Course notes for use with TWI Underwater Inspection Grade 3.3U & 3.4U Courses

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CHAPTER 1

INTRODUCTION TO INSPECTION

The basic need for inspection is to ensure that a structure or component will be able to perform its designed task safely. This will involve a need to inspect all structures regularly.

If the inspection is to be carried out underwater the only major difference to it being carried out in the air will be the cost. This will mean that there is a greater need for planning of the inspection program, so making maximum use of the personnel and time available.

As has been said all structures need to be inspected at regular intervals. The basic reasons as far as we are concerned are as follows:

a) Statutory requirements and insurance certification.
b) To ensure reliability and safety.
c) To help ensure that future structural designs improve (learn from previous mistakes).

Over the years there have been numerous occasions where machines and structures having been meticulously designed, have failed while performing tasks that should have been well within their design capabilities. In the case of offshore structures these failures will be extremely expensive in terms of lost production. They may even cost the crew their lives. The repair of the component will be far more costly than the equivalent repair carried out on a shore based installation.

There are five stages in the life of a structure, they are as follows:

a) Design. → NODE LOCATION + DATUM POINTS. eg. REFERENCE NUMBE
b) Manufacture of the raw material.
c) Fabrication of the structure.
d) Launch and installation. MOST STRESSFUL PART OF LIFE.
e) Service life.

At all stages of a structures life inspection will be carried out to some degree, in the case of an offshore structure this may progress as follows:

1. DESIGN

During the design stage previous designs will be assessed in order to try and ensure that any mistakes previously made will not be repeated in the new structure. The structure will be designed taking not of the appropriate government standards and requirements, thus the design will have some form of Quality Assurance Certificate when it is complete.

During the design stage all of the components on the structure will be assigned unique reference numbers. Also the components will have **Datum** points assigned.

Datum Points:

A datum point will be the position from which all subsequent measurements will be referenced, normally this point will be found by reference to the drawings, some structures will have the marks stamped onto them but this is not always the case in which case it may be necessary to mark the structure prior to carrying out the inspection. Typically datum points on tubular welds will be at the "Twelve O'clock position" and may be marked with punch marks as shown below:

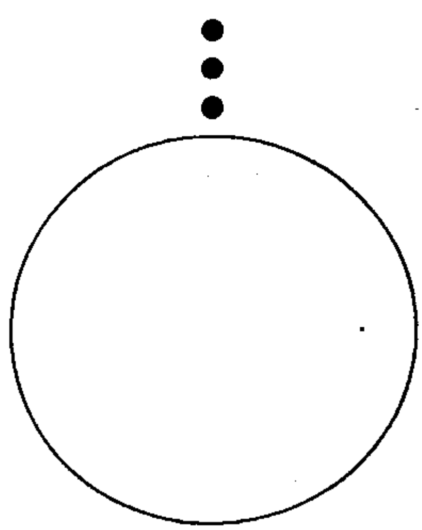

Fig 1.1 Datum points on a tubular brace

2. MANUFACTURE OF THE RAW MATERIAL

If the structure is to be made of steel then this will be made to specific requirements in terms of additives and procedures, otherwise the steel can have certain defects included, these defects are termed **inherent defects** as the structure inherits the defects from the raw material the following are common discontinuities and defects which can occur in steel:

IN PARENT PLATE.

i) Fish Tails COMMON IN OLDER STRUCTURES. LOOKS LIKE FLAKE

These are caused by the mould being too cold, the splashes solidify on contact, when the mould is full the fish tails are not fused properly to the steel.

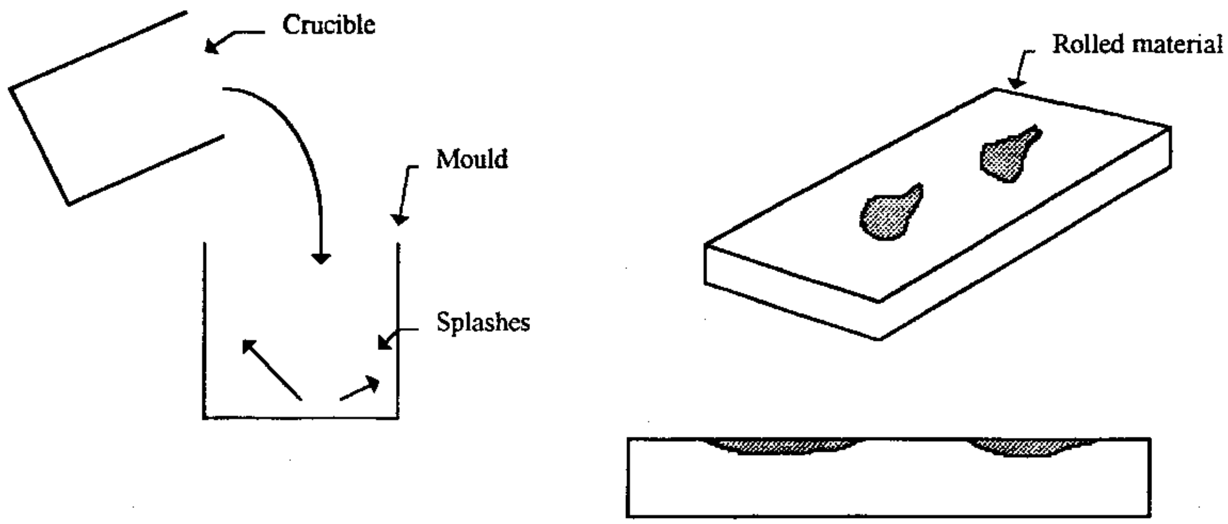

Figure 1.2 Fish Tails

ii) Laminations common.

Caused by shrinkage of the material in the mould due to poor control of cooling. As the metal cools there are tremendous forces set up pulling the material apart this results in a depression forming in the material called a pipe. This can extend right the way through the material in extreme cases, when the billet is rolled the pipe will become compressed and form a lamination.

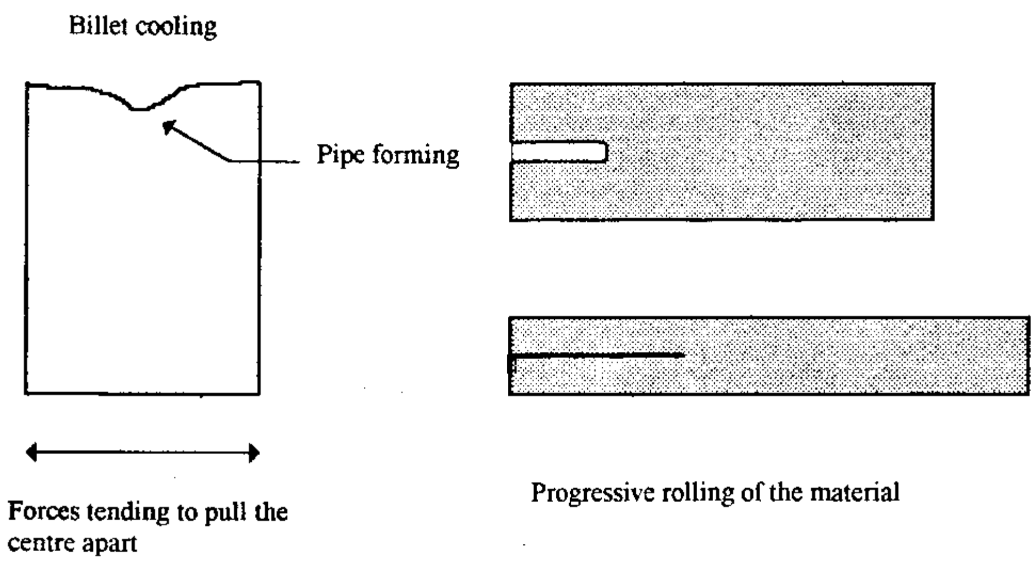

Figure 1.3 Laminations

iii) Inclusions and Porosity

If the material is not kept molten for long enough then the result is that the impurities and gas both of which are much less dense will not have time to reach the top of the material and so will become inclusions and porosity.

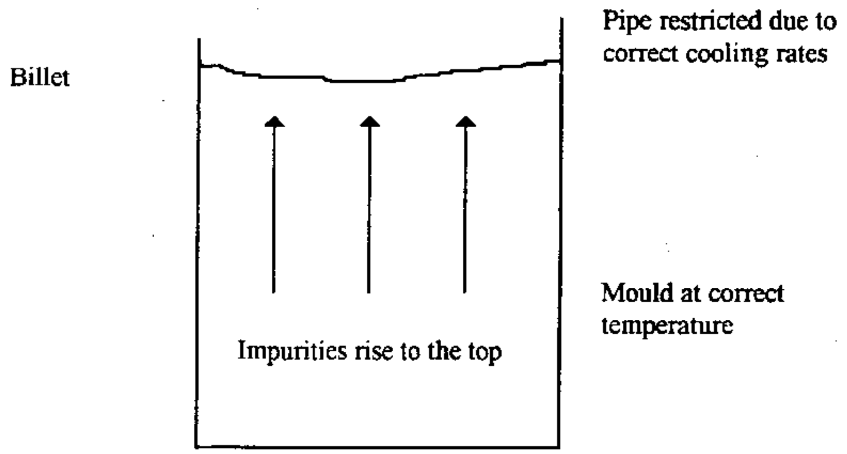

Figure 1.4 Inclusions and Porosity

Most of the above can be controlled by the adoption of good techniques. Provided that the mould is at the correct temperature, and that the material is kept hot for long enough, thus allowing it to cool at the correct rate then all of the impurities and the shrinkage should be contained at the top of the billet as shown. If the top is then cut off (this is called the hot top) then the resulting ingot of steel is of good quality and can be used.

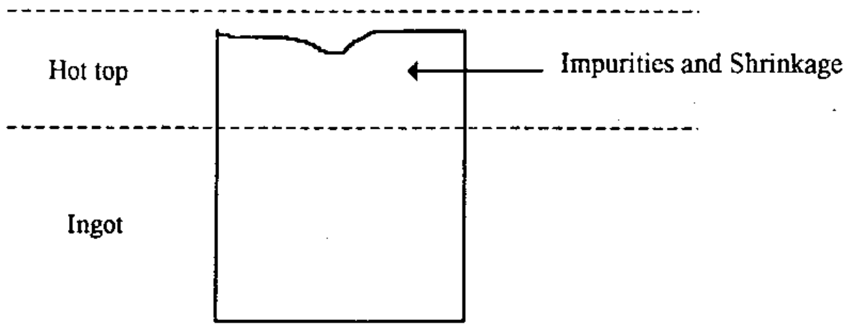

Figure 1.5 The Hot Top

Provided that the conditions are correct then the hot top will contain the majority of impurities and all of the shrinkage (pipe). If all the conditions are controlled properly and the correct additives have been made then the steel will be issued with a Quality Assurance Certificate.

3. FABRICATION OF THE STRUCTURE

Once the raw material has been selected the structure will then be built using approved methods. In the case of steel structures this means that it will be welded together with all of the possible problems which can occur from these techniques, some of the more common defects are as follows:

i) Hydrogen Embrittlement

This is sometimes called cold cracking as cracks can occur several hours after the weld has been fabricated. It is due to either damp consumables (welding rods) or welding in a damp environment. The hydrogen is liberated from the water and then is liable to dissolve into the parent plate causing the plate to become locally hardened, (usually in the heat affected zones of the welds) and so more brittle than the surrounding metal this will make it less able to flex.

ii) Metal and Internal Weld Defects

These will be dealt with in detail in the section on welding and weld defects.

iii) Residual Stress

This is stress which is locked up in the structure during the fabrication. It is due either to poor welding techniques or shoddy work practices in the fitting up of the members. Why will this be a problem? If a structural member is designed to carry a certain tensile load and the residual stress in the member is also exerting a tensile load, then the member may not be able to carry the combined load.

An example of residual stress could be a tubular welded at one end with insufficient support at the other end. When the second weld is fitted up the tubular will have to be pushed into place and so residual stress will be locked up in the tubular as shown in figure 1.6 below:

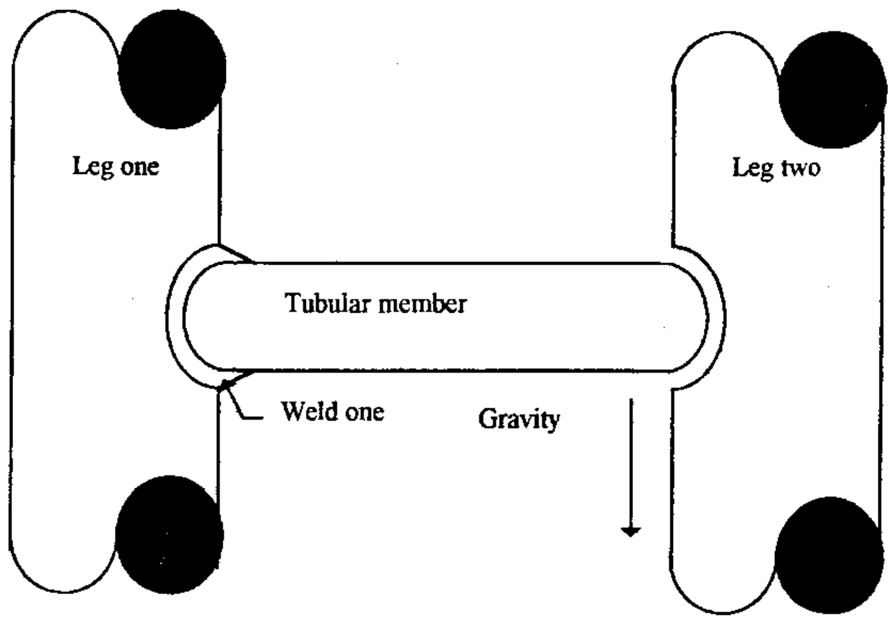

Figure 1.6 Tubular Member With only One End Welded

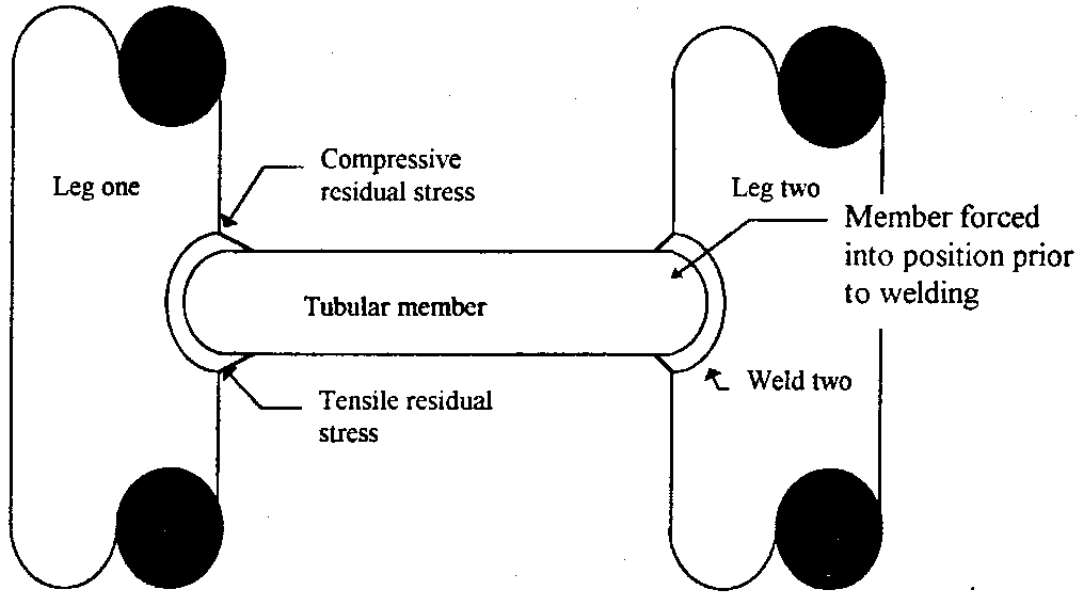

Figure 1.7 Residual Stress in a Tubular Member After Welding is Complete

iv) Machining Defects

GET HOT - BECOMES BRITTLE.

These can be caused by grinders or some other tool causing damage to the surface of the structure.

v) Accidental Damage

Dropped objects and poor crane work can cause damage.

vi) Coating Defects

Various coating defects can occur due to insufficient control of the environment and application techniques.

At the fabrication stage the structure will undergo the most stringent inspection, there are several reasons for this. One is the cost of inspection, it will cost a great deal more to inspect welds once the structure is in place and the weld is at depth. Once the weld is at depth an inspection may well involve the use of a diving support vessel with dynamic positioning and a full crew looking after a diver in saturation and this will of course cost much more that the same task done on the surface. This may just involve one man with an aerosol can and a magnet.

While the weld is being fabricated it is far more likely to suffer some defect than it will be once it has been completed. This being the case it would seem sensible to inspect every weld 100%. This is what the final operator would like as any defects would have to be put right by the fabricator at his own expense. The fabricator however would like to do no inspection at all, for obvious reasons. It is now the responsibility of the **Duty Holder**, probably the eventual owner or operator of the structure to demonstrate that sufficient inspection has been carried out to ensure - INCLUD SAFET the structures ability to perform the designed task safely. This has to be verified by an I.N.B. **Independent Verification Body** such as **Lloyds.** This system will normally result in approximately 60-70% of the structure being inspected. Even so, this is the stage in the structures life at which the most comprehensive inspection will be carried out culminating in a Quality Assurance Certificate which guarantees the structure has been built to the proper specifications, using the correct consumables, raw materials and techniques.

4. LAUNCH/INSTALLATION

The launch phase of the structures life will be the period when the stresses on the structure will be greatest. They are also very difficult to predict so quite often structures are designed to withstand the stresses involved with installation. The kind of defects that are common during the installation are as follows:

i) Accidental Damage

Due to handling of heavy objects causing dents and deformation.

ii) Residual Stress

SHOULD FLATTEN SEABED, SO ALL LEGS TOUCH SAME TIME.
Caused through setting the structure on an unstable foundation or an uneven sea-bed, etc.

iii) Piling Defects

Piling can cause the structure to be stressed violently and in some instances has caused failure of structural welds.

iv) Coating Defects

Removal of coatings damage to Monel sheathing, etc.

v) Location

It is obviously imperative that the structure is set in the right and proper place.

Once the structure has been set in place then the most comprehensive <u>in water</u> inspection will take place. This is called the post launch or post installation inspection and as such will be used as the baseline survey from which all subsequent surveys will be planned. Provided that the inspection finds no significant defects, particularly in a **Safety Critical Element (SCE).** And this inspection has been verified by an approved independent body then the structure can be used safely.

BASICALLY EVERYTHING ON STRUCT.
A **Safety Critical Element** is any part or parts of an installation and such of it's plant (Including computer programs), or any part thereof, the failure of which could cause or contribute substantially to; or a purpose of which is to prevent, or limit the effect of a major accident. Examples of Safety Critical Elements are as follows:
IE: IF GEAR FAILS (IE SOFTWARE) & CAUSES FAILURE.

Systems

Primary structure
Fire and water system
Fire and gas detection
Hydrocarbon containment

Subsystems

Mooring system
Deluge system
Control panel

Equipment

Main bearing (Mooring system)
Fire pump
Detection heads
Electrical equipment hazardous areas

5. IN SERVICE

It is very costly for an operator to have designed, built and placed a structure offshore. This investment must be recouped by the structure working for the full period for which it was originally designed. Any shortening of the life span will mean less profitability. Ultimately all of the effort which goes into placing a structure offshore should enable the structure to be used for its full designed life span. During that use the structure will inevitably start to deteriorate in the following manner:

i) Corrosion

Removal of metal due to electro chemical/biological attack.

ii) Erosion

Removal of metal due to fluid borne particles.

iii) Marine growth

This causes a variety of problems for the structure which will be detailed in the section on marine growth.

iv) Debris

This causes dents and deformation of the structure and also other problems which again will be discussed in a later section.

v) Fatigue

Caused by cyclic stress, either by the environmental hydrodynamic forces (wind and wave action) or the vibration of drilling and work on the structure.

vi) Overloading ALWAYS NEW GEAR COMING ON.

Almost all structures in the North Sea are overloaded due to the application of new techniques for oil retrieval, thus reducing the safety factor normally built in to allow for corrosion etc.

vii) Scour

This is the removal of the seabed by water current etc which will ultimately undermine the structure. This could cause failure especially in the case of concrete structures.

Because of the above it is obviously imperative that regular surveys are carried out, in order to maintain the operators investment and safe working environment for the personnel aboard. The Company must be able to demonstrate that all of the **SCE's** are in a safe condition and that any subsystems which contribute to safety remain in a serviceable condition at all times. These surveys must be verified by an independent verification body. Without this being done the structure can not be used.

LEGISLATION RELATING TO INSPECTION OF OFFSHORE STRUCTURES

In 1971 the Government brought into force the MINERAL WORKINGS (OFFSHORE INSTALLATIONS) ACT which was to provide for the health and safety of the persons working on offshore installations. The PETROLEUM AND SUBMARINE PIPELINES ACT of 1975 extended the powers of the original act to pipelines not covered previously. Using these acts the Department of Energy authorised the OFFSHORE INSTALLATIONS (CONSTRUCTION AND SURVEY) REGULATIONS 1974 (SI No. 289), these have now been revoked by **SI 913** which remains valid on existing installations until 30th June 1998. SI 289 laid down in very broad terms the minimum standards which must be employed in the design and construction of structures to be used in UK waters. The regulations call for each structure to be issued with a CERTIFICATE OF FITNESS which will be valid for up to five years. This certificate will have been issued subject to survey by one of the certifying authorities approved by the Secretary of State.

These regulations have now been superseded by **The Offshore Installations (Safety Case) regulations SI 2885 (1992)**. The **Health and Safety at Work Act** now relies on these

PIPEWORK INSP. EVERY YEAR.

ORIGINAL SI 289 EVERY 5 YEAR STILL IN FORCE TILL JULY.
NOW HSE OVERLOAF, REPLACED BY SI 913. WHICH IS ONLY TRANSITIONAL UNTIL JULY. THEN SI 2885.

regulations which are very broad based, as such they in turn rely on a further set of laws, guidance and approved codes of practice in order to ensure safety. The major Statutory instruments which support SI 2885 (1992) are as follows:

PFEER SI 743 (1995)	Prevention of Fire, Explosion and Emergency Response Regulations.
MAR SI 738 (1995)	Management and Administration Regulations
PUWER SI 2932 (1992)	Provision and Use of Work Equipment Regulations (Plant and Equipment)
DCR SI 913 (1996)	Design and Construction Regulations
PSR SI 825 (1996)	Pipeline Safety Regulations

The main aims of the above will be to reduce any risk to being **As Low As Reasonably Possible (ALARP)** ALL HAVE AN ACCEPTABLE RISK FACTOR.

As far as inspection of the structures is concerned SI 289 has been replaced by **SI 913** ([illegible]). 96. There are several differences between the old regulations and the new ones principally these are as follows:

DCR - Installations

SI 289	**DCR**
Report to regulator	Report to operator DUTY HOLDER
Prescriptive	Goal setting (SHOULD LOOK TO IMPROVE SITUAT
Predefined scope	All appropriate items. IE SOFTWARE.
Excludes wells	Independent and competent persons SOMEONE CERTI
	Includes wells

The new regulations **SI 913 (1996) & SI 2885 (1992)** rely on **Verification** rather than certification, this means that all work carried out on offshore structures must be verified by an **Independent Verifying Body (IDVB).** This requirement is in schedule 2 of SI 913, however it will eventually move to SI 2885. The regulations now call for there to be an appointed **Duty**

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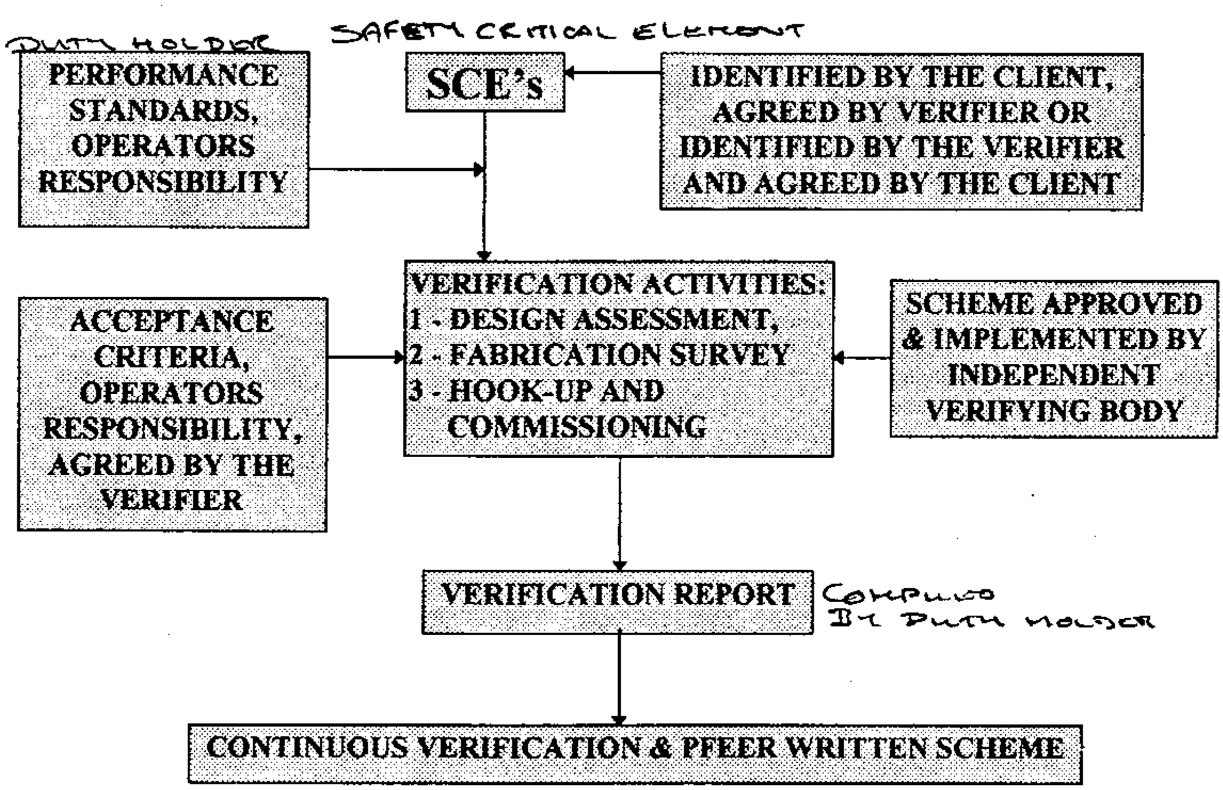
All work carried out on offshore stru. must be verified by Independant Verifying Body also IVB.

