened at the ends and at changes of direction, thin elsewhere and should be designated by capital letters. The direction of viewing being shown by arrows resting on the cutting line.



SECTION A-A



SECTION IN ONE PLANE

APPENDIX I - REFERENCES

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Petroleum and Submarines Pipelines Act - 1975

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Offshore Installations: Guidance on Design and Construction - 1984.

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BS 499 Part 3, Terminology of and Abbreviations for Fusion Weld Imperfections.

BS 5289 Visual Inspection of Fusion Welded Joints.

BS 6072 Method for Magnetic Particle Flaw Detection.

BS 4069 Magnetic Flaw Detection Inks and Powders.

BS 5044 Contrast Aid Paints Used in Magnetic Particle Flaw Detection.

BS 4489 Method for Assessing Black Light Used in Non-Destructive Testing.

BS 3683 Glossary of Terms Used in Non-Destructive Testing, Part 2; Magnetic Particle Flaw Detection.

BS 4360 Specification for Weldable Structural Steels.

BS 4397 Methods for Magnetic Particle Testing of Welds.

BS 89 Specification for Direct Acting Indicating Electrical Measuring Instruments and their Accessories.

BS 2597 Glossary of Terms Used in Radiography.

BS 2704 Calibration Blocks and Recommendations for their Use in Ultrasonic Flaw Detection.

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ISBN 0-7176-0848-4

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