Holder who can carry out a self certification scheme. Under this scheme the duty holder will be responsible for ensuring that the structure remains in a safe condition to carry out the designed purpose, there is no statutory requirement for inspection, but the duty holder would have to prove to the **Independent Verification Body** that there is no need to inspect that particular part of the structure to ensure safety. Below is a list of the Independent Verifying Bodies authorised at this time:

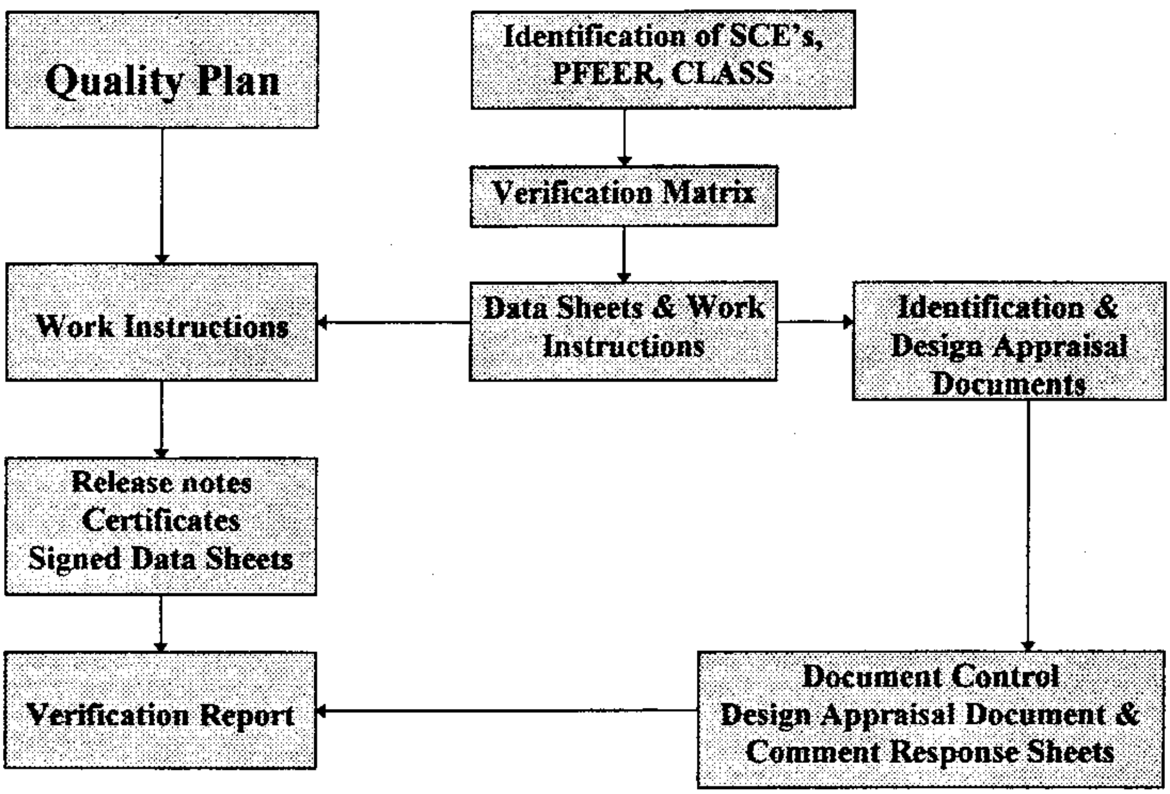
1) Lloyds Register of Shipping
2) Det Norske Veritas
3) Bureau Veritas and "COFREND"
4) Germanischer Lloyd
5) American Bureau of Shipping
6) The Offshore Certification Bureau

Used to be certifying authorities.

The above acts do not state guidelines for the survey that must be carried out, rather it is the responsibility of the Duty Holder (operator or owner) to prove that the survey proposed will ensure the safety of the structure and the personnel on board. The basis for an inspection program will normally be formulated as follows:



Prior to any structure being operated the Independent Verification Body (IDVB) and the Duty Holder will identify all of the Safety Critical Elements, these will be subjected to inspection to acceptance criteria agreed by the IDVB. The Duty Holder will then issue a quality plan including work instructions, release notes and signed data sheets. These will all be included in the Verification report, the following is an organogram showing the typical Verification and Methodology for Control:



In general the first major survey will ensure the following: BASELINE SURVEY

a) The structure is in the correct position.
b) That no significant damage has been caused during the installation process.
c) Any damage or anomalies will be located and noted in an effort to build up what will become the damage register for the structure. N.B. A damage register is a record of all damage and defects relating to the individual structure. FOR STRU. LIFE

This first major survey is sometimes called a BASELINE SURVEY and as such will be the start point for all subsequent inspections. It will normally be the most comprehensive underwater survey carried out on the structure, and will typically involve the following:

i) Complete visual inspection of all members and components.
ii) Complete visual inspection of foundations and seabed in the immediate vicinity.
iii) Cathodic potential readings.

Of course if there are any defects located then more inspection may be called for.

Once the structure has been accepted in theory there is no further need for inspection until either the Duty Holder or the Independent Verification Body identify a need. However the companies will inevitably have to carry out enough inspection to satisfy all concerned that the structure remains in good condition. The independent Verification Body could insist that operation of the structure be suspended at any time due to structural damage, major alterations or deterioration likely to impair the structures ability to carry out its designed purpose.

It is likely that the Duty holder will embark on a multi-year inspection routine, this will involve a number of annual surveys accumulating data and information on a progressive basis. This will be used to put together the Verification report on an ongoing basis. If this is the route taken then a typical survey will may involve the following:

1. Corrosion survey, including cathodic potential readings and an assessment of the protection system.
2. A full survey of risers, conductors and caissons including their supports and protection systems (to approximately 20m from the jacket).
3. Close visual inspection of a representative portion of the welds.
4. Possible magnetic particle inspection or electromagnetic inspection of a representative portion of welds. usually 20% of welds/year.
5. Physical damage survey and structural integrity survey.
6. Debris and marine growth survey.
7. Survey of the surrounding seabed for scour etc.

All of the above will be referenced to the design/fabrication/installation manual for that structure (as built drawings) and to previous inspection reports, allowing the company to create and update a damage register which is a record of all anomalies present on the structure. This will also enable them to issue an annual workscope detailing any inspection, repair or maintenance work to be carried out on the structure.

NOTES

CHAPTER 2

STRESS IN THE OFFSHORE ENVIRONMENT.

* M.C.

Stress can be defined by the following:

$$\text{Stress} = \frac{\text{Load}}{\text{Area}}$$ CARRYING LOAD.

There are three types of stress which can affect a structure offshore, they are:

Tensile Stress (σ)

$$\text{Tensile stress } (\sigma) = \frac{\text{Load}}{\text{Area}} = \frac{W}{a \times b}$$

A member which endures this kind of stress will have it's individual atoms pulled apart so as to eventually separate them. Of course not all tensile stress will pull the member apart, but the tendency is there so it is important to make sure that the stress never reaches a point where the member can no longer safely handle it.

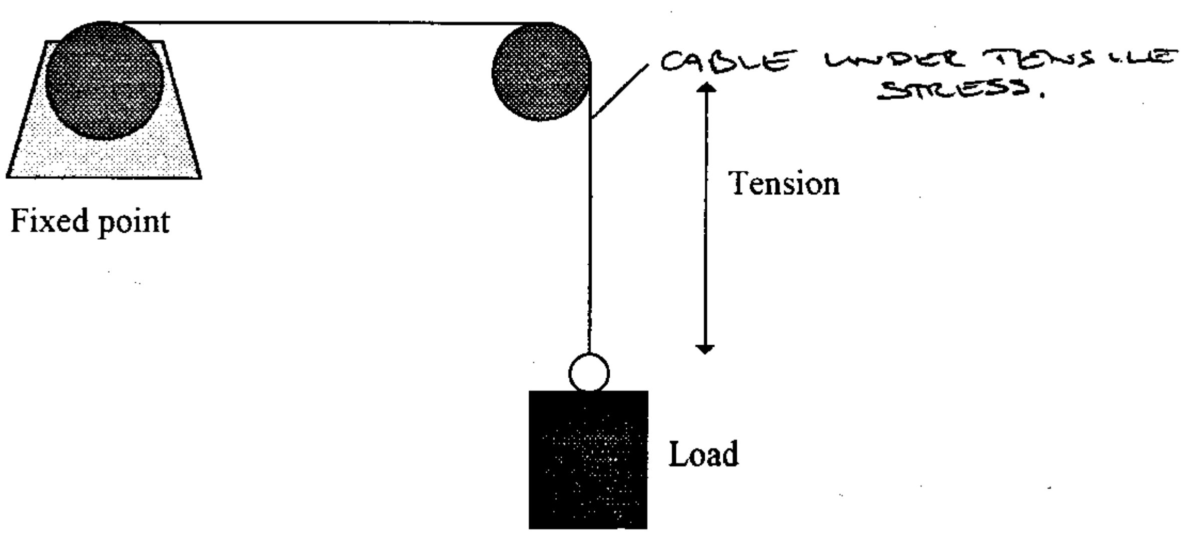


Figure 2.1 Tensile Stress

Compressive Stress (σ)

$$\text{Compressive stress } (\sigma) = \frac{\text{Load}}{\text{Area}} = \frac{W}{a \times b}$$

When a member is under compressive stress the atoms are being squeezed together. The stress must not be greater than the material can handle or it will be crushed.

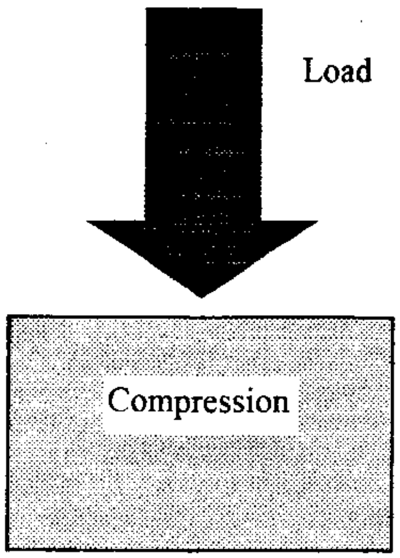


Figure 2.2 Compressive Stress

Sheer Stress (τ)

$$\text{Sheer stress } (\tau) = \frac{\text{Load}}{\text{Area}} = \frac{W}{a \times b}$$

Sheer stress is the action of the atoms being pushed past one another as in a guillotine or the torsion of a bolt being tightened, if the sheer stress becomes too great then the metal will break. Guillotine action.

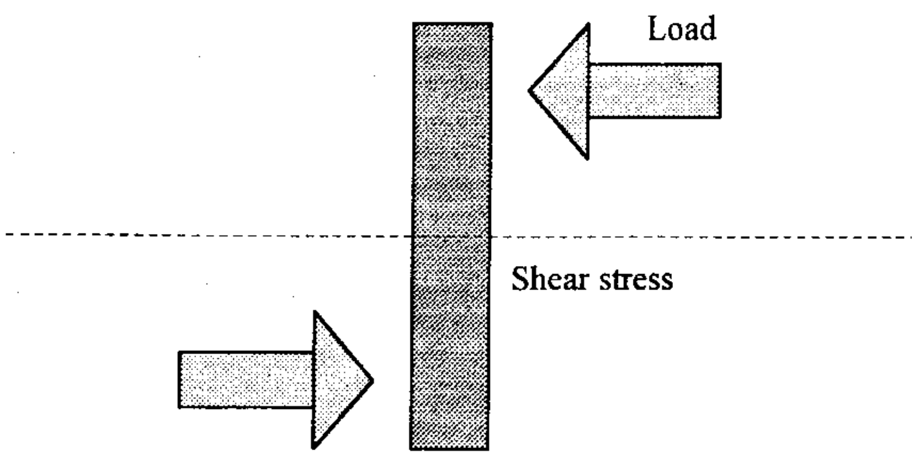


Figure 2.3 Shear Stress

MATERIAL BEHAVIOUR UNDER STRESS

If a material is put under stress it will be affected in some way. How much it is affected will depend on both how much stress is involved and the orientation of the stress. Different materials will react in quite different ways to the stresses which are imposed on them, for example concrete is very strong when under compression stress, but not so strong under tension stress or sheer stress. Steel is able to put up with a great deal of tension stress but is relatively weak in compression stress.

Each material is chosen carefully for the task it will have to perform. In addition the shape and form it will take is also carefully considered, e.g. a flat piece of paper will not take as much compression as it will if it is first rolled up to form a cylinder, the same can be said of steel.

LOADING OF A BEAM

When we load a beam which is supported at both ends it will be deformed to some degree regardless of the how large or small the load is.

If we progressively increase the load then the beam will deform more. Providing that we do not overload the beam it will return to its original size and shape when the load is removed. This deformation is called elastic deformation, the beam is said to have performed elastically.

Should we increase the load on the beam beyond a point known as the **Yield Stress** then the beam will no longer behave elastically and will become permanently deformed. We call this plastic deformation. Increasing the load even more will eventually bring us to a point known as the **Ultimate Tensile Stress**, If we load the beam beyond this point then the beam will fail.

— Highest stress levels in skin of material.

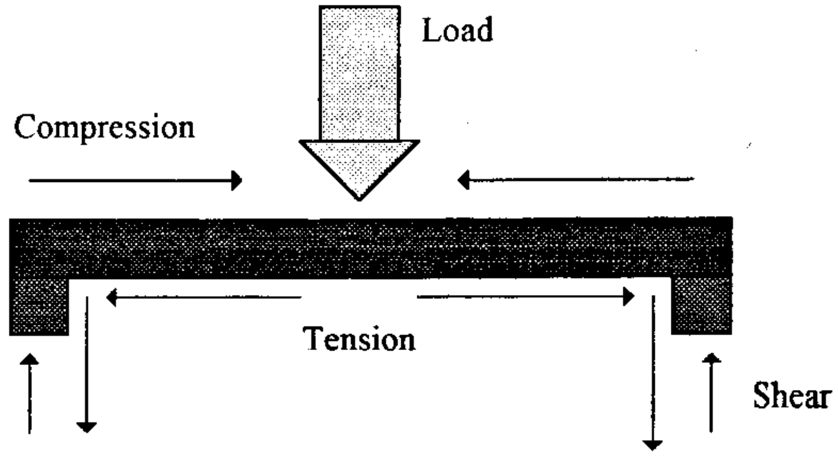


Figure 2.4 Stresses in a Beam Supported at Both Ends

As can be seen in figure 2.4 the greatest stress concentration in the beam will be confined to the skin of the beam. This is true in offshore structures, and is the prime reason why surface breaking defects are seen as the most significant.

DUCTILE FAILURE

The beam seen above will eventually have failed through progressive overloading. **The major sign of Ductile failure will be that the ends of the severed beam will be deformed**. This means that the two ends will not fit easily back together. This kind of failure is called **DUCTILE FAILURE** because the beam has exceeded its ductile limit.

Mc. **PROGRESSIVE LOADING OF A MATERIAL**

LOAD

↓

ELASTIC DEFORMATION
(will return to normal)

YIELD STRESS

↓

PLASTIC DEFORMATION
(will remain deformed)

ULTIMATE TENSILE STRESS (UTS)

FAILURE
(the beam will break)

Metal can also fail by **FATIGUE**. This is caused by the structure experiencing cyclic stress, this is reciprocating stress attempting to move the structure to and fro constantly over a period of time. In air there is always a load at which the structure will never fail no matter how many cycles it experiences. A rule of thumb is that if the structure can take 2,000,000 cycles without breaking then it will not fail due to fatigue. When we place the structure in a corrosive media (such as seawater), then this is untrue and in fact the structure will always have a finite fatigue life regardless of the applied load. This means that each time a structure in the sea vibrates it is moving towards eventual failure.

FATIGUE FAILURE

This occurs due to the metal becoming locally harder than the surrounding material due to working the component. When this happens it becomes more brittle and so is less able to flex and will instead fail by cracking. **The signs of fatigue failure are no local deformation** (due to the fact that the structure has never exceeded its yield stress). This means that if a component has failed by fatigue then the two parts will fit back together neatly. **The most** rc. **likely location for a fatigue defect in a welded structure will be the Heat Affected Zones** of the weld.

BRITTLE FAILURE

This is much the same as the above fatigue failure except that the local hardening does not come from working the component but rather because of:

a) Hydrogen Embrittlement

This can occur due to incorrect welding techniques, welding in a damp atmosphere, using damp consumables etc. The hydrogen liberated during the processes will dissolve into the parent plates thus making them brittle. This is often called cold cracking because the cracks can occur several hours after the weld has been fabricated.

b) Overprotection by Impressed Current

This can cause cracking of the welds around the impressed current nodes, due to Hydrogen Embrittlement.

or

c) Alteration of the Material Microstructure

This can occur because of incorrect cooling during fabrication of the welds (pre and post heating of welds), or maybe during heat treatment processes.

FORCES AND STRESSES ACTING IN OFFSHORE STRUCTURES.

All offshore structures are subject to very complex loadings which arise from drag forces, wind and wave action, drilling vibration, loading of the structures with modules and the like, boats being tied up to them and a host of other unpredictable loads. Because of this there will always be some doubt as to the structures capability, this will be compounded if there is any appreciable corrosion of the steel.

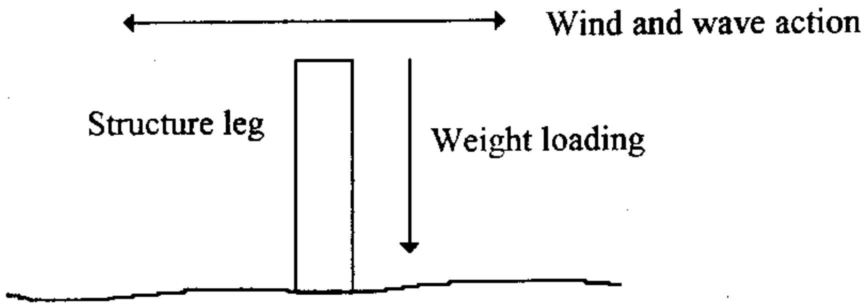


Figure 2.5 Forces Acting in an Offshore Structure

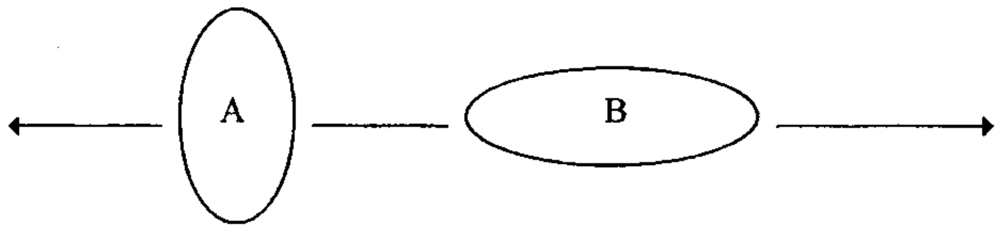
As can be seen the forces acting on the structure are very complex and so proper inspection of the structure is of paramount importance to ensure the continued safe operation of the structure in the offshore environment.

RESIDUAL STRESS

Residual stress can come about in a number of ways. For example, if when the structure is being built the welding technique is incorrect, then this can result in a build up of stress which can then become locked up in the structure. Residual stress can also occur if a pile driving operation is not carried out properly, this could result in some stress being locked up in the structure. The structure may well be able to cope with this stress, but a problem arises if the stress is acting in the same direction as another stress, which may well be the one for which the structure was originally designed. In this case the combined stress may well be too much for the structure to cope with and so it will fail, and even if the structural member can cope with the increased stress levels, the corrosion rate of that member will increase, sometimes dramatically.

STRESS CONCENTRATION

The shape and orientation of a defect relative to the direction of stress will change the effect that the stress has on the structure. If the long axis of the defect is at 90° to the direction of stress loading, then the defect is far more likely to propagate than if the stress is in the same direction as the long axis of the defect.



A = Most likely to propagate
B = Least likely to propagate

Figure 2.6 Stress and defect Orientation

Likely locations for the above to occur will be as follows:

a) Weld defects
b) Poor profile of welds
c) Corrosion pitting
d) Tool marks on the surface of the material
e) Node joints
f) Holes and cutouts in members

In the case of weld defects one method of short term repair could be the application of MC. **Stopper holes**.

STOPPER HOLES

Cracks grow because the stress is concentrated at the very tip of the crack, they can be stopped from increasing in size or at least slowed down by the drilling of "stopper holes". These are holes drilled at the ends of the crack thus spreading the stress which would otherwise be concentrated at the point of the crack. This is not a permanent solution but may be used until a lasting solution can be organised.

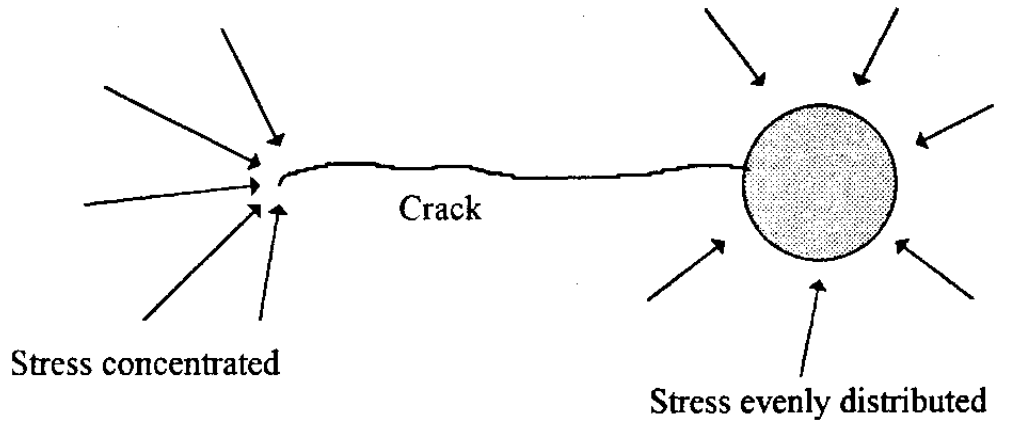


Figure 2.7 Stopper Hole

NOTES

CHAPTER 3

STRUCTURES AND EQUIPMENT USED IN THE OFFSHORE ENVIRONMENT

SEMI SUBMERSIBLE DRILLING RIGS

The semi submersible drilling rig is a floating platform that can be moved about relatively easily, from which drilling operations can be carried out. They are also used as "flotel" accommodation platforms alongside fixed platforms. The rig will be ballasted to a working draught and then will be anchored to the sea- bed by means of conventional anchor patterns of maybe 8 to 10 anchors. When drilling is taking place there will be a "Wellhead" situated on the sea-bed. This is the start point of the hole which will become the well. Onto the wellhead is placed a "Blow Out Preventer" more commonly known as a B.O.P. This is a series of valves which can isolate the well in the event of a down hole problem such as a high pressure gas "kick". Above the B.O.P. will be a ball joint allowing the riser to move slightly. Between the ball joint and the drill floor (on board the Semi-Submersible rig) will be the "Marine Riser" through which the drill string is lowered. In effect the drill floor is connected directly to the well and so the drilling mud and the drill waste can be collected and monitored.

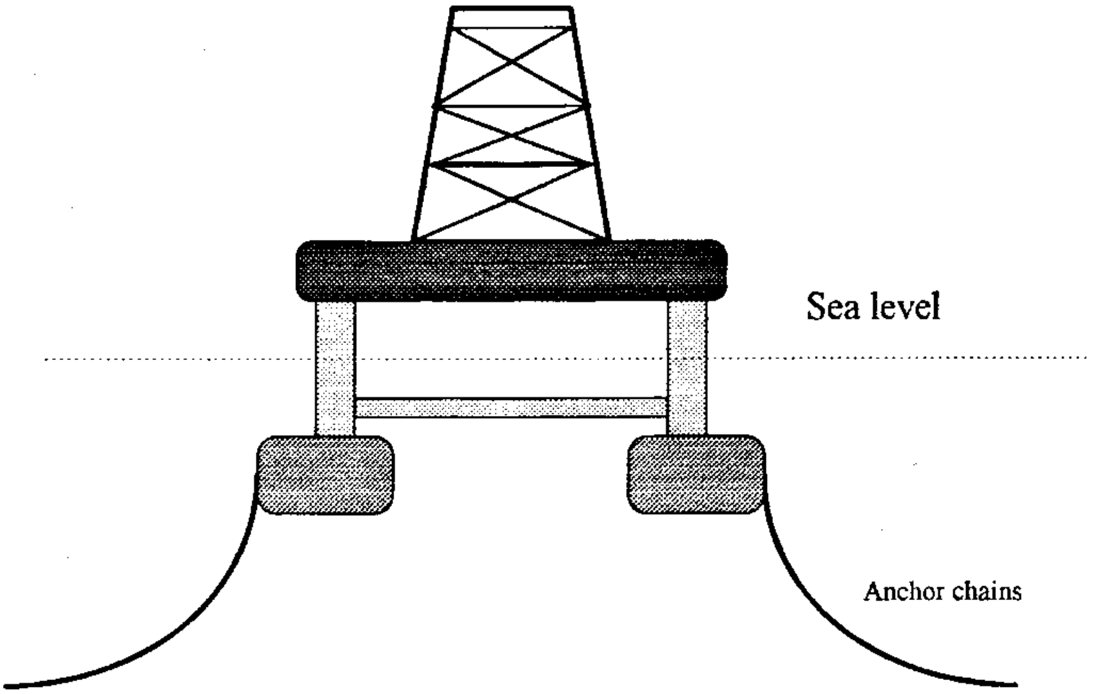


Figure 3.1 Semi-Submersible Drilling Rig

SEMI SUBMERSIBLE PRODUCTION PLATFORMS Shallow.

Semi submersible production platforms are essentially the same kind of vehicle as the drilling rigs shown above. The difference is in the fact that they are being used for the production side of the business. Typically they will have a number of wells connected to the rig floor, some of which may be remote or satellite wells. As shown below, the oil and gas will then be "exported" via a pipeline or perhaps by a buoy system.

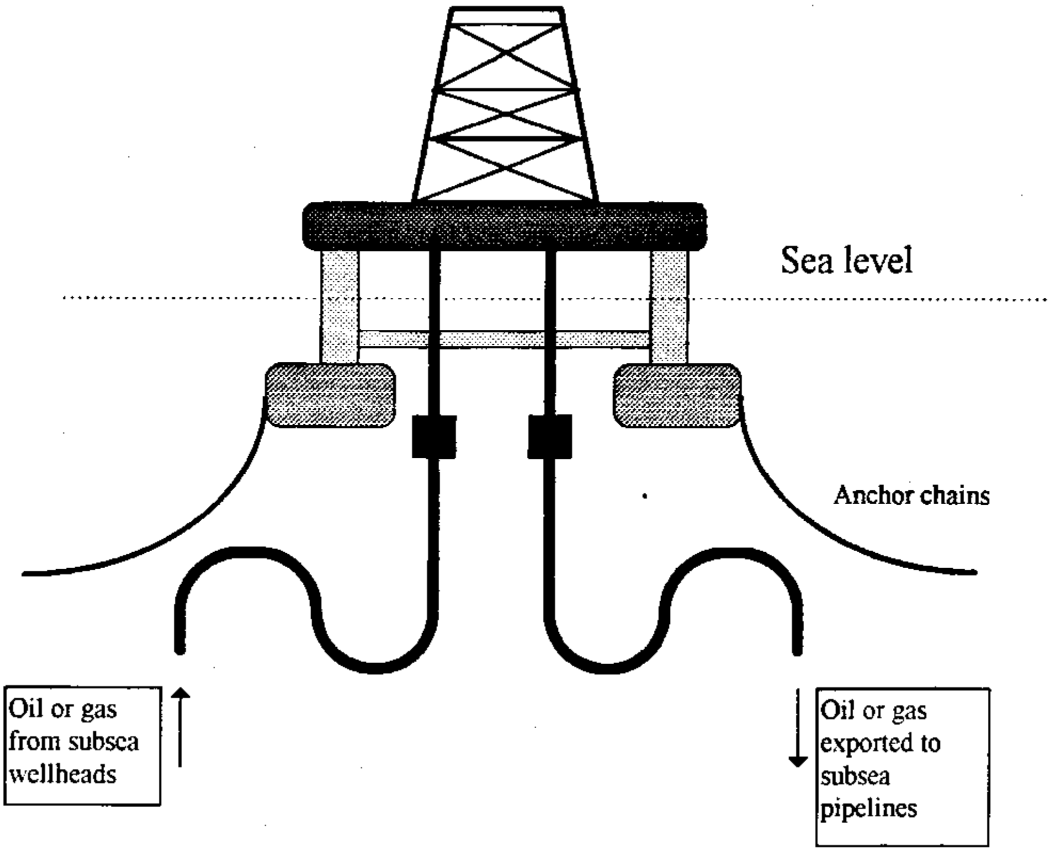


Figure 3.2 Semi-Submersible Production Platform

SELF ELEVATING PLATFORMS (JACK UP DRILLING RIGS) Shallow

Jack up drilling rigs are used principally for shallow water work but can work in water depths of up to approximately 250 feet. They differ from the semi submersible rigs in that although they float to the location, once there they lower legs to the seabed and jack the hull up out of the water. Once this has been done the rig will give a stable platform from which drilling operations can be carried out. The legs are not anchored to the seabed in any way other than by gravity. Because of this there is a danger of the legs being undermined by scour. For this reason Jack up Drilling rigs must be very carefully inspected with this particular problem in mind.

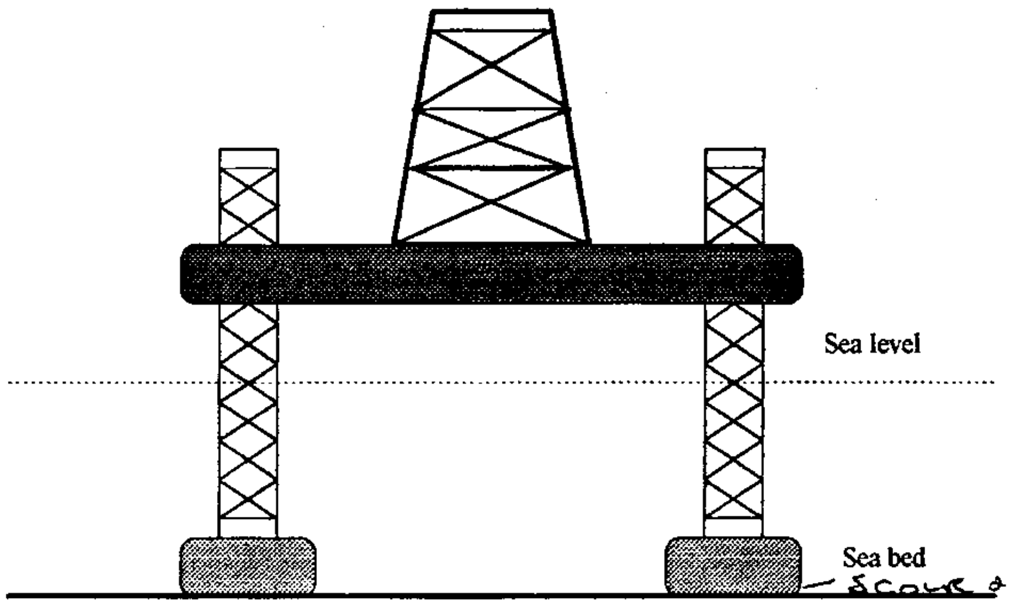


Figure 3.3 Self Elevating Platform (Jack up rig) SHALLOW

TENSION LEG PLATFORMS

Tension leg platforms have been designed principally to work in deep water. They consist of a floating platform much like a semi submersible rig, but instead of a conventional anchor pattern they are secured to the location by means of a series of metal tubes (normally 3 or 4 to each leg) under considerable tension supplied by the buoyancy of the structure, these tubes stretch from the bottom of the rig to piled subsea templates directly below the rig. They will be used for both drilling and production platforms.

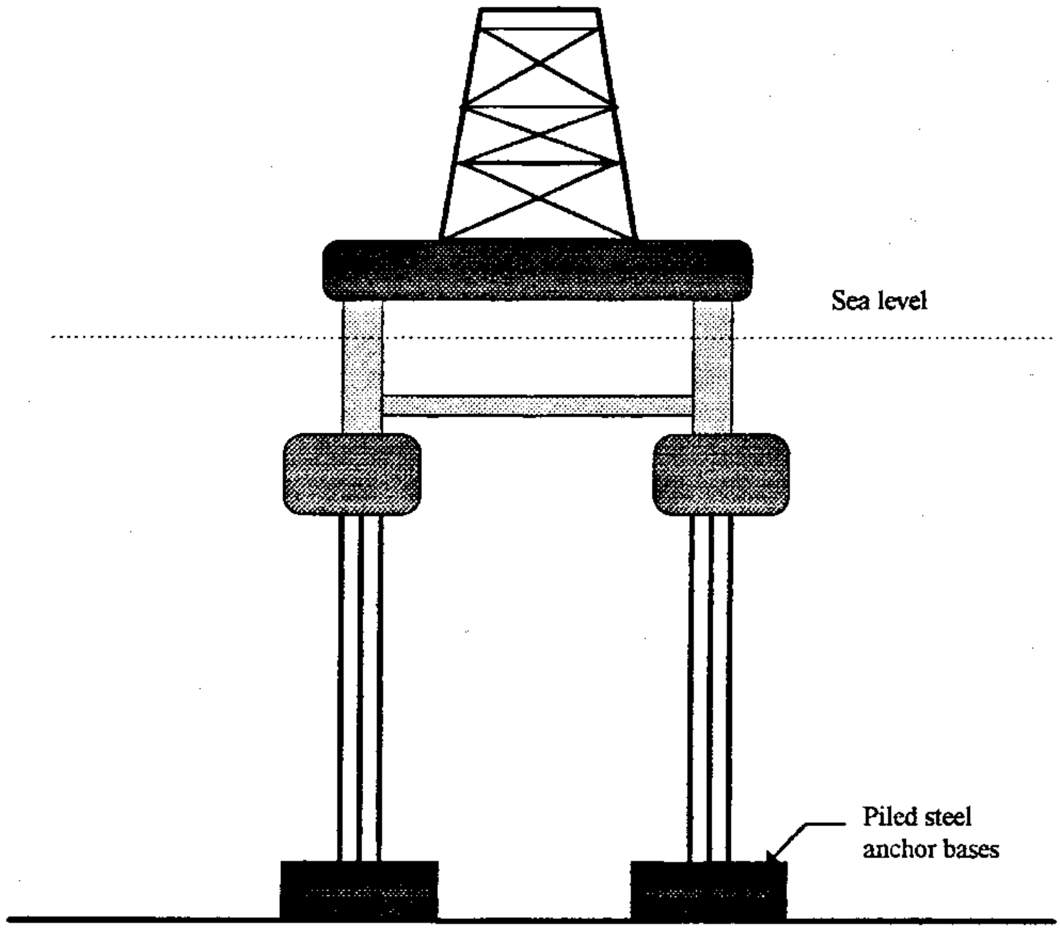


Figure 3.4 Tension Leg Platform (TLP) DEEP STEEL UNDER TENSION CAUSES CORROSION.

PILED STEEL JACKETS

Most fixed production platforms in the North sea are of the piled steel type. These platforms sit on the sea bed and are secured by means of piles which are driven through or around the main jacket legs (The legs of the structure tend to be referred to as the jacket). The structures are made up of a framework of steel tubular members designed to give rigidity and provide a stable and safe platform from which drilling and production can take place. The legs will normally not be exactly vertical, it is more likely that they will have a slight gradient, this is called the **Batter** of the leg. The batter of a leg may be for instance 1 in 25, which will mean that for every 25 metres you go down the leg, that leg will be 1 metre further out from the centre of the structure.

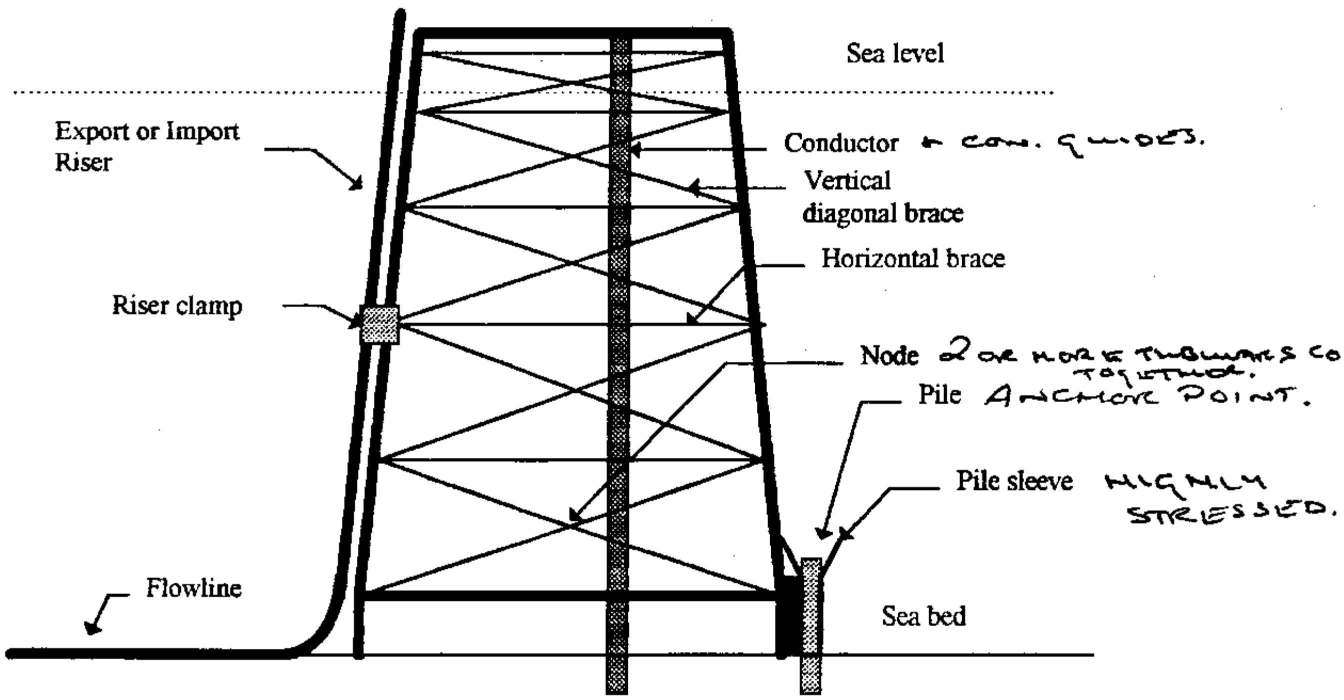


Figure 3.5 Steel Jacket

CONCRETE GRAVITY STRUCTURES

Concrete structures are not piled to the seabed they are held in position by their immense weight. There are a large number of different designs currently in use, each designed for the particular task and location involved, some are shown below.

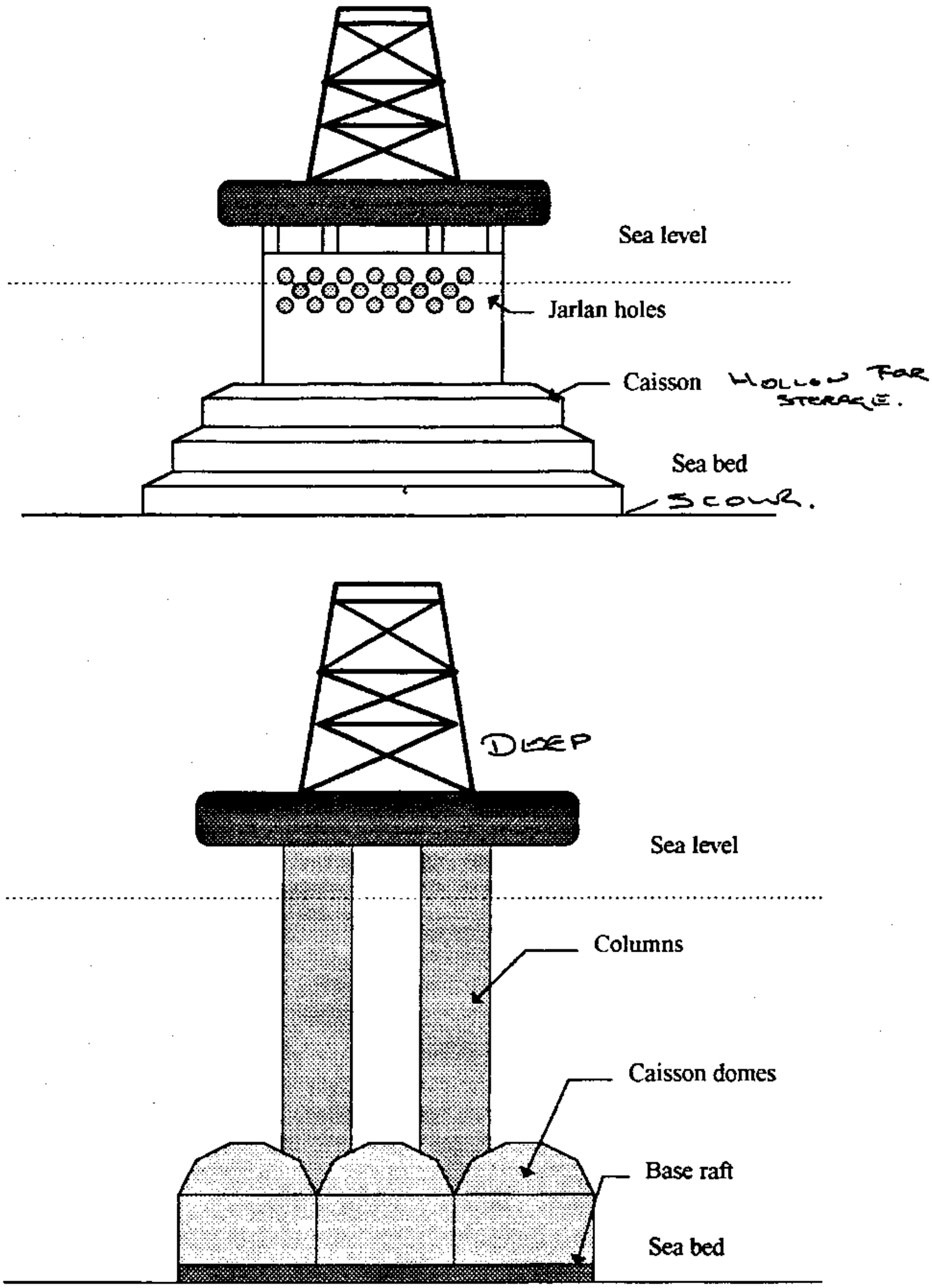


Figure 3.6 Concrete Gravity Structures

JARLAN WALLS 1m DIA.

Jarlan walls are perforated breakwater walls. The advantage of these is that the wall will only have to repel some of the energy generated by the wave action, the rest will dissipated through the hole. The specific design of the hole is of course crucial, but generally the wall should resemble figure 3.7 below.

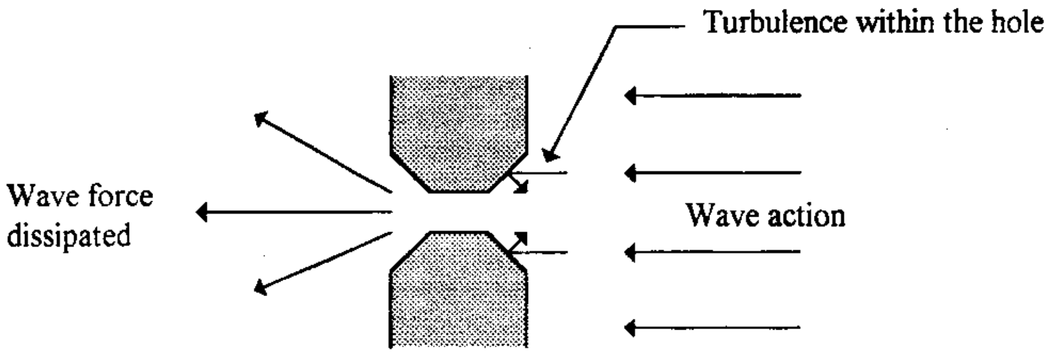


Figure 3.7 Jarlan Hole

PIPELINES

Pipelines and flowlines are the transport system used for oil and gas around the field and from the field to the shore base. They are made up of short pieces of pipe welded together these welds can be termed "field joints". Field joints are each 12 metres apart, these joints will often be covered with Bitumen and maybe a "Bend Protector" designed to reduce the possibility of the pipe buckling when it is laid down onto the seabed. The bend protector may simply be a thin sheet of steel which will quickly corrode away when the pipeline is on the seabed. The pipelines will often be coated with bitumen and then sprayed with a concrete "Weightcoat" in order to give the steel pipeline protection from corrosion, and physical damage, the concrete will also add weight and stability to the pipeline. The corrosion protection may well be achieved by a combination of weightcoat and sacrificial anodes placed at intervals along the pipe. The flowline must be supported along its whole length otherwise there could be a failure. If there are two pipelines crossing one another then the cross over will have to be supported properly to ensure that no undue stress comes onto either pipe.

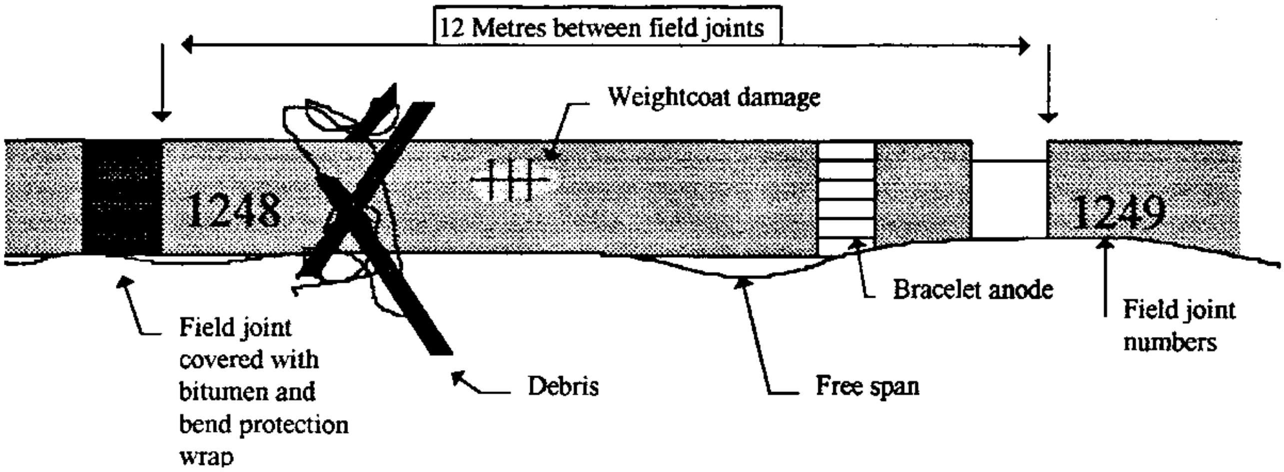


Figure 3.8 Pipeline

SINGLE BUOY MOORING (S.B.M.)

Single buoy moorings are used for the export of oil from the field to a tanker or perhaps import from a tanker to a refinery. They consist of a single buoy incorporating a swivel mechanism to which the ship is moored. The buoy is held in place by an anchor pattern typically consisting of six or eight anchors. The oil will be passed from a pipeline on the seabed via a pipeline end manifold (PLEM) and subsea flexible hoses to the buoy on the surface. These hoses may have buoyancy attached in order to keep them from touching the seabed. They will transfer the oil to the buoy where it will be conveyed via floating hoses to the waiting tanker.

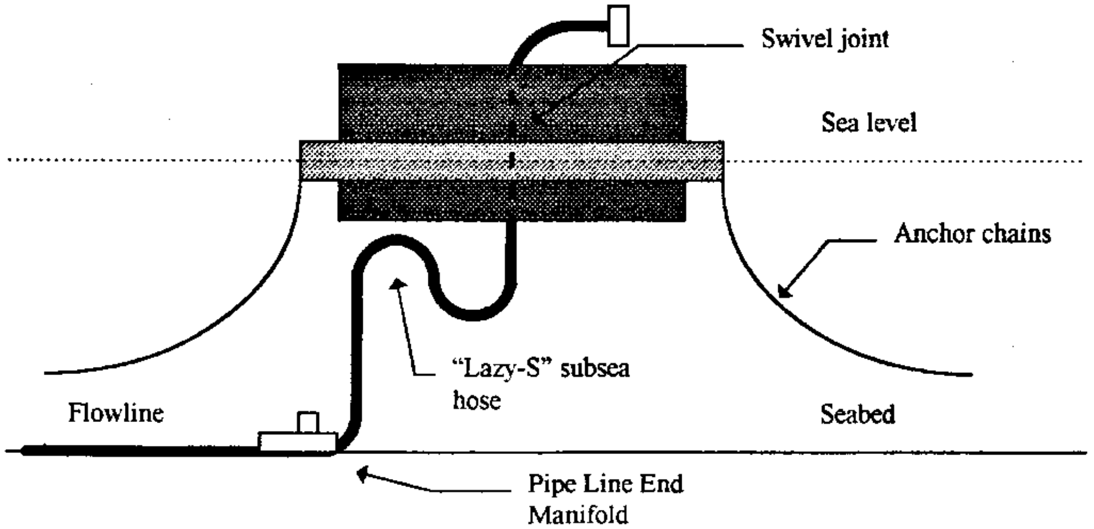


Figure 3.9 Single Buoy Mooring (SBM)

SINGLE ANCHOR LEG MOORINGS (SALM)

These are similar to the SBM previously mentioned except that they do not have flexible hoses from the seabed and the swivel will be on the seabed, also they will be anchored to the seabed by means of a piled steel template. They will be used in the same way to export oil to a tanker.

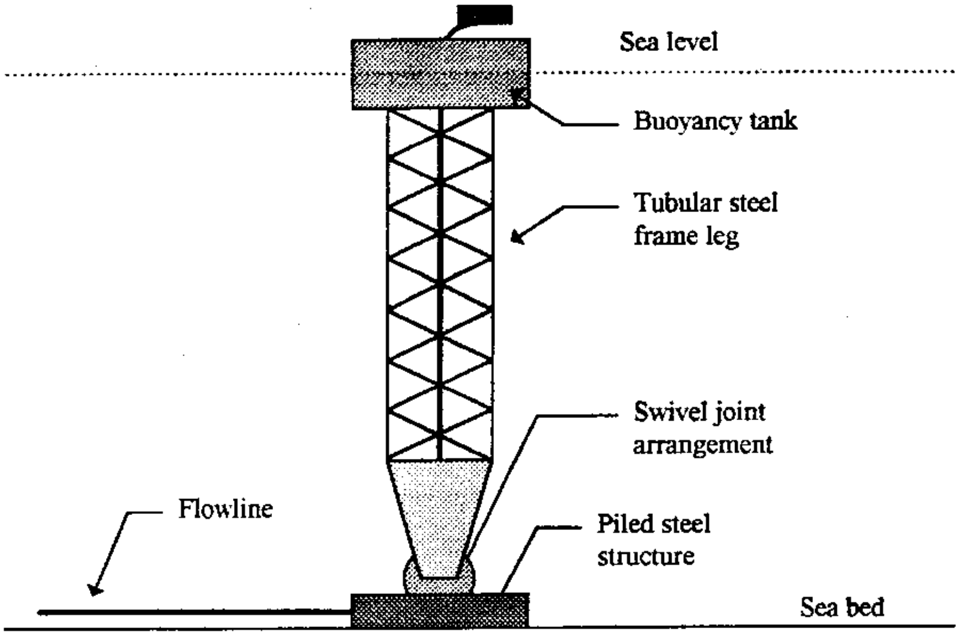


Figure 3.10 Single Anchor Leg Mooring (SALM)

SUBSEA COMPLETION AND EXPORT MANIFOLDS

Subsea completion's are wellheads that are scattered around the field away from the main structure. All that will be visible on the seabed will be a series of valves called the "Christmas Trees" and possibly a protection structure called an Igloo. All of the subsea completion's will be connected to the main platform via flowlines.

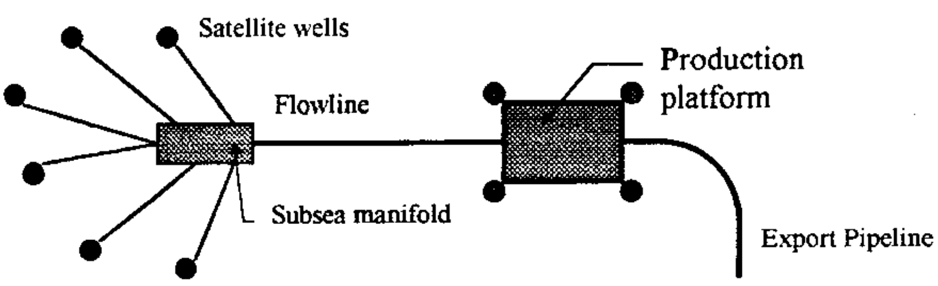


Figure 3.11 Subsea Completion

SUBSEA WELLHEAD (Christmas tree)

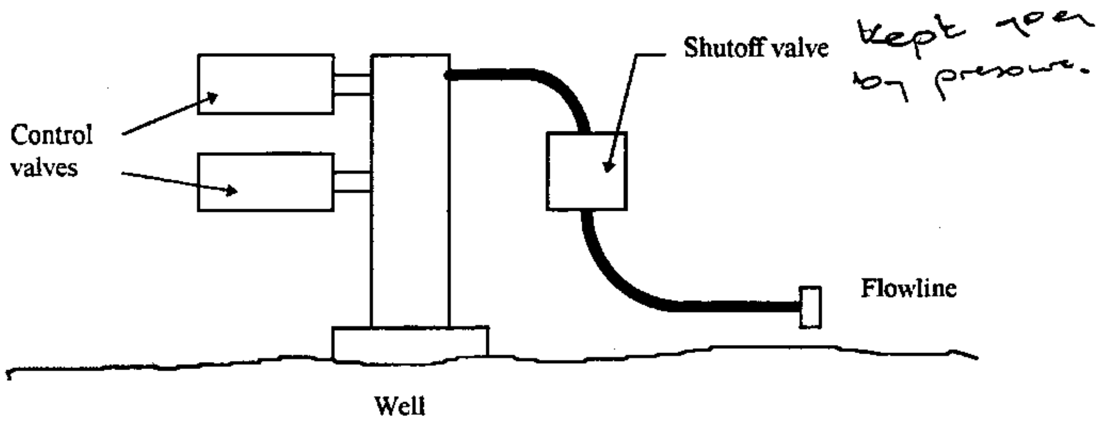


Figure 3.12 Subsea Wellhead

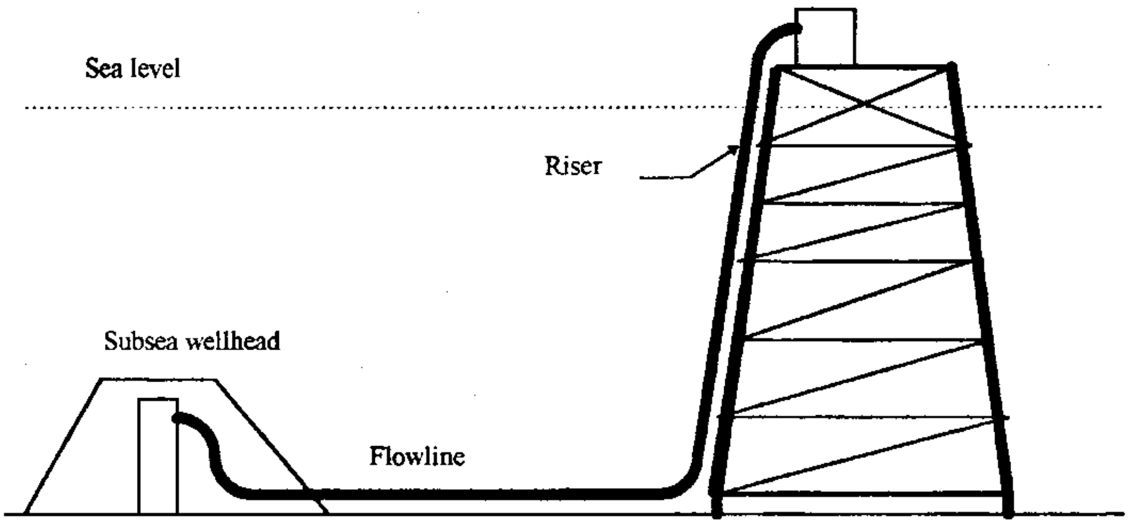


Figure 3.13 Subsea Completion Showing Flowline and Structure

RISERS

Risers are pipelines which run up and down the outside of structures. They are used to "import and export" oil and gas to and from the structure.

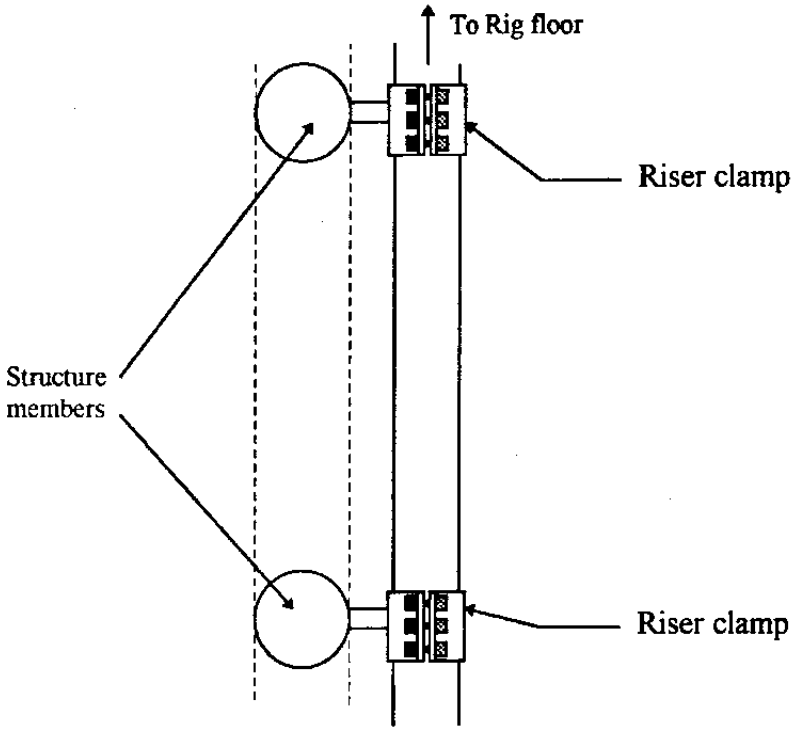


Figure 3.14 Risers

CONDUCTORS

Conductors carry the main wells, this means that the oil and gas will be carried from the seabed to the surface inside large pipes (usually 36"). These pipes are called conductors.

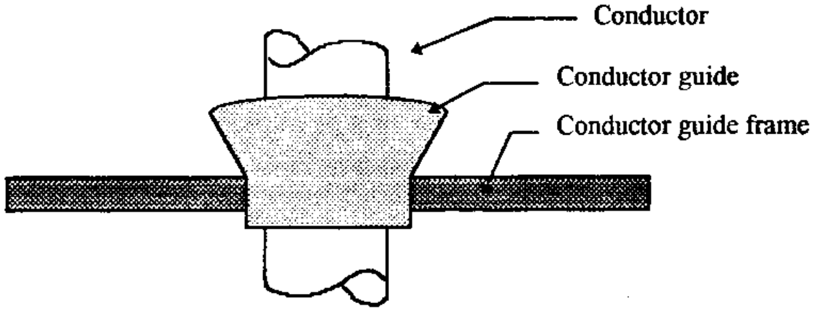


Figure 3.15 Conductor Guide Frame

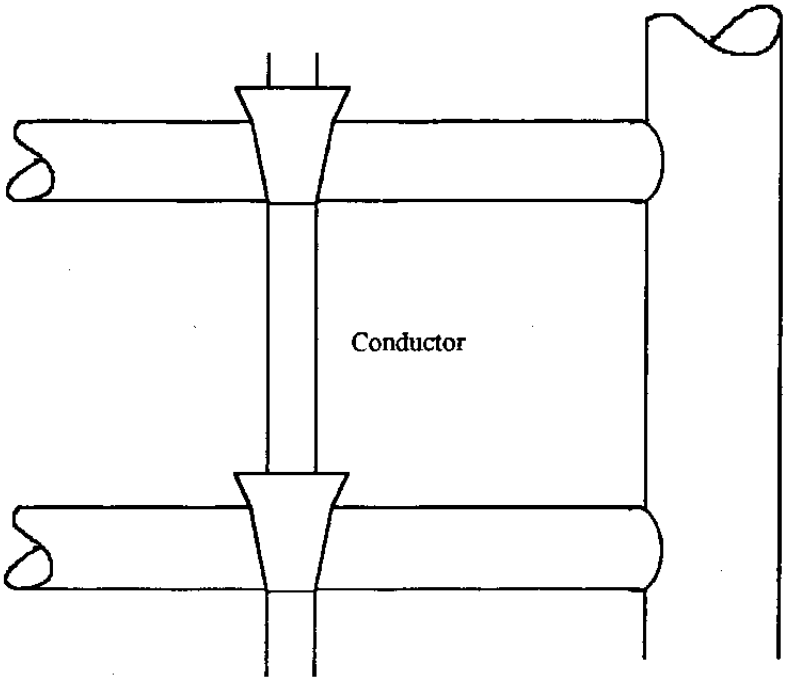


Figure 3.16 Conductor

SUBSEA WELLHEAD PROTECTION

These are sometimes called "Igloos". They consist of steel frames which cover the wellhead and protect it from accidental damage incurred from fishing equipment, anchors, etc being dragged over the wellhead.

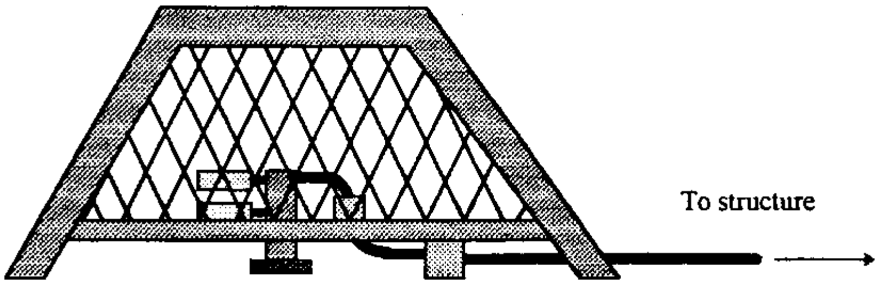


Figure 3.17 Subsea Wellhead Protection

NOTES

CHAPTER 4

MARINE GROWTH

Marine growth consists of the flora and fauna which inhabits the marine environment. Several species will find their home on a man-made structure which has been placed in the sea. The main problem from an engineering point of view is that the structural member involved will be increased in size, it will also loose its smooth finish so becoming rougher. Both of these will increase the forces acting on the structure and so the loads that need to be dealt with will also increase. The following is a list of the effects which marine growth will have on a structure:

INDETAIL. NB.

THE EFFECTS OF MARINE GROWTH

The effects of Marine Growth on an offshore structure will be extremely varied, however the following is a list of most of the major effects:

1 It will cause an increase in the mass of the structure without adding stiffness and so cause a decrease in the natural frequency of the structure. (frequency of oscillation) increases fatigue.

2 Increasing the drag coefficient of the structure, especially in the splash zone where the maximum water force is present. This will also be the furthest point from the anchor point of the leg. The sea bed and so the bending moment will be increased.

3 Obscuring the structures features such as valve handles and structural markings. When marine growth covers the structure it will also cover the markings on it and so a good number of the features will also be obscured.

4 Making close inspection of components impossible for the same reason as above.

5 Reducing the effective area of intakes and outfalls.

6 Increasing or decreasing the rate of corrosion of the structure.

7 Increasing the scour at the base of the structure due to the increased fluid velocity around the base of the structure.

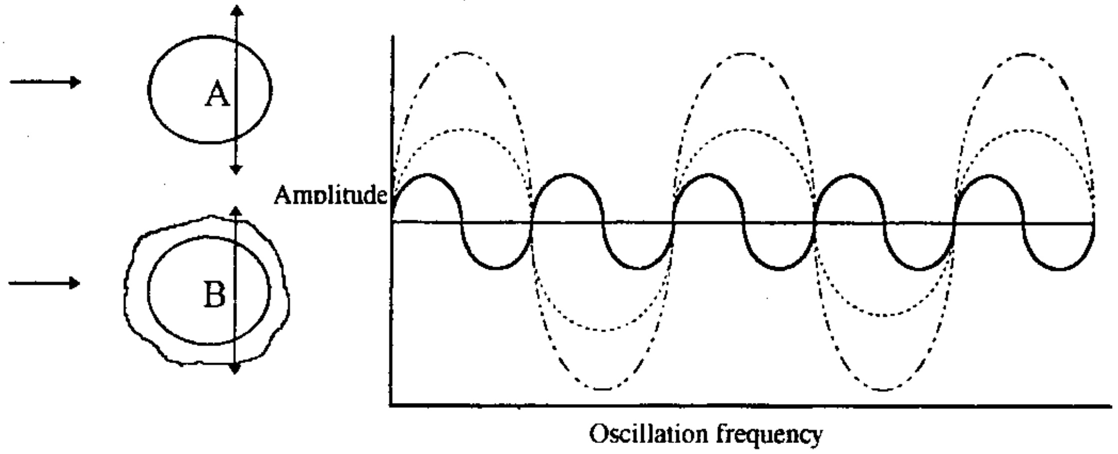
8 Increase the effects of wave slam in the splashzone

9 Increase the dead-weight on the structure due to wave action. in S.Z.

These will now be explained in some detail:

1 **It will cause an increase in the mass of the structure without adding stiffness and so cause a decrease in the natural frequency of the structure.**

Firstly we will look at the mass/frequency relationship. If a stick of a given diameter is placed into a fluid flow of a given velocity it will vibrate at a certain frequency. This is termed as the natural frequency of that object. If we now replace the stick with one of a larger diameter but do not change any of the other circumstances then the natural frequency of vibrations will decrease. The same effect can be seen in offshore structures. If the members are of a given size or mass then they will have a certain "natural frequency" (frequency of vibration in a given fluid flow). If then the size or mass of the members is somehow increased without this increase in mass adding strength to the member, (as happens with marine growth), then they will tend to vibrate at a slower rate. When the structure is conceived the designer will take into account the location and the environmental forces operating in that locale. One of the things which will be looked at is the prevailing wavelength of the sea. The structure should have a different natural frequency to that of the sea. If the two of them were to coincide then the forces acting on the structure will be compounded and so can act to break the structure. See figure 4.1 below.



A = Clean leg (No marine growth) Rapid oscillation shown as
B = Leg with Marine Growth Slower oscillation shown as
C = Prevailing wave action Shown as

Figure 4.1 Natural Frequency Effects

2 **Increasing the drag coefficient of the structure, especially in the splash zone where the maximum water force is present. This will also be the furthest point from the anchor point of the leg, which is the sea bed and so the bending moment will be increased.**

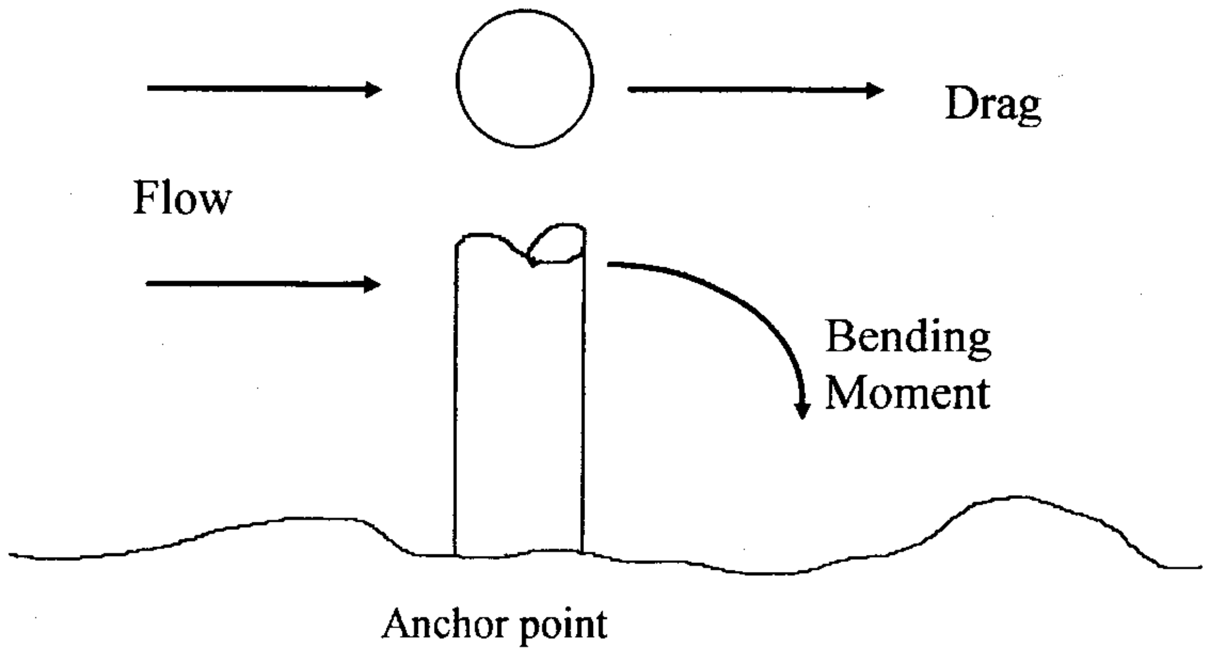


Figure 4.2 Drag and Bending Moments

Drag is the force tending to move or attempt to move an object which is held stationary in a fluid flow. The size of the force depends on a number of factors:

i) The area of the object presented to the flow. If we double the diameter of the object then the force will be increase four times. Increase the diameter three times and the force will increase nine times.

ii) The velocity of the fluid flow, the same thing as above will apply here i.e., if we double the velocity then the drag force will increase four times and so on, (the increase in the force is the square of the increase in either the size of velocity).

iii) How smooth the object is. If the object is made rougher then the force (drag force) will be increased.

Drag force can be expressed by using the following formula:

$$\text{Drag force} = \frac{1}{2} C_d \rho r A V^2$$

V is the velocity of the fluid flow
A is the projected area at right angles to the flow
ρ is the density of the fluid
C_d is the drag coefficient

The drag coefficient is a number which can be applied to assess the relative drag forces acting on a structure compared with a reference. This takes into account the shape of the structure and the roughness of its surface. It can be seen that as the growth increases both the area presented to the flow will increase and also the member will become rougher. When taken together this will have the effect of increasing the drag coefficient and thus the forces acting on the structure dramatically. Of course to be realistic we would normally have to take into account the wave action and thus the inertia (acceleration) of the water particles to find the total wave force acting on the structure. The formula for this is as follows:

Total wave force = drag force + inertia

$$\text{Total wave force} = \frac{C_d}{2} \rho D L V^2 + (\text{mass x acceleration})$$

Where:

C_d is the drag coefficient
ρ is the density of the fluid
D is the diameter of the member
L is the depth of submergence
V is the velocity of the water
Mass is the mass of water moving around the structure

3 **Obscuring the structures features such as valve handles and structural markings. When marine growth covers the structure it will also cover the markings on it and so a good number of the features will also be obscured.**

4 **Making close inspection of components impossible for the same reason as above.**

5 **Reducing the effective area of intakes and outfalls.**

6 Increasing or decreasing the rate of corrosion of the structure.

7 Increasing the scour at the base of the structure due to the increased fluid velocity around the base of the structure.

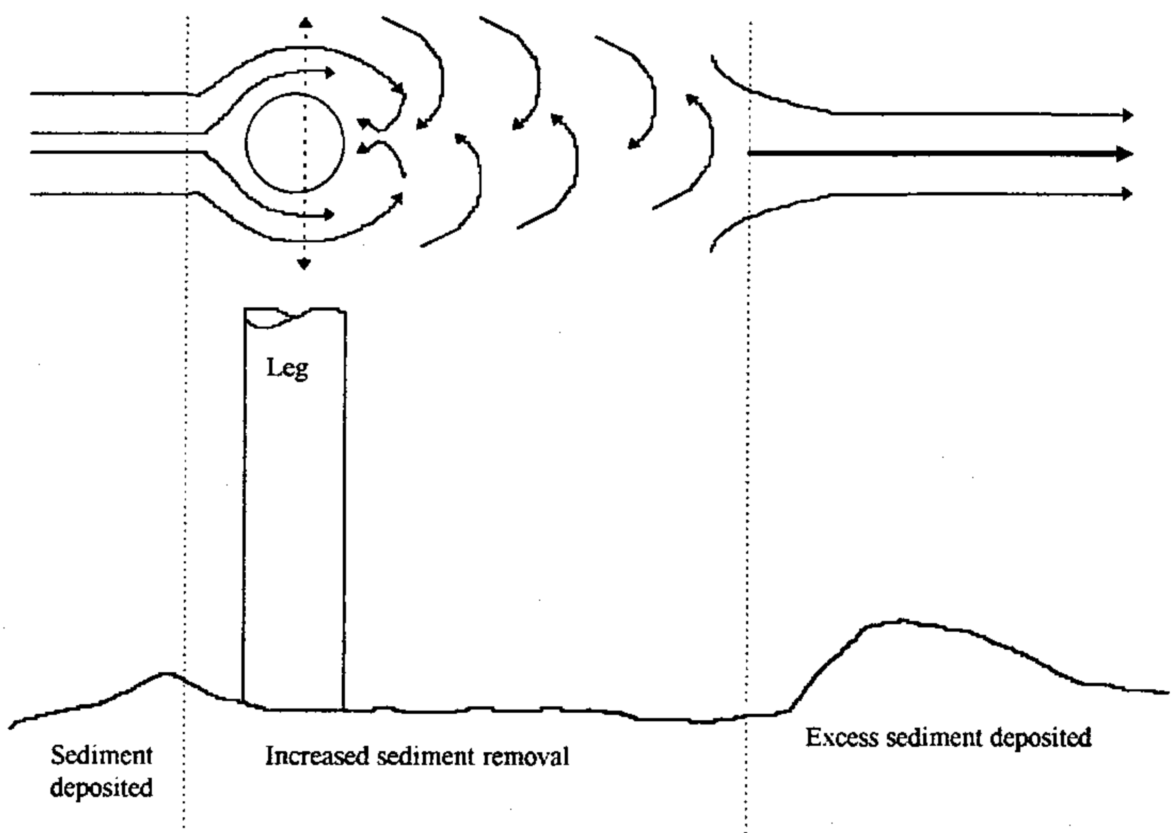


Figure 4.3 Drag and Scour

8 Increase the effects of wave slam in the splashzone

The result of increasing the size of the member in the splashzone will be to offer more surface area to the waves as they break over the structure, this will increase the loadings on the members substantially.

9 Increase the dead loading, especially in the splashzone HARD MG.

The marine growth which attaches in the splashzone will create a great deal of added weight when the sea level drops below the member, thus removing the supporting effect of the water. Also the water itself will tend to be held by the marine growth and this in itself will add weight loading to the structure.

c. *

FACTORS AFFECTING MARINE GROWTH

There are several factors which will affect the rate and intensity of marine growth on an offshore structure these are:

i) TEMPERATURE
ii) DEPTH
iii) FOOD SUPPLY
iv) FLUID FLOW RATE
v) CATHODIC PROTECTION LEVEL
vi) SALINITY

TEMPERATURE RISERS, COND. S.Z (HOT) MORE GROWTH.

As the temperature increases then the marine growth will also increase. In general a 10°C rise in temperature will double the rate of growth. At approximately 30°C the rate will start to be retarded until at approximately 35°C it is generally accepted that the growth will cease.

DEPTH

The penetration of the light is related to the depth. As the depth increases so the amount of light available will decrease and so the flora will not be able to photosynthesise food as effectively. This will limit the plant life which will in turn limit the number and concentration of animal life as the animals will very often feed on the plants. Figure 4.4 below is a representation of the accumulation likely to occur on an offshore structure in the North Sea.

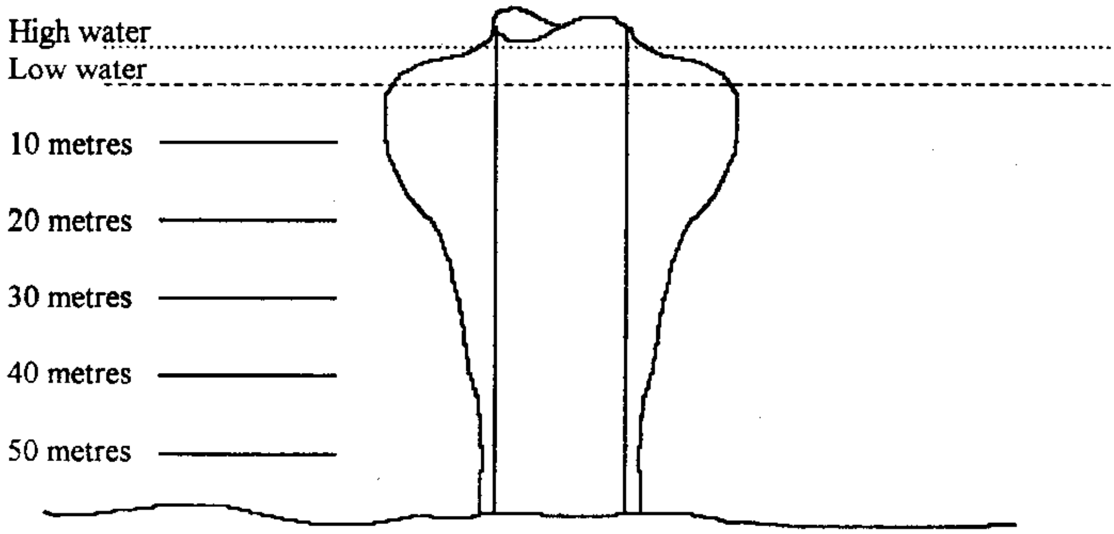


Figure 4.4 Accumulation of Marine Growth on an Offshore Structure

FOOD SUPPLY SE. FOOD WASTE OUTLETS MORE GROWTH.

The amount of nutrient available will dictate the rate of growth on a structure. The more nutrient available the more growth will take place, generally there will be more nutrients available near the surface and also around food waste outfalls on the structure.

FLOW RATE

In general the marine growth will find it difficult to attach itself in current of more than one knot. However if the flow reduces for a time as happens with tidal flow every 6 hours, then the organisms can become attached. Once attached they can hold on in very high flows, certainly upwards of 10 knots. Then the greater the flow the more nutrient may be available, so increasing the growth.

CATHODIC PROTECTION

In some cases the use of impressed current systems can promote an increase in growth, although the cause of this is not fully understood.

SALINITY OUTFALLS, STRU NEAR TO LARGE RIVERS.

In fresh water the type and rate of growth is extremely limited. As the salinity increases the growth will also increase until the salinity reaches normal (N.B. International standard seawater is between 3% to 3.5%) where the growth will be maximum. If the salinity then increases above the normal levels then the growth will again suffer.

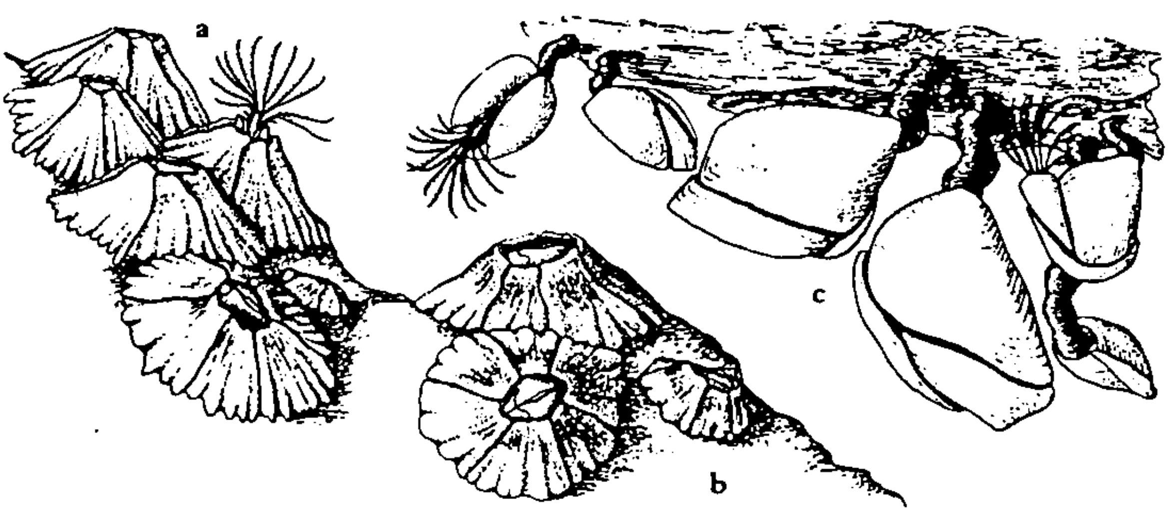
TYPES OF GROWTH

From an engineering point of view there are two groups of Marine Growth we need to be concerned with:

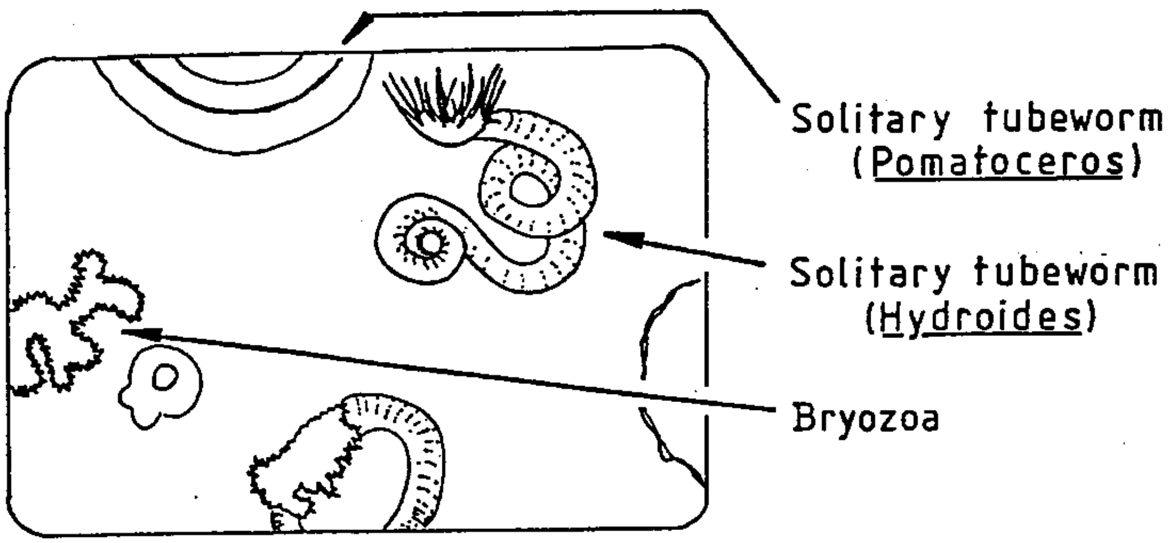
1. HARD GROWTH

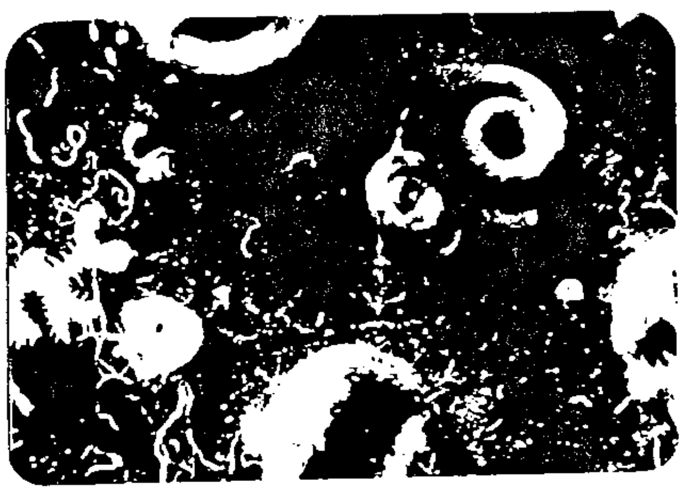
Made up of either calcareous growth or shelled organisms, some examples follow: N.B. Depths shown are maximum.

Type	Description	Depth
Tube Worm	Hard Calcareous Cast approximately 3 - 5 cm long	- 100m
Hard Corals	A hard exoskeleton enclosing a soft body	- 40m
Barnacles	Hard white sharp growths tapering from the base	- 120m
Mussels	Blue black shells up to 10 cm long attached to the structure by bysall threads	- 20m



The star barnacle (a) and acorn barnacle (b) are superficially similar in appearance, but the star barnacle has a kite-shaped opening to the shell, whilst the acorn barnacle has a diamond-shaped opening The goose barnacle (c) has a shell composed of five thin white plates supported on a long, slightly retractable stalk. It is usually suspended from driftwood.





Close-up of solitary tubeworms
See the drawing above for identification.

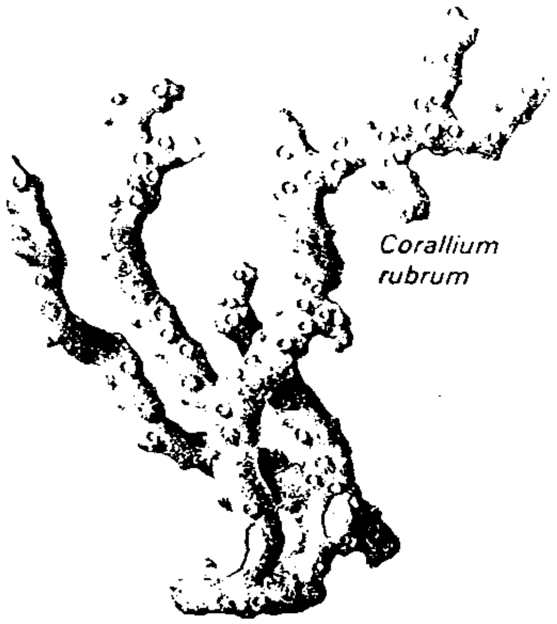


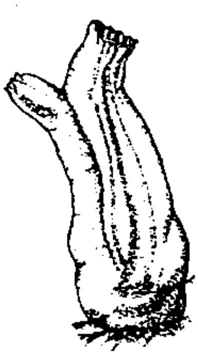
Figure 4.5 Examples of Hard Marine Growth

SOFT GROWTH

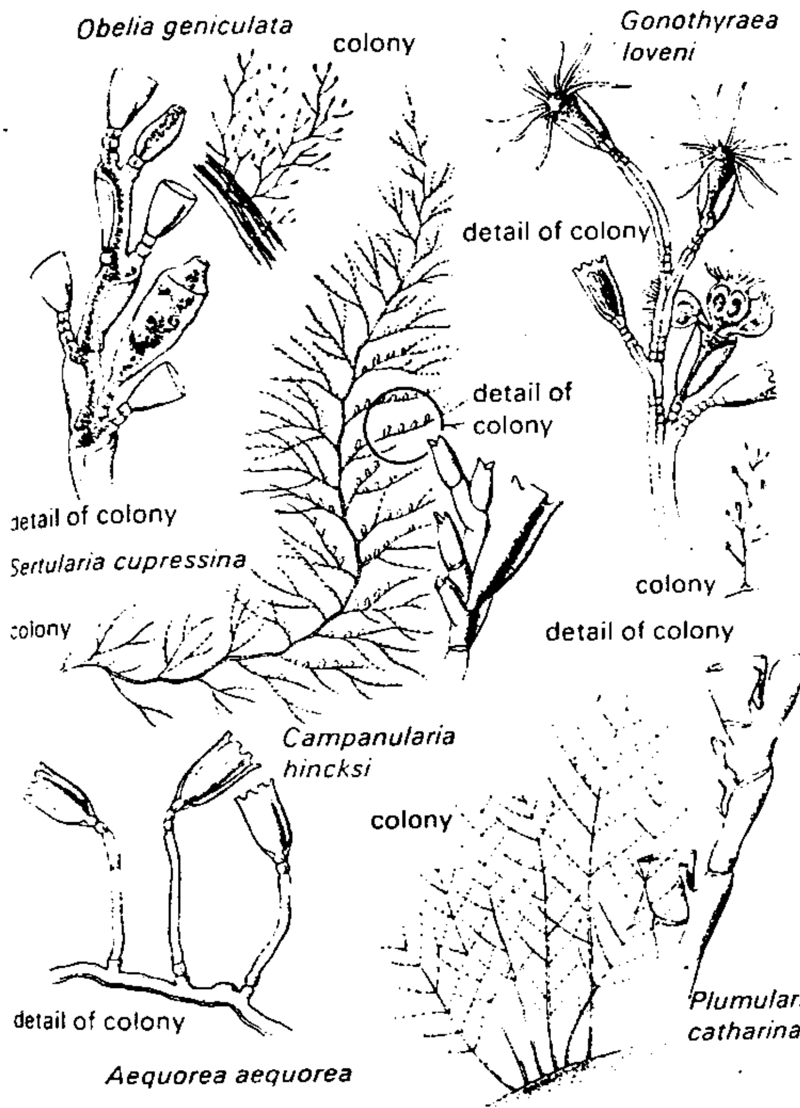
DEEP SHALLOW.

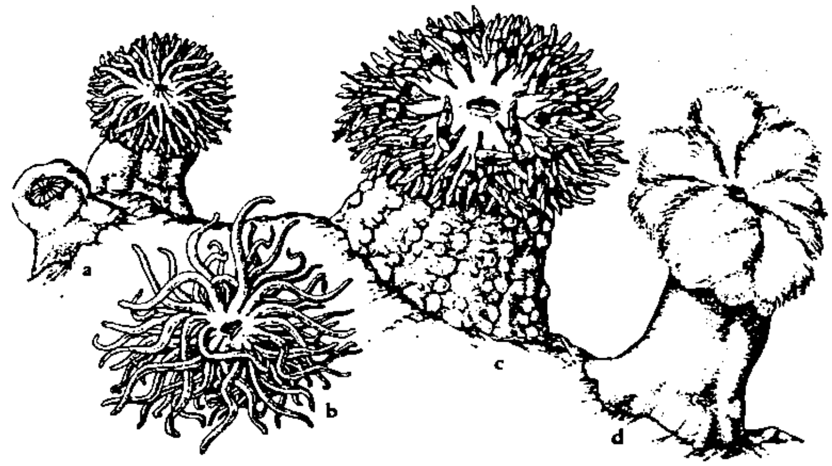
This is made up of a large number of animal life as well as the plant life which would be expected. Examples follow:

Type	Description	Depth
Algae	Soft slime coating	- 20M
Seaweeds	Kelp, Thongweed, Bladder wrack etc	- 30m
Dead mans fingers	Soft white growths with polyps Animal	- 150m
Soft corals	Soft covering to structure "	- 6000m
Bryzoa	Moss like covering "	- 1000m
Sponges	Filter feeding animal	- 1000m
Hydroids	Plant like animals	- 1000m
Anemones	"Flowering" animals	- 1000m



Alcyonium digitatum





Four common anemones of rocky shores: (a) beadlet (b) snakelocks (c) dahlia and (d) plumose.

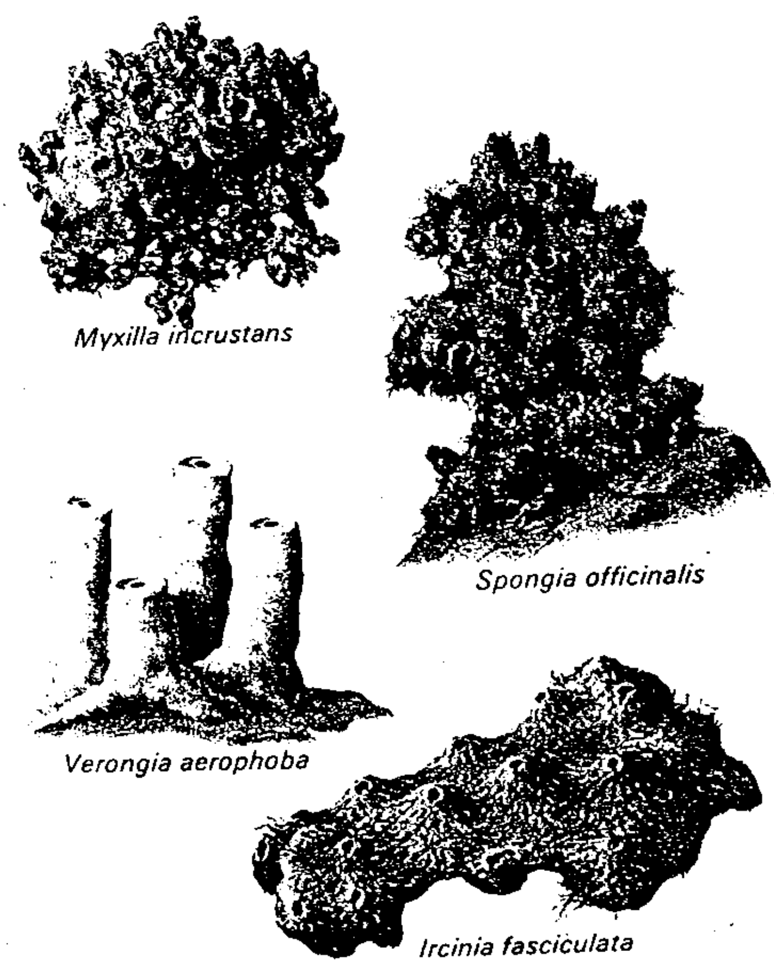


Figure 4.6 Examples of Soft Marine Growth

Q.

METHODS OF MARINE GROWTH REMOVAL

EFFICENCY.

FOR SMALL AREA.

Method	Advantages	Disadvantages
Hand cleaning (Scraper, wire brushes)	Inexpensive, easy to deploy, no training necessary	Diver fatigue, slow, difficult to achieve bright shiny finish
Pneumatic tools	More efficient than hand tools, less diver fatigue MC.	Depth limitation, difficult to control, exhaust air causes problems and there is a high maintenance requirement, NOISY. Needle gun most detrimental and so should not be used
Hydraulic tools	Same as pneumatic but with no depth limit	Expensive, choice of tools is limited, bulky/heavy hoses
H.P Water jet	Fast and effective, good for intensive cleaning, this will be the least detrimental method of cleaning a structure STEEL.	Hazardous, polished finish, reflects light in CCTV/Photography, least detrimental to the structure
AFTER TRAINED. Grit blasting	Cleans to matt finish, removes all growths	Hazardous, high level of maintenance, large backup required
Low pressure air grit entrainment	Fast and effective, low noise level and possible ROV deployment	Can be limited by depth (but with large air compressors this depth will fairly deep, typically 200 - 300m), large air compressors will be needed
Cavitation jets	Effective for removal of hard marine growth, relatively safe, do not require grit	Will not remove soft growths
Marine growth inhibitors PAINT, COPPER CLADDING, HENDERSON RING.	No diver intervention after installation	Will only remove soft growths and only in the splash zones

It should be noted that the advantages and disadvantages quoted are general. For example one of the hand cleaning advantages is that it is inexpensive, this is only if the amount of cleaning is limited to a small area, otherwise the cost in terms of time can be very high.

* DRAW H.P WATER JETTING SYSTEM & GRIT

LP WATER → HP. PUMP

GRIT HOPPER

DIVER/ROV GRITTING GUN

RETRO. - CLEANING JET

SAFETY ASPECTS OF HIGH PRESSURE WATER JETTING

When using high pressure water jets and grit blasting the pressures can be in excess of 15000 PSI, therefore we must have some basic rules for their use.

1. Never block or wire the trigger open.

2. When in use never point at anything other than the area to be cleaned.

3. Keep away from the retro-jet.

4. Never place any part of your body between the gun and the area to be cleaned.

5. Ensure high pressure hoses and fittings are tight and in good condition.

6. When grit blasting be aware of the hazard from grit damaging the life support system.

7. When grit blasting, if the grit has penetrated suit, gloves etc then consult medical advice immediately.

8. Do not fool around, treat the equipment with respect or it can kill or injure someone.

9. Minimum lance length should be 60cm.

In the event of injury the following information about the management of accidents with high pressure water jets has been made by the "Diving Medical Advisory Committee" (D.M.A.C.).

The wound caused may appear insignificant and give little indication of the extent of the injury beneath and the damage to deeper tissue. Large quantities of water may have punctured the skin, flesh and organs through a very small hole that may not even bleed.

Initial mild damage to the wall of an organ may result in subsequent rupture, particularly if infection has been introduced. The development of subsequent infection is particularly important in abdominal injuries.

MANAGEMENT

The outcome depends upon the extent of the initial injury and the presence or absence of infection, and even though the injury seems trivial on the surface and the patient has no complaints, it is of great importance to arrange for medical examination as quickly as possible. Where surgical examination is not immediately possible in a remote situation, first aid measures are confined to dressing the wound and observing the patient closely for the development of further complaints over four or five days. The development of fever and a rising pulse rate suggest that the injury is serious together with persistence or occurrence of pain. On evacuation, the diver should carry the following card which outlines the possible nature of the injury:

> This man has been involved with high pressure water jetting up to 14,500 lb/in^2 (100 Mpa, 1000 bar, 1019 Kg/cm^2) with a jet velocity of 900 miles per hour (1440 Kg/hour). Please take this into account when making your diagnosis. Unusual infections with micro-aerophilic organisms occurring at low temperatures have been reported. These may be gram negative pathogens such as are found in sewage, bacterial swabs and blood cultures may therefore be helpful

NB. **STANDARDS OF SURFACE FINISH**

The system which has generally been adopted in the North sea is an adaption of a Swedish standard originally used for the assessment of blast cleaning of steel prior to painting. In our circumstances this is termed the "SA system".

SA 1 - Light cleaning, removal of gross fouling (for general visual inspection).

SA 2 - Cleaning to paint coat including removal of loose paint and corrosion products.

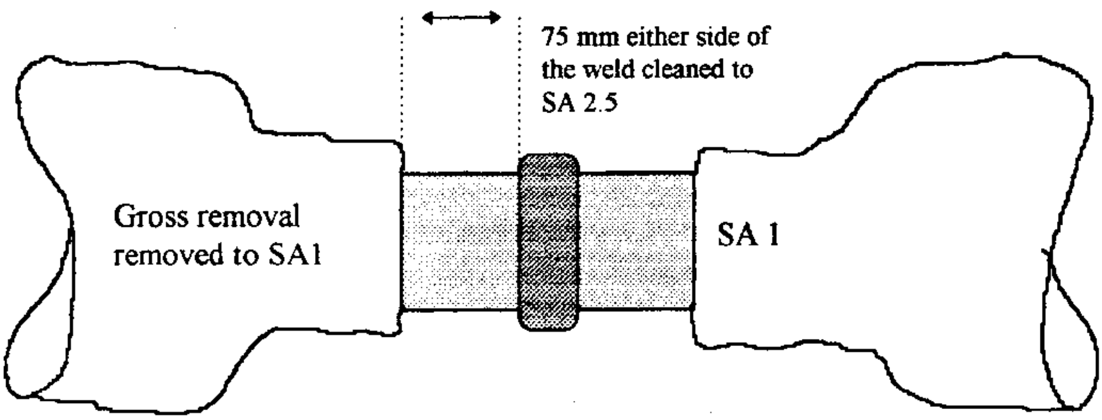
SA 2½ - Very thorough blast cleaning with grit entrainment resulting in dull matt metal finish (Close Visual and Magnetic Particle Inspection as well as most other methods including CCTV and Photography, as the matt finish will not reflect light unduly). This is the most commonly adopted level of cleaning used offshore as it allows the most versatility.

SA 3 - Thorough blast cleaning to bright shiny metal. This is good for most inspection but will reflect light in CCTV and Still Photography.

The size of the cleaned area is also very important and is dependant on the method of inspection in use. Generally the following is used:

For Close Visual Inspection and Magnetic Particle Inspection the **area to be cleaned to SA 2½ should extend to at least 75mm either side of the weld**. In addition enough of the surrounding area should be roughly cleaned to at least SA1 in order to allow access of the inspection equipment and intimate contact of the inspection equipment.

MC.



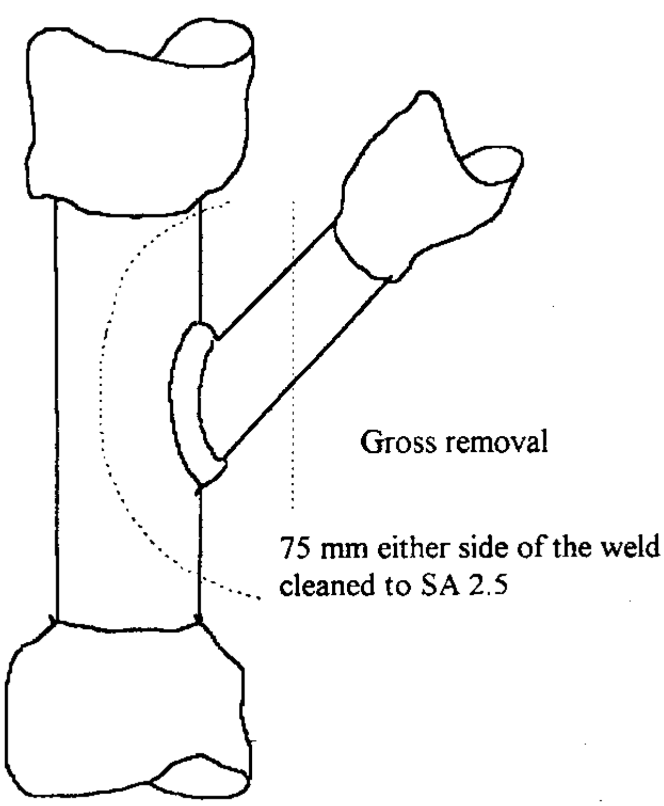


Figure 4.7 Cleaning of a Nodal Structure

NOTES

CHAPTER 5

DETERIORATION AND MODES OF FAILURE OF AN OFFSHORE STRUCTURE

Modes of deterioration of an offshore structure can be broadly classified into six groups:

1. Gross structural damage
2. Corrosion or erosion
3. Fouling defects M G & DEBRIS.
4. Coating defects
5. Scour
6. Metal and internal weld defects

We shall now look at the above categories in more detail:

1. GROSS STRUCTURAL DAMAGE

These are obvious defects which will be discovered during routine general visual inspections or post incident inspections. The following are some of the typical defects which will fall into this category:

a) Deformation of the structure
b) Loss of concrete matrix
c) Missing bolts from flanges and clamps etc
d) Paint coating damage or coating damage in general
e) Damage to cables or ducts
f) Unstable foundation
h) Missing members, anodes or components

2. CORROSION OR EROSION

This will be covered much more fully in the chapter on corrosion, but suffice to say at this point that any corrosion will be detrimental to the structure. It will tend to erode the safety factors built in with regard to the structures ability to carry loads.

3. FOULING DEFECTS

These consists of **both marine growth and debris**. For the effects of marine growth see the chapter titled MARINE GROWTH. Debris is any type of foreign body on or near the structure such as wire strops, containers, soft line, scaffolding bars and drilling equipment, etc. The effects of debris can be as follows:

a) Structural Damage

This will be dents and deformation of the structural members, caused by debris collision while on the way down through the structure.

b) Galvanic Corrosion

Also called dissimilar metal corrosion, caused when two different metals are in electrical contact with one another in an electrolyte (to be explained in the chapter on corrosion).

c) Overloading of the Cathodic Protection System

Caused by large quantities steel debris being in electrical contact with the structure, this will create an excessive load on the structures corrosion protection system, making it inadequate resulting in corrosion of the structure itself.

d) Safety Hazard to Divers

Divers will be at risk due to snagging and fouling of umbilicals, and from falling objects.

4. COATING DEFECTS

Paint and bituminous coatings can have the following defects:

a) Poor surface adhesion
b) Blistering of the coating
c) Flaking
d) Sagging and wrinkling
e) Cracked surface coating

The first three will be a progression with flaking being the worst lack of adhesion. If any blisters are found they should be burst enabling an assessment of the metal underneath. Sagging and wrinkling will normally be associated with bituminous or thicker coatings. Cracked surface coating will possibly allow water to come into contact with the surface of the steel.

Metal coatings

Metal coatings will cause trouble if they are breached in any way. They can also cause an increase in the corrosion of the structure below the coating if the coating is more noble than the steel (see inspection of coatings in the chapter on corrosion).

5. SCOUR

Scour is the undermining of seabed from around the structures foundation. This will be brought about due to an increase in the water flow rate around the base of the structure, in extreme cases this could lead to failure of the structure. This would be especially serious with a concrete structure.

* 6. METAL AND INTERNAL WELD DEFECTS (as per BS 499)

British Standard 499 groups internal metal and weld defects into the following six categories:

1. **Cracks** - Fracturing of the material. FATIGUE CRACKS MOSTLY HAZ.

2. **Cavities** - Gas pores in the material.

3. **Solid inclusions** - Copper, tungsten or slag etc, can become included during the fabrication of the weld.

4. **Lack of fusion and penetration** - Caused during fabrication, (lack of fusion is when the weld metal is not fused to the parent plate or a previous weld run). Lack of penetration would be where the weld metal does not extend to the back wall of the material and so will result in an insufficient throat thickness.

5. PERFECT SHAPE IS FLAT. **Imperfect shape** - Due to the parent plates being wrongly aligned or the wrong quantity of weld material being deposited.

6. **Miscellaneous** - Such as <u>arc strikes</u> STRAY FLASH or spatter; they are a result of the weld but may not be included in it.

* Note: A fuller description of BS 499 and the terms included in it will be found in the chapter on welding processes.

DETERIORATION OF THE OFFSHORE STRUCTURE

The deterioration of a structure could be said to start at the construction stage and continue on into the service life of the structure.

Problems will arise at each stage of the structures life, some of which are:

1. Manufacture of the Steel or Raw Materials

There are a number of defects which can be included in the raw material from which structures are made. These will stem from the molten stage at the steel works. These defects are termed **INHERENT DEFECTS** some of which are listed as follows:

a) Laminations, due to the pipe being included when the billet of metal is rolled.

b) Solid inclusions, such as slag and impurities from the molten stage.

c) Gas pores, included in the molten stage of the billet.

d) Stringers, rolled inclusions.

e) Fish tails, splashes solidifying on to a mould which has been allowed to cool to quickly.

2. Fabrication of the Structure

During the construction of a structure a number of defects can be included. If they are deemed to be significant then they will obviously be rectified before the structure is launched, (assuming that they are identified), as this is the most cost effective time to do remedial work.

The defects which can commonly occur are as follows:

a) Welding defects, as per B.S.499 (see metal and internal weld defects).

b) Grinding and tooling defects.

c) Accidental damage, dropped objects etc.

d) Residual stress, locking stress into the structure during welding and construction.

Some of these anomalies may be judged to be allowable depending on their size and orientation relative to the stresses involved and as such could be left unrepaired. These will become areas of particular interest in subsequent inspections.

3. Launch and Installation of the Structure

The launch phase will be the most stressful time for a structure. It will have to be either mounted on a barge or towed in a horizontal attitude to the location, then turned through 90 degrees and then piled onto the seabed. These manoeuvres are difficult to predict in terms of stress. The structure may well have been designed with regard to this being the worst stress that it will have to endure, indeed there will most likely be some members which become redundant items once the structure is installed. The kind of defects which can be included at this stage are as follows:

a) Accidental damage, dropped objects and shipping.

b) Piling defects, grouting defects and weld failure due to pile driving stress.

c) Scour or seabed abnormalities.

d) Poor positioning.

4. In Service

Once the structure has been launched successfully and the post launch inspection (baseline survey) has been carried out the structure will gain its verification and be **Fit For Purpose**. When the structure is in use the following defects can occur:

a) Fatigue due to hydrodynamic forces (wind and wave action) and vibration of the structure from drilling operations etc.

b) Overloading, due to changes in the production techniques. It is likely that the structure will have to carry a larger payload than was originally foreseen and this can cause problems which could lead to ductile failure, especially if there is any significant corrosion to compound the problem.

c) Corrosion of the steel causing a reduction of the wall thickness and an uneven surface. This can lead to stress concentration so reducing the safety factor.

d) Fouling, both marine growth and debris can be detrimental to the structure.

e) Accidental damage. As the structures are designed to high specifications if they become damaged then they will not be able to perform properly and so could fail.

f) Scour and unstable foundations will of course affect the structure.

g) Internal metal and weld defects (as per B.S.499, for more information on BS 499 see chapter 7 Welding processes).

NOTES

CHAPTER 6

INSPECTION OF CONCRETE STRUCTURES

IN DEPTH QUESTIONS.

Concrete structures are of a quite different design to that of the steel structures used offshore. The basic reason for this difference is that whereas steel is able to withstand tensile stress to a relatively high degree, concrete can not withstand tensile stress to any great degree. However concrete withstand a very great amount of compressive stress.

It is obvious that any structure which is in a harsh environment such as the North Sea will have to put up with a wide range of different stresses, so the construction of the concrete structure must allow it to withstand the effects of all types of stress.

Concrete does this by the inclusion of reinforcing bars or pre- stressed tendons which will in effect relieve the tensile and shear stresses that the structure would have to endure. This means that a concrete structure will have quite a considerable content of steel. In fact it could be approximately the same weight of steel as would be in a steel structure standing in the same depth of water. The metal used will not have to be of such a high grade, and so will be cheaper. The problem will arise if the steel in the reinforcing is in some way weakened, such as can happen with corrosion. If this happens then the structure could fail.

WHAT IS CONCRETE?

Concrete is a hard man made rock which can be cast into almost any shape. It is made up of large aggregate (Normally crushed Basalt, Limestone or Granite). In an offshore structure this large aggregate will have a diameter of between five millimetres and twenty millimetres (Possibly stones up to forty millimetres can be included). This will be mixed with fine aggregate which will be up to five millimetres in diameter, it is typically made up of washed alluvial sands. Both large and fine aggregate will be mixed with cement.
TO GET RID OF SALT.

NB Cement is a mixture of chalk, limestone, shale and gypsum, which is sintered in a kiln and then ground to a fine grey powder.

When all of the above are mixed in the right quantities and water is added then it will form a homogenous mixture with no voids, which will then set to form a hard man made rock. (This is a chemical process called **HYDRATION**).

THE FORMING OF CONCRETE

There are two ways in which we can form concrete they are:

1. Static Shuttering

Static shutters are used to form complicated configurations or shapes which need to be made more than once, such as arches, small walls and the like. The shutters can be made from wood, steel or glass reinforced plastic. The shutters will be held in place with an arrangement of tie rods and she bolts as shown in figure 6.1.

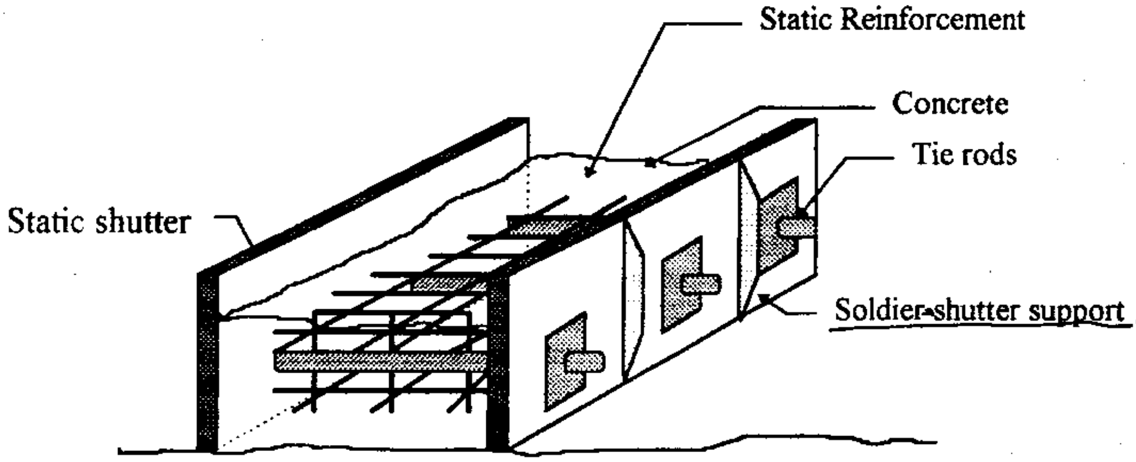


Figure 6.1 Concrete Formwork (Static Shuttering)

Advantages

a) Good for complicated shapes.
b) Can cast the same shape many times.

Disadvantages

a) Will produce a higher number of construction joints.
b) Will be slower when building a large structure of similar shape.

2. Slipform shuttering

Slipform shutters will be used to form large areas which do not vary greatly in shape, such as walls and the columns in offshore structures. They will be arranged in such a way that the concrete can be poured continuously and as the shutter fills it will be raised. (In an offshore structure they will be raised at approximately 200 to 250 millimetres per hour). The rate of climb will be dictated by the setting time of the concrete, which must be self-supporting as it emerges from the bottom of the shutter. This will enable a very consistent and quick building process. The shutters are jacked up on jacking rods which will eventually become a part of the reinforcing cage inside the structure, (see figure 6.2).

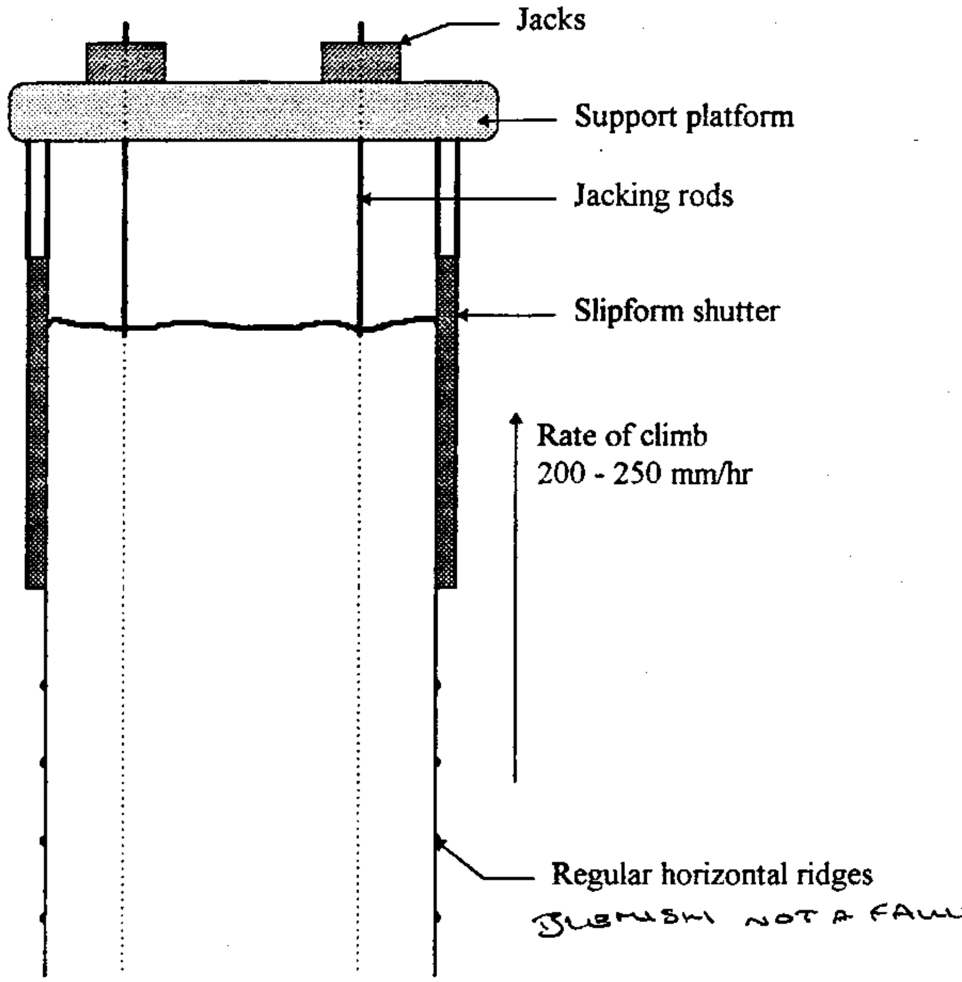


Figure 6.2 "Slipform" Shuttering

Advantages

a) Good for large areas of similar shape.
b) Will produce fewer construction joints.
c) Can pour concrete continuously.

Disadvantages

a) Cannot be used to form complicated shapes.
b) Will need to be supplied with a constant flow of concrete.
c) Will need a lot of large plant and equipment.

REINFORCING OF CONCRETE

Concrete is very strong in compression but will not withstand shear or tensile stresses well. Because of this we need a method of relieving these stresses, there are two methods widely used and they are:

1. Reinforcement Bars REBAR.

These are steel bars which are embedded in the concrete. Thus the structure can transfer stress from the concrete to the steel bars accordingly allowing the overall structure to cope with all types of stress. The size and density of the reinforcement bars (Re-bar) will be dictated by the amount of load they will be expected to carry.

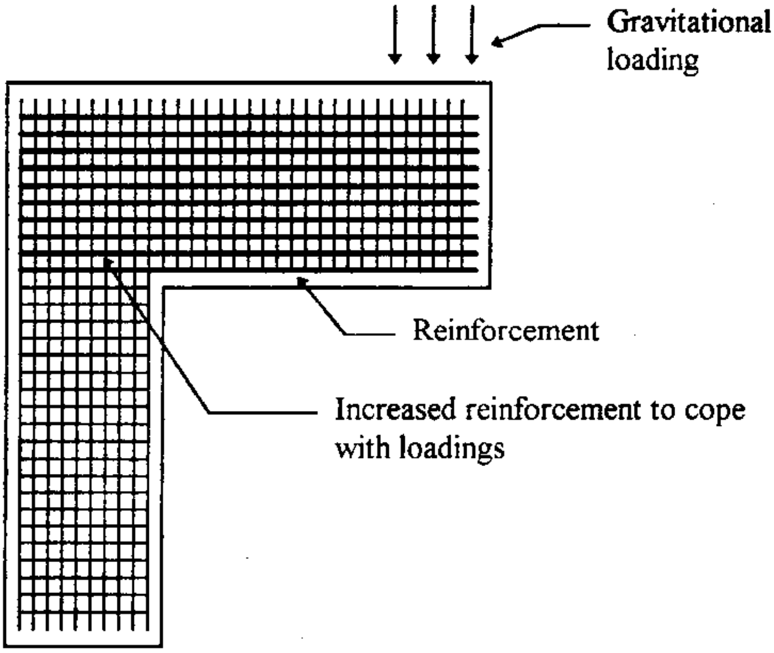


Figure 6.3 Static Reinforcement (Re-bar)

CONCRETE NOT PRECAST

MC. **2. Pre-stressed Tendons**

This method will produce the strongest form of concrete. The technique will involve running steel tendons through ducts in the structure. These tendons will then be anchored to the structure at one end. They will then be put under tension, while they are still under tension the other end will be anchored to the structure, then the tension will be released. The tendon will naturally try to regain its normal size and shape and in so doing will impart compressive stress into the structure. The compression should be sufficient to overcome any tensile or shear stresses which the structure may have to endure, for instance if the compressive stress imparted by the tendons is ten tonnes, and the tensile load is five tonnes then the structure will still be comfortably in compression and so will not fail.

Problems arise if the tendon fails. If this occurs then the structure will no longer be able to cope with the stresses and so will collapse, often without warning. From an inspection point of view the anchorage points are of prime importance as these are often the only visible points of the system. They are called **CACHETAGE POINTS** and will frequently be in pairs. They resemble a mound of concrete, possibly with a small tube emerging from it. They should be checked for cracking and staining. INSTANTANEOUS FAILURE, DISADV. MC.

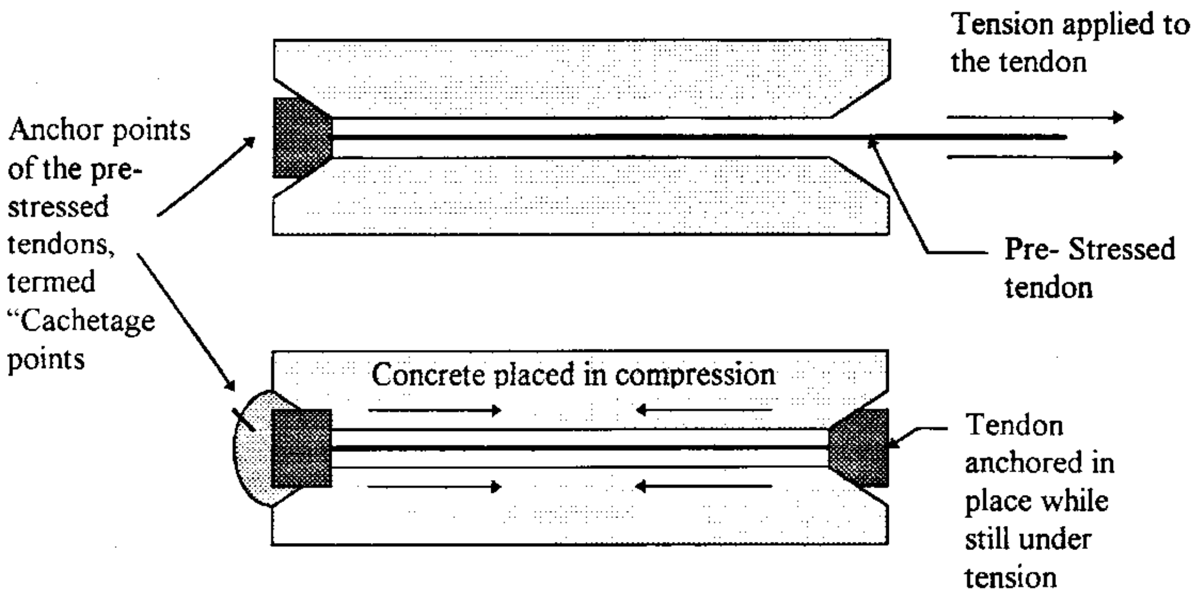


Figure 6.4 Pre-Stressed Concrete Reinforcement

The Protection of the Reinforcing Cage

Concrete is a porous substance and as such it will allow a certain ingress of sea water at all times. There is no concrete structure which has no cracks in it, this is not a problem unless the flow of water becomes too great. The re-bar is protected by the concrete changing the pH of the water to between 10 and 12. At this value the steel will not corrode significantly. This process is called **PASSIVATION**. If the flow of water becomes to great then the concrete will not be able to pacify the water quickly enough and so the re bar will corrode.

INSPECTION OF CONCRETE STRUCTURES OFFSHORE

The first problem that a diver will face when starting to inspect a concrete structure will be location and relocation. He will at first sight be faced with a huge featureless wall on which he will have to locate and accurately place defects so that they can be relocated at a later date.

There are a number of ways in which this can be achieved.

1. The Grid System

This system relies on a grid having been painted on to the surface of the concrete, probably at the time of construction. Each box will have a unique number which will probably also be painted on to the structure at the appropriate point. The diver will be guided to the proper box and the inspection will normally take place one box at a time.

2. The Shot Line and Tape System

This system owes its origin to archaeological digs. A vertical line is established which is graduated at regular intervals, (usually 1 metre). The diver then takes a tape measure and moves away from the line, being careful to stay at the same depth. In this way defects can be tied in to the vertical line and so can be relocated easily.

NB Diagrams of both of the above systems are included in the chapter, Structural Marking Methods and Size Reference.

TERMINOLOGY

There are twenty six terms applied to the inspection of concrete structures offshore and they are divided into three groups:-

* NB. **CATEGORY A (DEFECTS):** Serious

1. Cracks. in service
2. Delamination. "
3. Pop out. "
4. Impact damage. "
5. Tearing. - cons
6. Exposed reinforcement. in service
7. Faulty repair. in service
8. Variable cover. - cons

CATEGORY B (AREAS OF CONCERN):

1. Embedded objects.
2. Cast in socket.
3. Recessed metal plate.
4. Water jet damage.
5. Abrasion.
6. Honeycombing.

CATEGORY C (BLEMISHES): Normal characteristics.

1. Construction joint.
2. Formwork misalignment.
3. Blowholes.
4. Scabbling.
5. Rubbing down marks.
6. Good repair.
7. Regular horizontal ridge.
8. Irregular horizontal ridge.
9. Vertical drag marks.
10. Resin mortar repair.
11. Curing compound.
12. Grout run.

In addition to the above terms there are some signs which the diver inspector should be aware of, these are as follows:

1. Exudation - This is soluble salts leeching out from a crack or fissure in the concrete, it can be seen as a white substance adhering to the surface of the concrete along the line of the crack out of which it is leeching. On the surface this exudation will always run down the wall, however when in water the exudation may well be drifting upward or sideways, this is due to the density of the exudation being very similar to that of seawater.

2. Spalling - This is where a piece of concrete has been either knocked off or perhaps pushed out of the surface of the concrete, the spall is the loose piece of concrete and will inevitably have come from a spalled area which will be covered by one of the above terms.

DESCRIPTION AND PROBABLE CAUSE OF CONCRETE TERMS LISTED ABOVE

DEFECTS (Category A)

1. STRUCTURAL CRACKS NORMALLY FROM OVER LOADING.

Cracks can be divided into three categories:

a) Fine cracks - a fracture of the concrete not more than 1mm wide.

b) Medium cracks - fracture is between 1mm and 2mm wide.

c) Wide cracks - fracture is more than 2mm wide.

The edges of the fracture will normally be sharp and the aggregate may also be fractured. The normal cause is structural movement.

Although all concrete structures have some cracks in them they will not become significant until they are measurable, this will usually only occur in service.

2. DELAMINATION CHECKED WITH HAMMER, FROM TOP DOWN.

In this defect there will be a thin sheet of concrete which will have become partially detached from the main structure and in some cases can even become completely detached. Beneath the Delamination the surface of the structure will be much rougher and will show aggregate.

Delamination will usually be caused by corrosion of a layer of reinforcement or possibly impact damage.

Delamination is principally an in service defect.

3. POPOUT

A popout can be described as a small conical depression in the concrete surface, usually with a piece of corroding reinforcement at the bottom of the pit.

It is caused by the expansion of isolated particles in the concrete (or the corrosion of the ends of reinforcing bars). This causes the surface of the concrete to be put under tension and will so produce local failure in the form of a conical piece of the concrete popping out from the structure. The edges will usually be sharp and well defined.

Pop outs are an in service defect.

4. IMPACT DAMAGE

Impact damage can be described as a rough area in which the smooth surface of the concrete has been removed by means of a blow or impact.

It is caused by a blow from an object, which will dislodge part of the structure usually at the edges or corners.

The impact damage could occur either during the construction phase or the installation phase. It should have been found and corrected.

5. TEARING

Tearing can be crack like in it's appearance, but the width will vary and the edges are often rough and indistinct. Coarse aggregate will not be broken. It will be widest at the mid length point and it will tend to taper towards the ends. There may be some indications of rust staining.

While the concrete is inside the slipform shutter it adheres to the surface of the shutter and so when the shutter is moved upwards then the concrete is torn apart.

Tearing is formed during the construction phase. JUST ABOVE CONST. JOINT.

6. EXPOSED REINFORCEMENT

The steel reinforcement bars become visible on the surface of the concrete accompanied by rust staining.

There are two ways in which this can occur either by displacement of the steelwork during construction or by removal of the outside covering of concrete during the in service life of the structure (impact damage).

7. FAULTY REPAIR

This is any repair which will allow the ingress of sea water to the reinforcement cage. Normally this will have the appearance of a patch which will be of different texture and colour to the surrounding concrete. There could also be cracking around the edge of the repair and maybe a poor porous surface to the repair.

The cause is normally a defect that has been repaired badly.

8. VARIABLE COVER

50 - 80 mm.

Concrete protects the reinforcement cage by passivation but in order for ~~this~~ to be effective then there must be a minimum thickness of concrete over the reinforcement. This defect may not be visible, but in extreme cases there may be some rust staining seen.

The cause is either due to the reinforcement cage being displaced or the slipform shutter being dislodged.

Variable cover is a construction defect.

All of the above are defects primarily because they will allow a more or less unrestricted flow of seawater to the reinforcement cage, thus allowing corrosion to take place.

AREAS OF CONCERN (Category B)

1. EMBEDDED OBJECTS

This will consist of objects such as wire, nails, wood etc, which have been accidentally dropped into the concrete while it is still wet and become embedded objects. They will all have been included at the time of construction.

2. CAST IN SOCKETS

The visible description of cast in sockets is just a small hole which may have some threads visible inside. They will have been caused by the use of bolt fixings during the construction phase. The bolts will have been removed leaving the sockets still embedded in the concrete. They may well be filled with resin mortar.

Cast in sockets will have been included during the construction phase.

3. RECESSED METAL PLATE

This is a metal plate which has been cast into the structure. Usually it will be recessed some way into the concrete in order to allow the slipform shutter to pass unhindered. The recess will have rough uneven sides, there may also be some corrosion of the plate and so possibly some staining and cracking of the concrete around the plate.

These plates will be included in the structure during the construction phase.

4. WATER JET DAMAGE

Water jets can be used to cut through concrete, so great care must be taken in order to prevent the damage of the surface of the concrete during cleaning operations. If damage occurs it will form dark lines in an irregular pattern over an area of concrete which has been cleaned. Aggregate may be exposed and the surface will feel rough to the touch.

The damage is caused by the use of pressures which are to high, or by the use of a jet which is too small.

Water jet damage will occur in service.

MC. **5. ABRASION** LOOKS LIKE POLISHED SURFACE.

Abrasion can look similar to water jet damage but the surface will be smooth. Although the aggregate may well be visible the edges will be well defined.

Abrasion is caused by continual movement of hard objects against the concrete wearing away the surface, normally in service.

6. HONEYCOMBING NORMALLY ABOVE CONST. JOINTS.

Honeycombing will appear as an area of coarse aggregate which has little or no grout around it. Voids will be apparent in the concrete. The course aggregate will not be broken.

It is caused by insufficient compaction or vibration of the concrete during construction, or maybe grout loss beneath a shutter. Also it can be caused by the concrete not having sufficient fine material present.

Honeycombing occurs during the construction phase.

BLEMISHES (Category C, normal characteristics of concrete)

1. CONSTRUCTION JOINT

This will be a fairly straight line on the surface with irregular ridges and/or depressions along its length. The edges may be indistinct and may be accompanied by some tearing. The coarse aggregate will not be broken. The colour or texture of the surface above and below the joint may differ somewhat.

This blemish is formed at the end of one pour of concrete and beginning of another pour where the formwork has not been tailored to fit the structure very well.

Will occur during the construction phase and may be useful as a datum for the location of defects etc.

2. FORMWORK MISALIGNMENT

This will show as a step or a ridge on the surface of the concrete.

It is caused by the poor tailoring or fitting of shutters during the fabrication of the structure.

It will occur during the construction phase.

3. BLOWHOLES

These will be small holes in the surface of the concrete usually less than 10mm in diameter with sharp edges. There will not normally be any aggregate visible.

Blowholes are caused by air bubbles being trapped against the formwork face. There will always be some blowholes in a concrete structure but they will not be significant unless they are frequent, due to insufficient vibration of the liquid concrete slurry.

Will occur during the construction phase.

4. SCABBLING

This will have a rough surface appearance due to the surface of the concrete having been removed so exposing the course aggregate.

This is an intentional removal of the smooth surface, usually prior to placing further concrete. It will normally be done at the construction phase.

5. RUBBING DOWN MARKS

Irregular marks on the surface of the concrete may have the appearance of brush marks on wet concrete.

These are caused by the rubbing down of the concrete to remove surface blemishes as they emerge from the formwork. It may indicate a repair.

Rubbing down marks will have been done at the construction phase.

6. GOOD REPAIR

This will be a repair which has a smooth and complete appearance which is not likely to allow sea water ingress to the reinforcement cage.

This will have been done to repair a slight defect from the construction phase.

7. REGULAR HORIZONTAL RIDGE

These are ridges formed on the surface of the concrete, which are spaced regularly and will normally extend all around the structure.

As the slipform shutters rise the concrete should be self- supporting as it emerges from the bottom of the shutter. The shutter will be jacked up approximately once every hour and will then be stationary for the next hour. While the shutter is stationary there is often some sagging of the concrete from the base of the shutter which will form a ridge.

Will be formed during the construction phase.

8. IRREGULAR HORIZONTAL RIDGES

Irregular horizontal ridges may be from 50mm to 250mm apart but will not expose aggregate.

These ridges are a feature of slipforming. The shutters are tapered at the top and the pressure of each pour of concrete may cause outward movement of the shutters at the bottom allowing grout seepage.

These are formed during the construction phase.

9. VERTICAL DRAG MARKS

These are straight vertical marks with a course surface, sometimes referred to as pebble runs.

The drag marks are normally caused by stones or pebbles being trapped behind the slipform shutters and being dragged up the structure with them, so causing indentations in the surface of the concrete. They can also be caused by dents or deformations in the shutter itself.

Vertical Drag Marks are formed during the construction phase.

10. RESIN MORTAR REPAIR

This is a patch of a plastic type of substance on the surface of the structure.

It indicates that a defect has been repaired, maybe in the service life of the structure.

It can be an in service blemish.

11. CURING COMPOUND

These are large areas of coloured coatings which may well be peeling off and flaking.

Curing compounds are applied to concrete during the construction process to reduce water loss by evaporation during the curing of the concrete.

Therefor Curing Compound will be applied during the construction phase.

12. GROUT RUN

These will often be associated with a construction joint and will have the appearance of ragged, irregular runs of grout, adhering to the surface of the concrete.

They are formed by the leakage of concrete from the bottom of poorly fitting shutters. The concrete underneath will be unaffected by the run and so it will not pose a problem.

Grout runs will be formed during the construction phase.

SOME GENERAL TERMS

SPALLING

Spalling does not appear as a specific term, this is because spalling is now considered to be a symptom of one of the above. A spall is a loose piece of concrete which must have come from a spalled area which will be described by one of the above terms.

GROUT

Semi fluid slurry consisting of cement and water.

GUNITE

Concrete sprayed by compressed air. Will have high strength and density, used to repair walls and as weight coat on pipelines. It has a darker coloration than normal concrete.

CABLE DUCT

Cast tubular duct through which the pre-stressed tendons will run. Normally grout filled after tensioning.

PRESTRESSED CONCRETE

Concrete where all of the tensile and shear stresses are relieved by the introduction of compressive stress to the structure.

BASE RAFT

Foundation slab bearing on to the seabed.

CAISSON

Large cylindrical structure.

CELL

Void bounded by diaphragm walls.

INVERT

Lowest point of an opening or a tunnel.

SOFFIT

NC. The underside of a concrete beam, opposite of an invert.

JARLAN HOLE

Perforation in a breakwater wall, used to dissipate the forces from wave action, some of the force will be repelled and some will be admitted through the wall thus reducing the forces acting on the wall.

LAITANCE

This is a fine powdery substance which accumulates on the surface of concrete as it sets, it will need to be removed prior to any new pour being applied.

EXUDATION Sign of crack or something wrong.

Exudation consists of salts which dissolve in the concrete when fluid is passing through a crack, it shows on the surface of the concrete as a whitish semi-fluid, which accumulates around a defect. Note that on the surface it will always run downwards, however in water it may drift sideways or even upwards, owing to the fact that its density may be less than the water around it.

When inspecting concrete defects the following must be reported accurately:-

LENGTH OF DEFECT.
WIDTH OF DEFECT.
DEPTH DEFECT EXTENDS INTO THE CONCRETE.
POSITION ACCORDING TO THE MARKING PROCEDURE IN USE.

ALL CONCRETE DEFECTS WILL BE REPORTED IN THREE DIMENSIONS.

WEATHERING

Weathering is the term used for the deterioration of concrete due to environmental forces, these can be as follows (The equivalent to concrete corrosion) :

i) Erosion from water borne particles both in the splash zone and near the sea bed, can be caused by Cavitation in high flow environments.

ii) Frost damage in the splash zone, water will penetrate the structure to a degree and will then freeze and expand thus causing the normal structures porous concrete to crack and fall away.

iii) Chemical attack, salt attack will cause the structures concrete to become softened, it occurs near the surface of the structure and will take a very long time to show. Alkali reaction from the aggregate, can cause cracking of the concrete over a number of years.

iv) Corrosion of the reinforcement, this can occur if the electrolyte (seawater) is allowed to flow to freely through the concrete to the reinforcement cage, can cause catastrophic failure especially in the case of pre-stressed concrete structures.

All of the above are the concrete equivalent to corrosion in steel.

Offshore Technology Report OTH 84 206

The following is the method of identification of typical blemishes visible on the surface of concrete underwater, according to the **Offshore Technology Report OTH 84 206** which is the definitive document for companies inspecting concrete structure in the North Sea. This document groups the aforementioned terms as follows:

GROUP	DESCRIPTION
1	**Construction Irregularities**
2	**Redundant Built-In Items**
3	**Concrete Materials**
4	**Repairs and Surface Treatments**
5	**Superficial Marks and Stains + Marine growth**
6	**Physical Damage and Deterioration**

Of the above groups, the first four will most likely, but not always occur during the construction phase and groups five and six will be normally found to have occurred during the in service life of the structure.

Group 1 - Construction Irregularities

a) Typical surface finishes

- i) Slipform shutter
- ii) Slipformed surface, horizontal ridges
- iii) Slipform surface, vertical drag marks
- iv) Plywood shutter
- v) Board shutter

b) Shuttering effects

- i) Shutter misalignment

c) Construction joint

- i) Typical construction joint
- ii) Construction joint with seal

d) Grout/concrete overruns from shutters

- i) Runs of hardened grout
- ii) Sheets of hardened grout/concrete

e) Construction stains

- i) Surface staining during construction

Group 2 - Redundant Built-In Items

a) Built-in items

i) Recessed metal plates
ii) Flush metal plates
iii) Sockets and bolts
iv) Cast-in bolt
v) Pipework etc

b) Construction equipment

i) Attachments for construction purposes
ii) Shuttering equipment - tie rods
iii) Shutter plates and bolts

Group 3 - Concrete Materials

a) Blowholes
b) Aggregate bridging
c) Honeycombing
d) Popouts

Group 4 - Repairs and Surface Treatment

a) Making good

i) Small repairs
ii) Infill to bolt holes

b) Resin systems

i) Crack repair
ii) Seal to construction joint

c) Epoxy/pitch epoxy paints

i) Surface seal to construction joint
ii) Seal to built-in items
iii) Seal to surface of concrete
iv) Cementatious repairs

Group 5 - Superficial Marks and Stains

a) Stains

i) Rust stains from external ferrous objects
ii) Staining from internal sources

b) Exudation

i) Moderate deposits
ii) Heavy deposits

c) Surface cleaning marks

i) Water jetting marks

Group 6 - Physical Damage and Deterioration

a) Impact damage

i) Superficial damage

b) Abrasion

i) Abrasion by suspended object

c) Structural cracks

i) Fine - 0 to 1mm wide
ii) Medium - 1 to 2mm wide
iii) wide - Over 2mm wide

d) Deterioration of surface treatments

i) Peeling of epoxy surface treatments

e) Spalling

i) Uneven spalling

To help in the identification and on the job classification, it may help to use **KEY WORDS**, these are as follows:

KEY WORDS

1 Grooves/Rebates/Ridges/Channels
2 Cracks/Flaking/Peeling/Separation
3 Stains/Runs/Drips/Deposits
4 Holes/Depressions/Voids
5 Strips/Bands/Patches/Coating
6 Nuts/Bolts/Plates/Beams
7 Lines/Marks/Streaks
8 Surface appearance: Smooth
9 Surface appearance: Coarse/Rough

The method of use of the above would be as follows:

1 Examine the affected area and decide on the most obvious feature from the above list

2 Look to the table below

3 Follow down the left hand column and select the detailed description most closely matching the affected part

4 The title and name for the affected part will be shown on the right hand side

1 - Grooves/Rebates/Ridges/Channels

Description	**Title**
Irregular horizontal ridges across the surface which may be from 50mm to 250mm apart	Slipform surface - horizontal ridges
Fine regular parallel horizontal ridges at approximately 50mm centres	Slipform surface - horizontal ridges
Vertical grooves or bands with rough edges	Slipform surface - vertical drag marks
Small dark ridges in a regular pattern on a smooth plain surface. patterns may be visible	Plywood shutter Wood grain
Parallel ridges on a rough surface on which wood grain patterns may be visible	Board shutters
Perpendicular ridge or step in the concrete surface	Shutter misalignment

Description	Title
Generally straight line on the surface with irregular ridges and/or depressions along its length	Construction joint
Straight narrow rebate/channel with sides perpendicular to the concrete surface. A black rubbery material may be seen in the rebate	Construction joint with seal
Irregular and generally horizontal crack-like lines and/or ridges. Layers of the concrete surface may be detached along the line	Sheets of hardened grout

2 - Cracks/Flaking/Peeling/Separation of Material

Description	Title
Irregular and generally horizontal crack-like lines and/or ridges. Layers of the concrete surface may be detached along the line	Sheets of hardened grout
Rough irregular area with the surface missing and/or detached and the larger stones clearly visible	Superficial Impact damage
Cracks in the concrete surface	Structural cracks
Flaking or separation of a coloured plastic like skin from the concrete	Peeling of epoxy surface treatments
Pieces of concrete lifting or separating from the surface leaving an irregular depression in the concrete, which has a different surface texture to the surrounding area. Cracks may be evident	Spalling

3 - Stains/Runs/Drips/Deposits

Description	Title
Surface appears to have run forming irregular horizontal ridges across the surface which may be 50mm to 250mm apart	Slipform surface - horizontal ridges

Ragged runs or drips of material identical in colour and texture to the surrounding area adhering to the concrete surface	Runs of hardened grout
Streaks or patches of colour usually showing signs of liquid flow	Staining of surface during construction
Red brown surface discolouration which may reproduce the outline of the object that made it	Rust stains from external ferrous objects
Red brown surface discolouration coming from within the concrete behind an infill area	Staining from internal sources
White deposits coming from a crack or construction joint	Exudation

4 - Holes/Depressions/Voids

Description	**Title**
Small circular hole. Threads may be visible internally	Built-in items - sockets and bolts
Small recesses in which the ends of steel rods may be visible	Shuttering equipment - tie rods
Individual rounded holes in the surface, usually less than 10mm across	Blowholes
Irregular holes on vertical surfaces 10mm to 20mm across	Aggregate bridging
Rough stony surface with voids between the stones	Honeycombing
Small conical depression in the surface of the concrete	Popouts
Rough irregular area with the surface missing and the larger stones clearly visible	Superficial impact damage

Irregular depression with a different surface texture to the surrounding concrete as a result of concrete lifting or separation from the surface. Holes, fissures and reinforcement may be visible. Cracks may be evident	Spalling

5 - Strips/Bands/Patches/Coating

Description	**Title**
Vertical grooves or bands with rough edges	Slipformed surface - Vertical drag marks
Patches of colour usually showing signs of liquid flow	Staining of surface during construction
Strip or patch of material similar in appearance to the main concrete, probably of slightly different colour and texture	Small repairs
Neatly finished circular patch or irregular round patch with rough untidy surface	Infill to bolt holes
Regular band of smooth, coloured, plastic like material. Small dark patches and/or small diameter pipes may be visible at regular intervals along the band. It may trace an irregular path across the surface	Crack repair
Regular band of smooth, coloured, plastic like material running horizontally across the concrete filling a rebate or channel	Seal to construction joint
Broad black, white or grey band usually horizontally	Surface seal to construction joint
Smooth coloured band around a built-in item	Seal to built-in item
Irregular areas of smooth, coloured material	Seal to surface of concrete

Red brown surface discolouration	Rust stains
Regular shaped, light coloured, polished band of concrete	Abrasion by suspended object
Patches formed by flaking or separation of a coloured plastic like skin from the concrete	Peeling of epoxy surface treatments

6 - Nuts/Bolts/Plates/Beams

Description	**Title**
Metal plate set back from concrete surface	Recessed metal plates
Metal plate flush with the surrounding surface	Flush metal plates
Small circular holes	Sockets and bolts
Bolt usually showing signs of corrosion either projecting or flush with the concrete surface	Cast in bolt
Beams, plates etc. Fastened to the concrete. These items may be corroding and covered by marine growth	Attachments for construction purposes
Small recess in each of which the end of a steel rod may be seen	Shuttering equipment tie rods
Steel washer plate approximately 100 x 100mm retained on a steel rod by a wing nut, nut or wedge	Shutter plates and bolts

7 - Lines/Marks/Streaks

Description	**Title**
Irregular horizontal lines/marks running across the surface 50mm to 250mm apart	Slipformed surfaces - horizontal ridges

Fine regular parallel horizontal lines/marks on concrete surface at 50mm centres	Slipformed surfaces - horizontal ridges
Vertical marks ranging from deep narrow grooves with rough edges to broad irregular bands with a coarse surface	Slipformed surfaces - Vertical drag marks
Straight dark lines/marks forming a regular pattern on a smooth plain surface. Wood grain patterns may be visible	Plywood shutter
Parallel lines/marks on an irregular rough surface on which wood grain patterns may be visible	Board shutters
Perpendicular ridge or step in the concrete surface	Shutter misalignment
Generally straight line on the surface with irregular ridges and/or depressions along its length	Construction joint
Generally smooth surface is marked by irregular horizontal lines	Sheets of hardened grout or concrete
Coloured patches of streaks usually showing signs of liquid flow across the surface	Staining of surface during construction
Red brown lines, streaks or marks on the concrete surface	Rust stains
White marks emanating from a crack or construction joint	Exudation
Dark streaks or marks, frequently curved forming an irregular pattern over a concrete surface	Water jetting marks
Dark irregular lines which may vary from very fine to several mm wide formed by a fracture of the concrete	Structural cracks

8 - Surface Appearance: Smooth

Description	Title
Smooth plain surface crossed by straight small dark ridges. Wood grain pattern my be visible	Plywood shutter
Smooth strip or patch of material similar in appearance to main concrete by probably of slightly different colour and texture	Small repairs
Smooth neatly finished circular patch	Infill to bolt holes
Regular band of smooth, coloured plastic like material. It may trace an irregular path across the surface	Crack repair
Regular band of smooth, coloured, plastic like material running horizontally across the concrete filling a rebate or channel	Seal to construction joint
Smooth broad black, white or grey band usually horizontal Smooth coloured band around a Built-in item	Surface seal to construction joint Seal to Built-in items
Irregular areas of smooth, coloured coating	Seal to surface of concrete
Regular shaped light coloured, polished, band of concrete	Abrasion by suspended object
Smooth coloured bands or areas which may be irregular in appearance	Peeling of epoxy surface treatments

9 - Surface Appearance: Course/Rough

Description	Title
Surface has a coarse texture with horizontal and vertical ridges	Slipform shutter

Parallel ridges on a rough surface on which wood grain patterns may be visible	Board shutter
Generally straight line on the surface with irregular ridges and/or depressions along its length	Construction joint
Ragged runs or drips of material identical in colour and texture to the surrounding area adhering to the concrete surface	Runs of hardened grout
Rough stony surface with voids between stones	Honeycombing
Rough irregular area with the surface missing and/or detached and the larger stones clearly visible	Superficial impact damage
Irregular depression caused by pieces of concrete separating or lifting away from the surface. Within the depression the surface may be rough and uneven with cracks	Spalling
White deposits coming from a crack or construction joint	Exudation

NOTES

CHAPTER 7

WELDING PROCESSES

In order for the underwater inspector to be able to assess welds properly it is very important to have an understanding of the processes involved in the fusion of two metal plates together.

There are a very large number of fusion processes currently used in industry (approximately 35). The underwater inspector needs only to have an appreciation of three of these fusion processes, these are as follows:

1) Flux shielded arc techniques
2) Inert gas shielded techniques
3) Friction welding

1) FLUX SHIELDED ARC TECHNIQUES

These can be split into a further three groups:

a) Manual Metal Arc (MMA). STICK WELDING flux = slag inclus
b) Automatic Metal Arc. S.W by machine!
c) Submerged Arc. SEAM OR PLATE WELDS.

With all of these methods the weld pool is shielded from oxidisation by the flux vaporising and forming a gas shield over the weld pool. When the weld solidifies the flux will form a deposit on the surface of the weld, termed slag, which can become included in the weld to form a slag inclusion.

a) Manual Metal Arc

This is the common "stick" welding. The rod will carry an electric current which when in close proximity of an earthed workpiece will cause an arc to form. This melts the parent plates and the filler rod to form the weld. Electrostatic attraction of the charged molten drops to the earthed workpiece means the weld can be done positionally. The flux which is carried around the rod is vaporised to form the shield. The rod is consumed and will form the filler material for the weld.

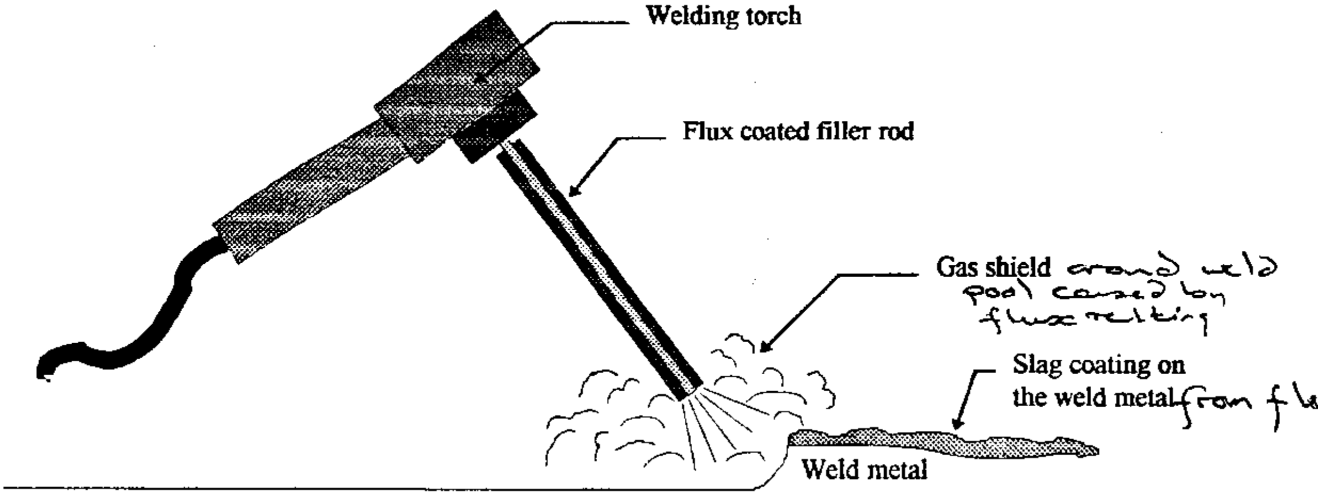


Figure 7.1 Manual Metal Arc Welding

b) Automatic Metal Arc

This method is similar to the above, the difference being that the filler rod does not carry the electricity. This is picked up by spirally wound wires on the outside of the flux coating. The rod is fed automatically to the workpiece. Apart from these differences the process is the same as above.

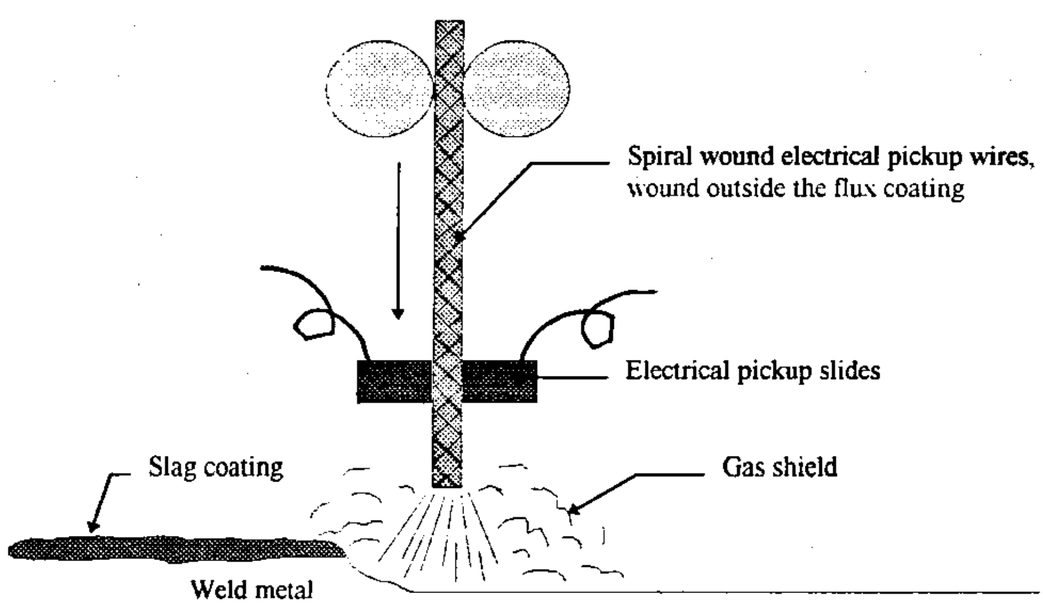


Figure 7.2 Automatic Metal Arc Welding

c) Submerged Arc => SEAM WELDS ON PIPES.

With this method the electricity is again carried by the filler rod but the powdered flux is poured down a tube so that the weld groove is filled. The arc then is produced inside or submerged in the flux.

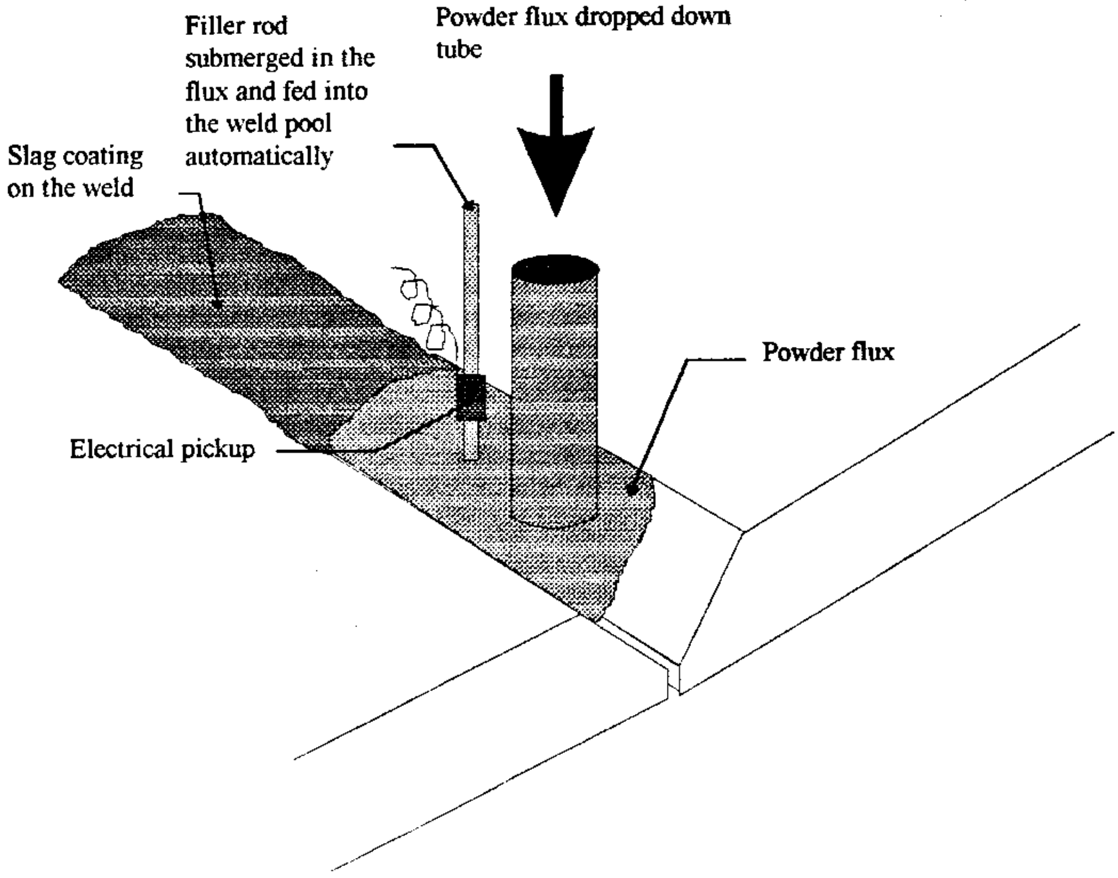


Figure 7.3 Submerged Arc Welding

2. GAS SHIELDED ARC TECHNIQUES

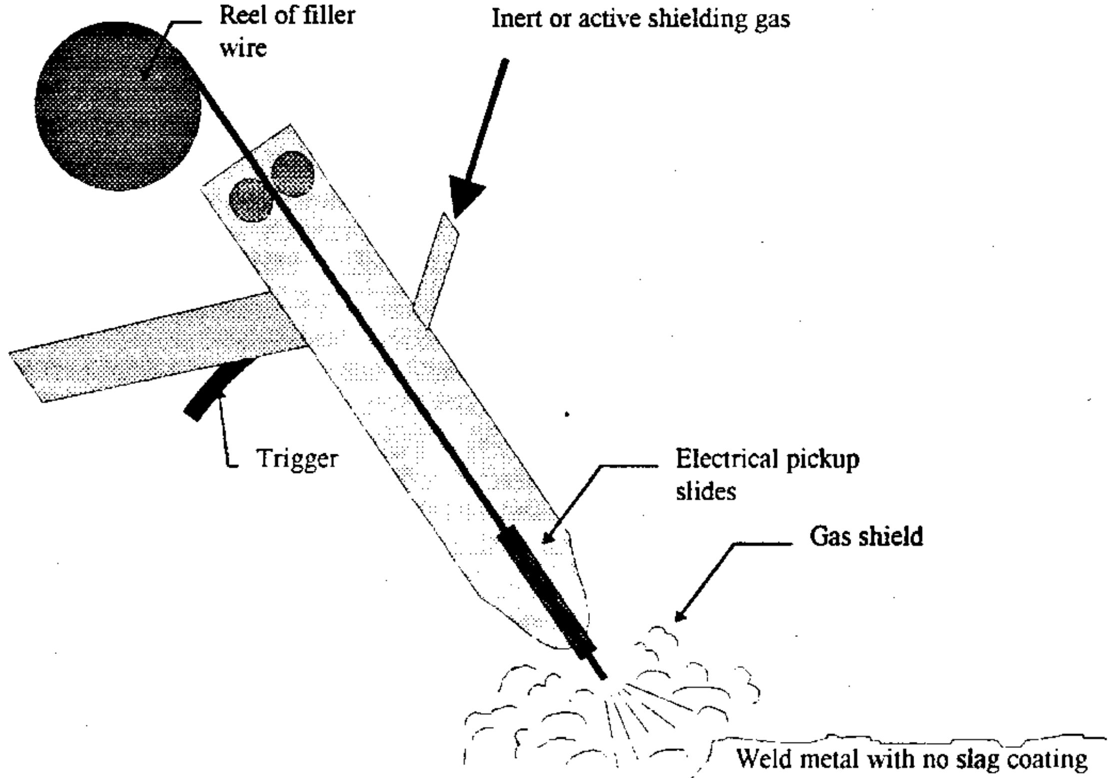
These can be split into a further two groups:

a) Metal Inert Gas (MIG) or Metal Active Gas (MAG).
b) Tungsten Inert Gas (TIG).

With both of these methods the weld pool is shielded not by flux vaporising, but instead by applying either an inert gas or active gas via a shield nozzle to the workpiece at the point of the weld pool.

a) Metal Inert Gas or Metal Active Gas THIN MATERIALS OR ALLOYS.

This method has the filler wire contained on a spool being fed through a gas nozzle to the workpiece. The arc is formed between the filler wire which is carrying the electricity and the workpiece. The shield gas is fed continuously through the nozzle when the trigger is depressed. This method can deposit Copper into the weld if the copper electrical pick up is dipped into the weld pool. MIG is generally used for Aluminium or Magnesium but may sometimes be used for hyperbaric welds, MAG is normally used for steel welds when on surface, however as the shield gas will normally be CO_2, it could cause problems for the divers if it were used in a chamber.

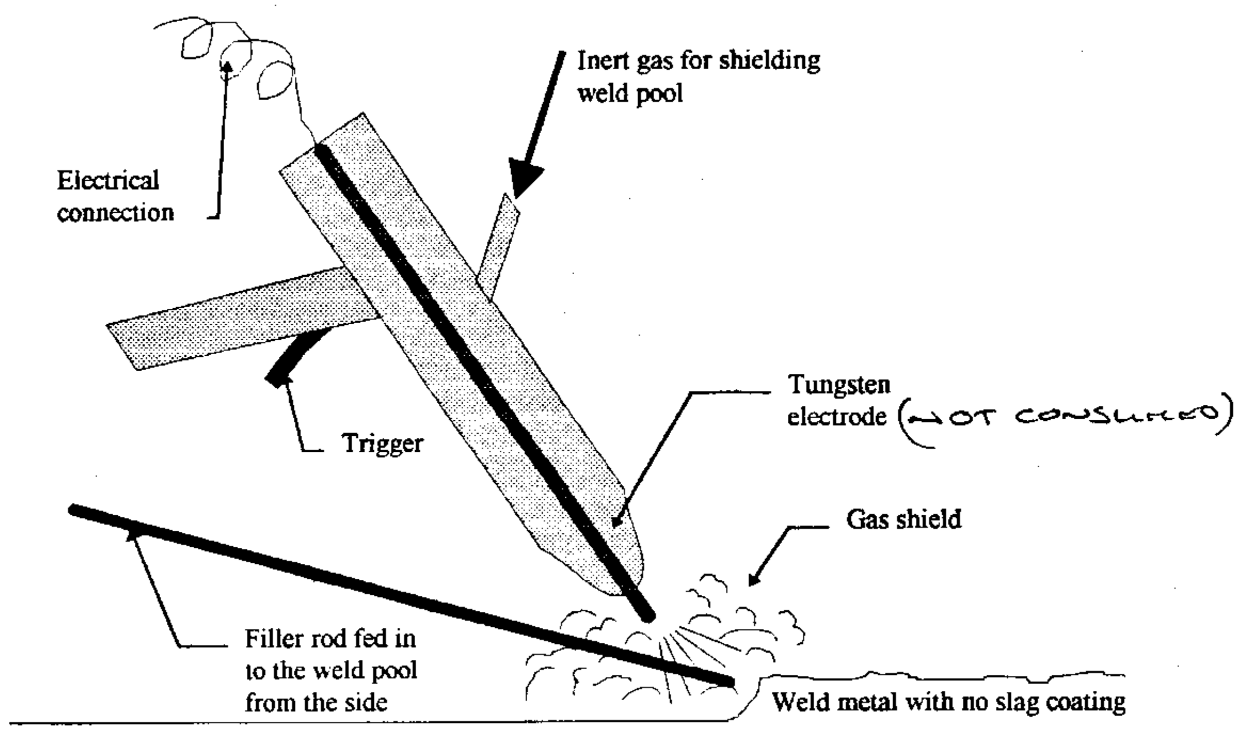


can get copper inclusion. Serious prob, copper shrinks qu causes cracking.

Figure 7.4 Metal Inert Gas (MIG) Welding TUBULAR & PIPE WELDS.

b) Tungsten Inert Gas

This method is much the same as above except that the filler rod is fed in from the side much as in gas welding. The electricity is carried by the Tungsten electrode inside a ceramic holder. The weld pool is shielded by the inert gas being fed through the nozzle. This method can deposit Tungsten into the weld if the electrode is dipped into the weld pool.



POSS. TUNGSTEN INCLUSION NOT AS BAD AS COPPER DIFFICULT TO S

Figure 7.5 Tungsten Inert Gas (TIG) Welding

All of the above methods use an electric arc to produce enough heat for the fusion of the parent plates (typically 6000° C). As the molten drops are electrically charged they will be electrostatically attracted to the workpiece allowing overhead welding.

3. FRICTION WELDING

This method does not rely on the use of electricity to melt the workpiece, rather it relies on friction. The component to be welded is placed into a machine capable of rotating at high speed. As well as producing an axial pressure to the workpiece, the component is rotated at high speed while pressure is applied. The result being that the fusion faces of both workpiece and component will melt. The rotation is then abruptly stopped and the weld is allowed to cool.

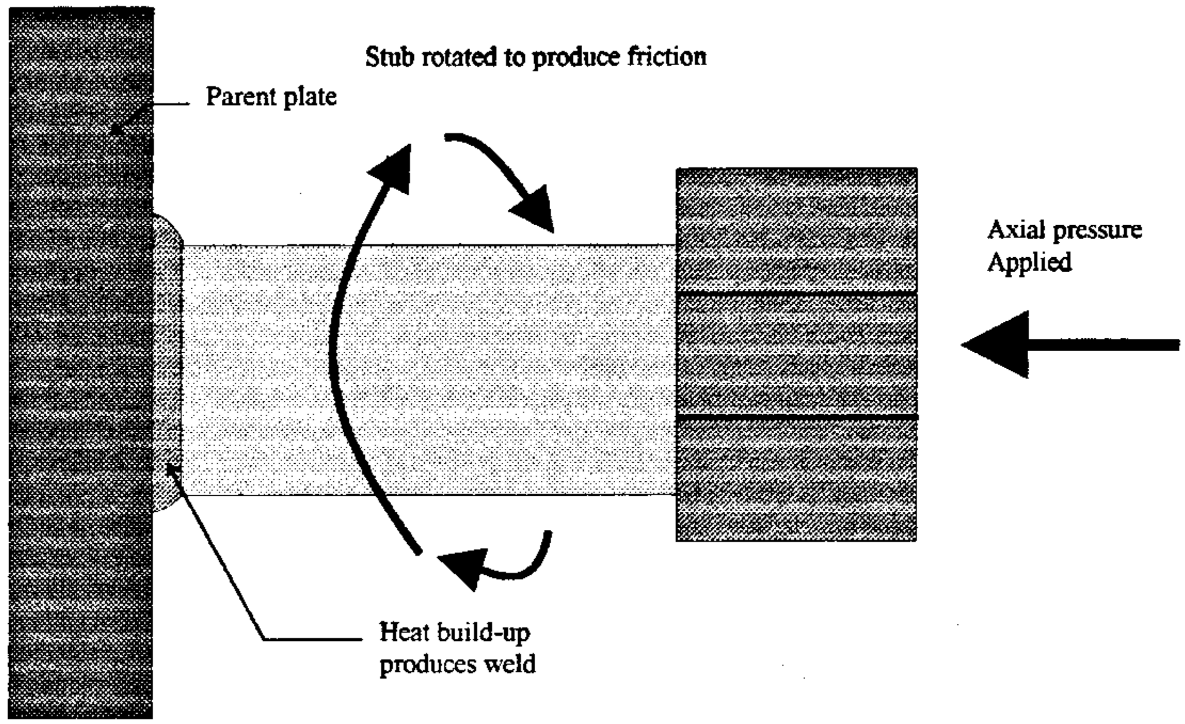


Figure 7.6 Friction Welding

TYPES OF WELDED JOINT

There are approximately 110 different welded joint variations, most of which are not widely used in the construction of offshore structures. The underwater inspection personnel need to have a knowledge of only five main types of joint which are:

1. Butt Joint

Two parent plates fitted together at an angle of between 135° and 180°. This will be used offshore for circumferential and seam welds.

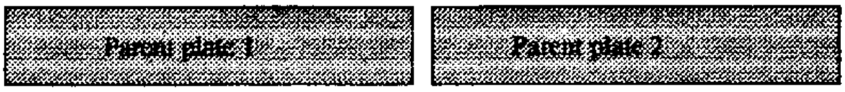


Figure 7.7 The Butt Joint

2. "T" Joint

The two parent plates are fitted together at an angle of between 5° to 90°. This means the end of one piece and the face of the other piece will come into contact, such as the joint between two tubular members as in a node.

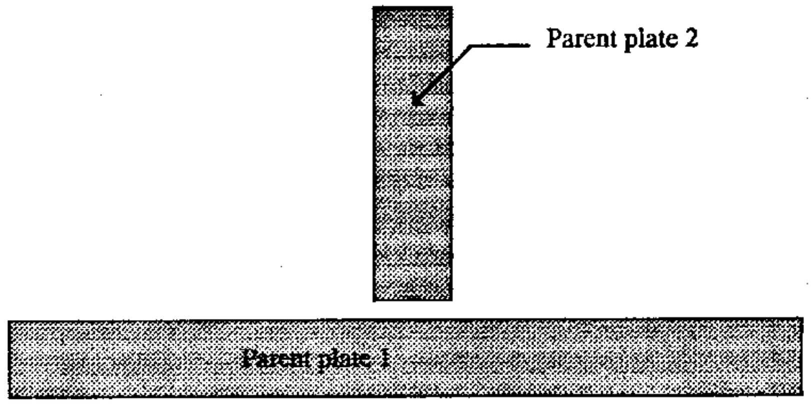


Figure 7.8 The "T" Joint

3. Lap Joint

The two parent plates are fitted one on top of the other the angle will be 0° to 5°.

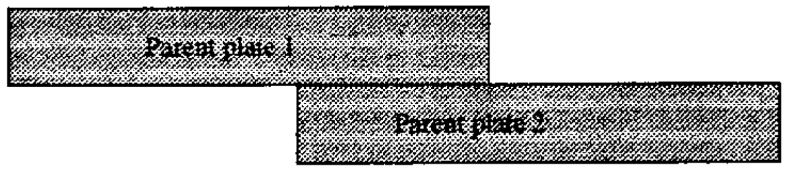


Figure 7.9 The Lap Joint

4. Corner Joint

The two parent plates make a connection at the edges to make a joint at an angle of between 30° to 135°.

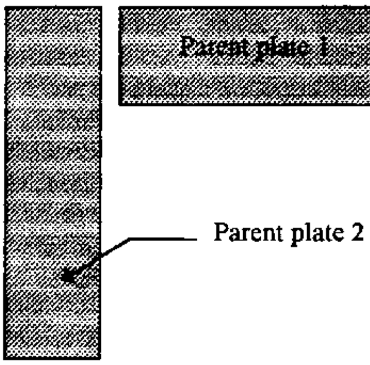


Figure 7.10 The Corner Joint

5. Cruciform Joint

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

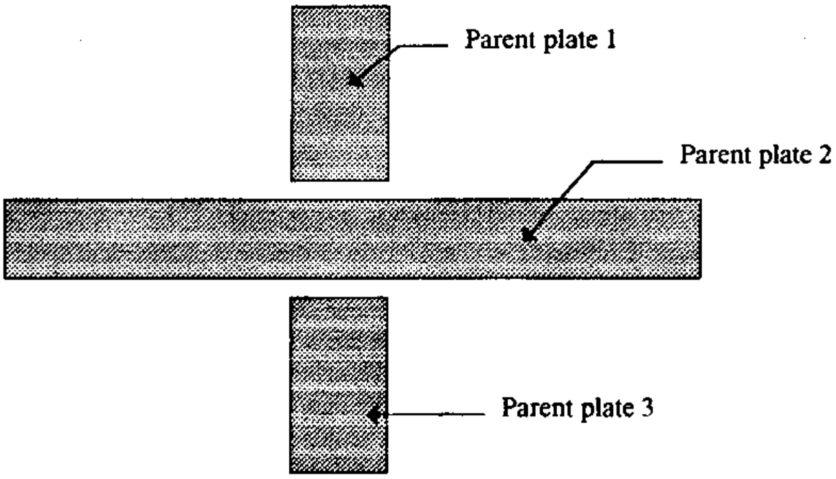


Figure 7.11 The Cruciform Joint

The most common joint used and therefore inspected offshore is the "T" joint.

TYPES OF WELD

There are two types of weld most often referred to during inspection, they are "butt" and "fillet" welds. There are a number of variants, ie V, J or U but these just refer to the preparation. An inspector would not know from visual assessment the nature of a weld "prep". It would simply be described as a butt weld or fillet weld.

The general definition of a butt weld is: full penetration weld.

"A **tension** resisting weld in which the bulk of the weld metal is contained **within** the planes or thickness of the joined parent metals".

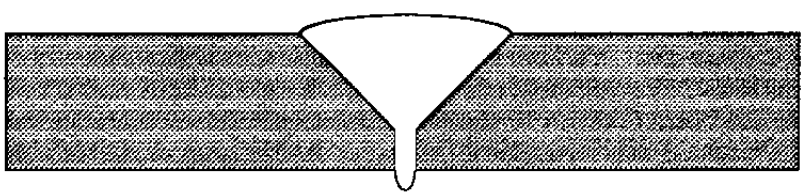


Figure 7.12 Butt welded Butt joint (Single "V")

The general definition of a fillet weld is:

"The bulk of a fillet weld is contained **outside** the parent metal planes or thickness. Therefore fillet welds tend to have less strength".

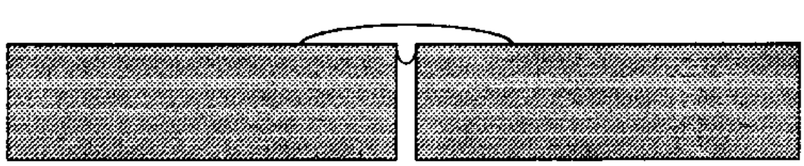


Figure 7.13 Fillet welded Butt joint

For this reason most welds found offshore by inspection personnel will be the butt type.

WELD DEFINITIONS FROM BRITISH STANDARD 499

British standard BS 499 is titled Welding Terms and Symbols. It dictates the terms and symbols to be used in welding. The following is an extract of the important terms from the point of view of the underwater inspector.

1) Parent plate - The metals which are to be joined by the weld.

2) Filler rod - Filler metal in the form of a rod. Sometimes the filler rods will be laid into the weld in layers, these will be termed **Filler Beads**

3) Run or pass - Weld metal deposited in a single run.

4) Weld zone - The area containing the weld and both heat affected zones.

5) Heat affected zone - The part of the parent plate which has been affected by heat but which has not melted.

6) Cap, Face of the weld - This is the exposed surface of a weld usually single, multi-beaded or weaved. This refers to the method used to lay the material into the weld, if the weld is a bead weld the welder will lay the rod into the weld without movement from side to side, this may give the appearance of several lines of weld material running along the axis of the weld. A weave weld will be formed by the wélder weaving the welding rod from side to side during the fabrication of the weld, this will produce a weld which has one single woven lay of weld in the cap.

7) Excess weld metal, - Weld metal lying outside the plane joining the weld toes or in excess of the specified weld size.

8) Toe of the weld - The junction between the face of the weld and the parent metal.

9) Root - The point at which the back of the weld intersects the parent metal.

10) Root bead, run - Weld bead protruding beyond the plane of the backwall of the parent plates.

11) Root gap - separation between the parent plates to be joined.

12) Root face - The un-bevelled portion of the parent plate adjacent to the root gap.

13) Throat thickness - The total thickness of the weld metal.

14) Effective throat thickness (design throat thickness) - Weld thickness for design purposes, usually a line between both toes or maybe slightly raised.

15) Weld width - The shortest distance between the outer toes of the weld.

16) Leg of a fillet weld - The distance from the root of the weld to the toe of the weld.

17) Residual welding stress - Stress remaining in the metal structure as a result of the welding.

18) Prepared face - The bevelled portion of the parent plate prior to welding.

19) Single V butt weld - A butt weld in which the prepared faces will form a V in section, welded from one side only.

20) Double V butt weld - A butt weld in which the prepared faces will form two opposing V's in section, welded from both sides.

21) Prepared angle, weld prep - The angle of bevel between the prepared face and the perpendicular line.

22) Included angle of a butt weld - The angle between the prepared faces.

23) Included angle of a fillet weld - The angle between the parent plates.

24) Weldment - this is sometimes the term used to describe the total weld zone.

25) Fusion Zone - Point at which parent plate melts and mixes with weld metal

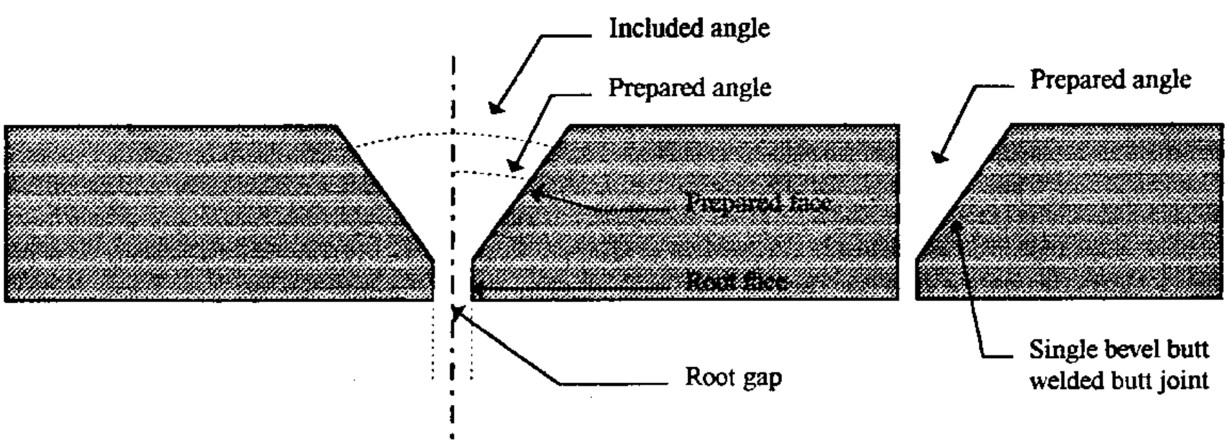


Figure 7.14 Plate Edge Preparation (Single "V" & Single bevel welded from one side only)

26) DOG SCARS - SCARS LEFT OVER FROM POSITIONING DEVICES DURING FABRICATION.

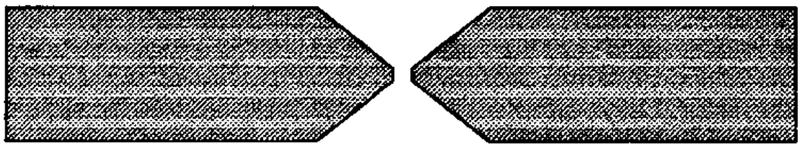


Figure 7.15 Double "V" Butt weld (Welded from both sides)

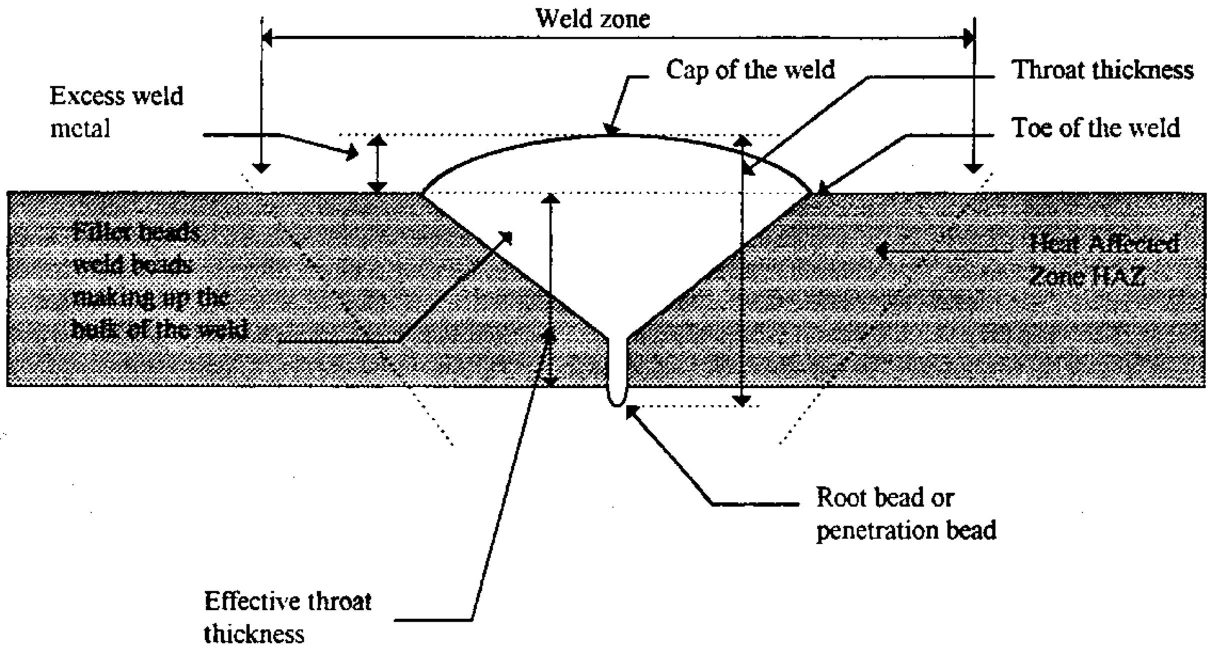


Figure 7.16 Butt Weld Terminology

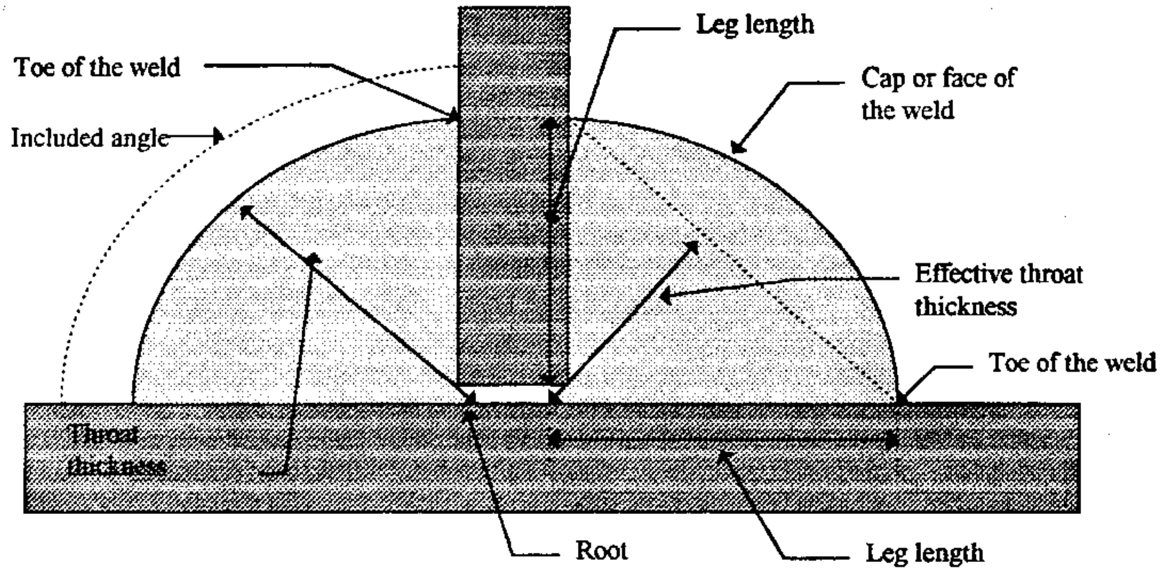


Figure 7.17 Fillet Weld Terminology

NODES AND NOZZLES

Nodes are the general term given to the joint between two or more tubular members offshore, in fact the joint can be either a node or nozzle.

Node - A node is a joint where only the minor member (known as the brace) is prepared and will be made to fit around the major member (known as the chord) as shown in figure 7.18 below. Note: That the chord is normally the major member, in the case of like size tubulars it will be the through member, the brace is the minor member or the tubular which terminates at the joint.

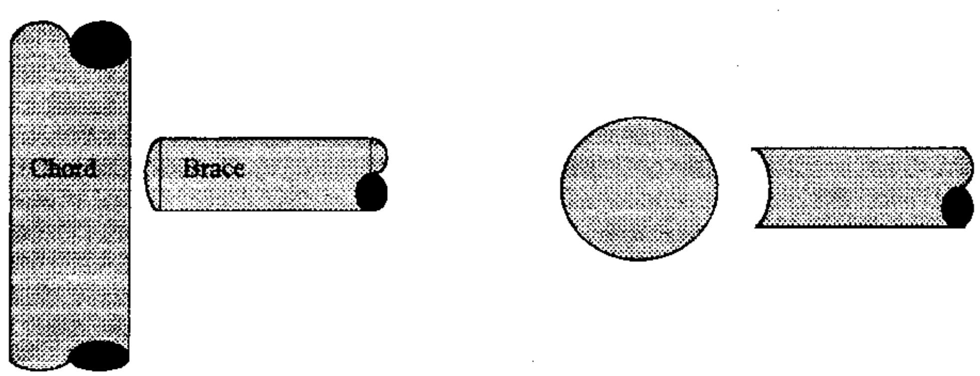


Figure 7.18 Node

Nozzle - The difference here is that **both** the brace and the chord are prepared and made to fit together, this should produce the stronger joint.

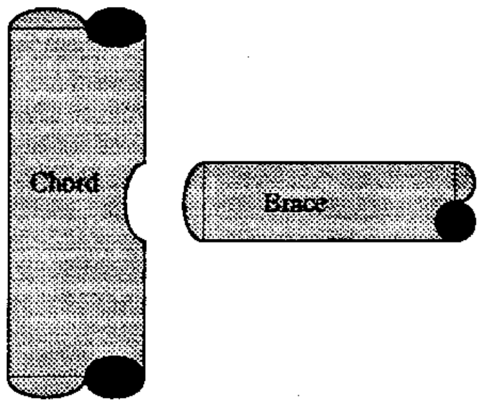


Figure 7.19 Nozzle

nB

DEFECTS IN WELDS (BS 499)

IDENTIFICATION

There are **six** categories of defects according to BS 499 and the International Institute of Welding, these are as follows:

1 **Cracks**
2 **Cavities**
3 **Solid inclusions**
4 **Lack of fusion and penetration**
5 **Imperfect shape**
6 **Miscellaneous**

These will now be explained in more detail:

1. CRACKS

A linear discontinuity produced by fracture, cracks may be longitudinal, transverse, edge, crater, centreline, fusion zone, weld metal or parent metal.

2. CAVITIES

There are a number of discontinuities which fall into this category:

Blowholes:	A cavity generally of less than 1.5 mm in diameter formed by entrapped gas during the solidification of molten metal. GENERALLY SINGULAR.
Porosity:	A group of gas pores, can be located in a variety of locations.
Elongated cavities:	A string of gas pores situated parallel to the weld axis.
Shrinkage cavity:	A cavity due to the shrinkage of the weld metal whilst in the plastic condition.
Wormhole:	An elongated or tubular cavity formed by entrapped gas during the solidification of molten metal, can give a herringbone appearance on a radiograph. TEND TO BE INTERNAL
Crater:	A depression due to shrinkage at the end of a run where the source of heat was removed.
Crater pipe:	A hole in the centre of a crater due to incorrect welding techniques.

3. SOLID INCLUSIONS

Inclusion:	Slag or other foreign matter entrapped during welding. The defect is more irregular in shape than a gas pore.
Oxide inclusion:	Metallic oxide entrapped during welding,
Tungsten inclusion:	An inclusion of tungsten from the electrode during TIG welding.
Copper inclusion:	An inclusion of copper due to the accidental melting of the contact tube or nozzle in self adjusting or controlled arc welding or to pick up by contact between the copper nozzle and the molten pool during MIG or Mag welding.
Puckering:	The formation of an oxide covered weld run or bead with irregular surfaces and with deeply entrained oxide films, which can occur when materials forming refractory oxides are being welded.

4. LACK OF FUSION AND PENETRATION

Lack of Fusion:	Lack of union in a weld, this can be either: a) Between weld metal and weld metal. b) Between parent metal and weld metal.
Lack of side-wall fusion:	Lack of union between weld metal and parent metal at a side of a weld.
Lack of root fusion:	Lack of union at the root of a joint.
Lack of inter-run fusion:	Lack of union between adjacent runs of weld metal in a multi run joint. NEVER SEEN ON CUI.
Incomplete root penetration:	Failure of weld metal to extend into the root of a joint.

5. IMPERFECT SHAPE

Excess weld metal:	Weld metal lying outside the plane joining the toes.
Excess penetration:	Excess weld metal protruding through the root of a fusion weld made from one side only.
Root concavity:	A shallow groove which may occur in the root of a butt weld.
Incompletely filled groove:	A continuous or intermittent channel in the surface of a weld, running along its entire length, due to insufficient weld metal The channel may be along the centre or along one or both edges of the weld.
Undercut:	An irregular groove at the toe of a run in the parent metal or in previously deposited weld metal, due to welding.
Overlap:	An imperfection at the toe or root of a weld caused by excess weld metal flowing on to the surface of the parent plate without fusing to it.

Burn through: A localised collapse of the molten pool due to excessive penetration, resulting in a hole in the weld run.

Unequal leg length: Non standard term, meaning the variation of leg length on a fillet weld.

Poor restart: Non standard term, meaning a local surface irregularity at a weld restart.

Misalignment: Non standard term, meaning misalignment between the two welded pieces such that their surface planes are not parallel (or are at an angle).

6. MISCELLANEOUS

Stray flash: The damage on the parent material resulting from the accidental striking of an arc away from the weld.

Excessive dressing: A reduction in metal thickness caused by the removal of the surface of a weld and adjacent areas to below the surface of the parent metal.

Grinding mark: Grooves in the surface of the parent metal or of a weld made by a grinding wheel or a surfacing tool.

Tool mark: An indentation in the surface of parent metal or of a weld resulting from the application of a tool e.g. a chipping tool, in preparation or dressing.

Hammer mark: An indentation in the surface of parent metal or of a weld due to a hammer blow.

Torn surface: A surface irregularity due to the breaking off of temporary attachments.

Surface pitting: An imperfection in the surface of the parent metal usually in the form of small depressions.

Spatter: Globules of metal expelled during welding on to the surface of parent metal or of a weld.

Dog Scar: A welding scar left over from fabrication, normally it will be situated perpendicular to the weld, immediately alongside. A dog is a device used to position the fabrication during welding.

Internal defects can be broadly categorised into two types:

PLANAR DEFECTS MAINLY IN SERVICE

These will have large surface area but low volume, so they are essentially two dimensional defects such as laminations and cracks. Fatigue cracking is a planar defect and is the most dangerous form of in service deterioration **(fatigue cracks mainly occur in the heat affected zone of the weld).** LACK OF FUSION, LAMINATION. ETC.

VOLUMETRIC DEFECTS

These will have a comparatively small surface area but a large volume, they include undercut, lack of penetration, cavities and porosity amongst others. Primarily, volumetric defects occur while the weld is molten during the fabrication of the weld and general cannot occur in service.

The above groups (planar and volumetric) are purely used as general categories for the six groups of defects from BS 499.

The most common defects to occur in service are **fatigue defects which normally occur in the heat affected zone of the weld**, and of course these are planar defects. It is quite unusual for volumetric defects to occur as normally these occur while the metal is molten. Normally we will employ techniques which will be effective on planar defects when searching for or assessing in service defects. POROSITY, SLAG INCLUSION. UNDERCUT. CAVITIES.

REPORTING OF DEFECTS

Once a defect has been located the following should be accurately reported:

1. **Type:** Accurate assessment and description of the defect using correct terminology.

2. **Location:** Give the relative location, HAZ/CAP/TOE (giving which toe or haz ie chord toe or brace toe etc), together with its start position measured in millimetres from the 12 o/clock datum mark.

3. **Dimensions:** Overall length of the defect stating whether it is intermittent or continuous, where necessary, report depth and width in millimetres.

4. **Orientation:** For a crack like defect indicate the orientation of the plane of the defect to the axis of the weld ie. transverse or longitudinal.

5. **Branching:** State if the defect is branching giving the location, length and orientation of each branch.

DIMENSIONAL CHECKING OF WELDS

In order for a weld to be able to carry out its designed purpose it must be of the correct proportions, this will involve the diver having to carry out measurements of the weld to specific requirements. These requirements will be laid down by the client, and there are a number of special gauges available to aid this task, the following are the majority of these measurements commonly needed and the gauges which can be used to assess them:

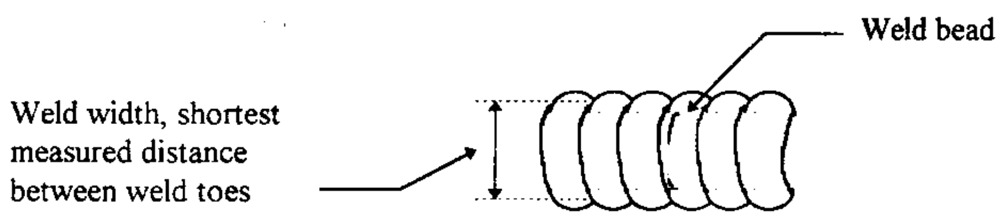


Figure 7.20 Measurement of weld width

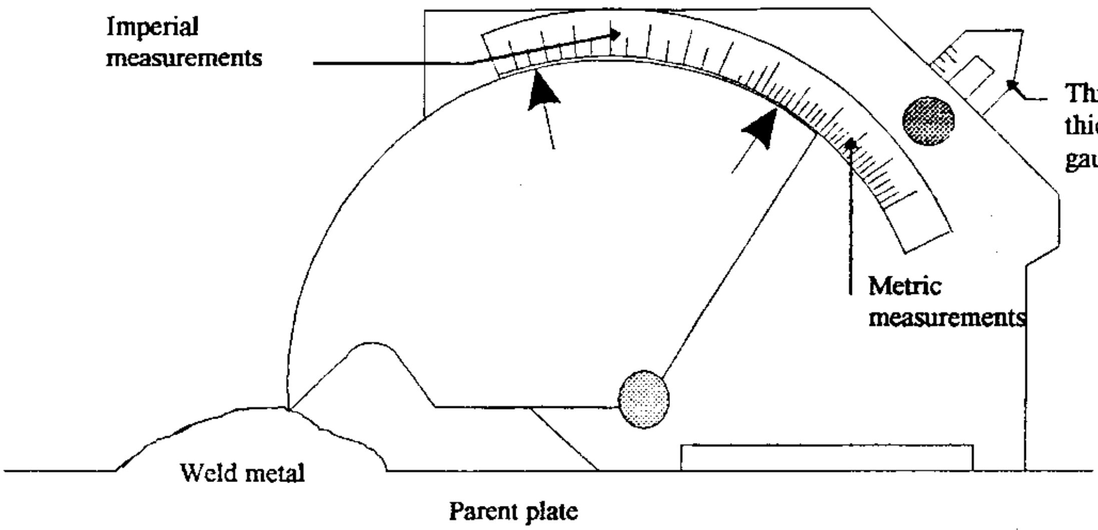


Figure 7.21 Welding Institute gauge measuring Excess weld metal

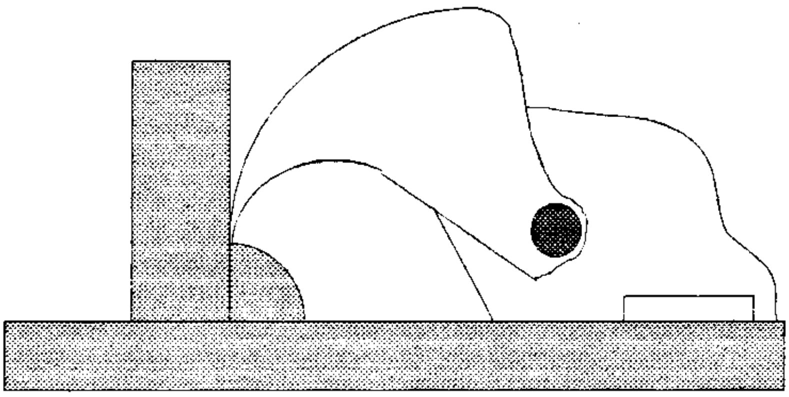


Figure 7.22 Measurement of leg length of a fillet weld

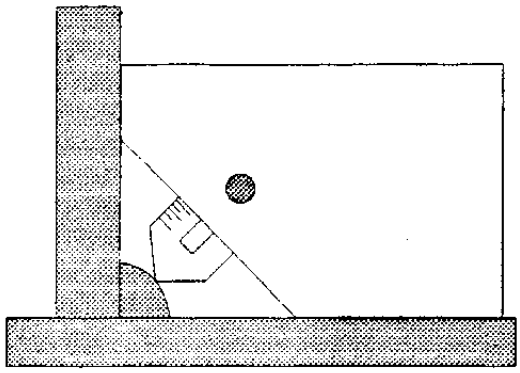


Figure 7.23 Measurement of Throat Thickness of a fillet weld

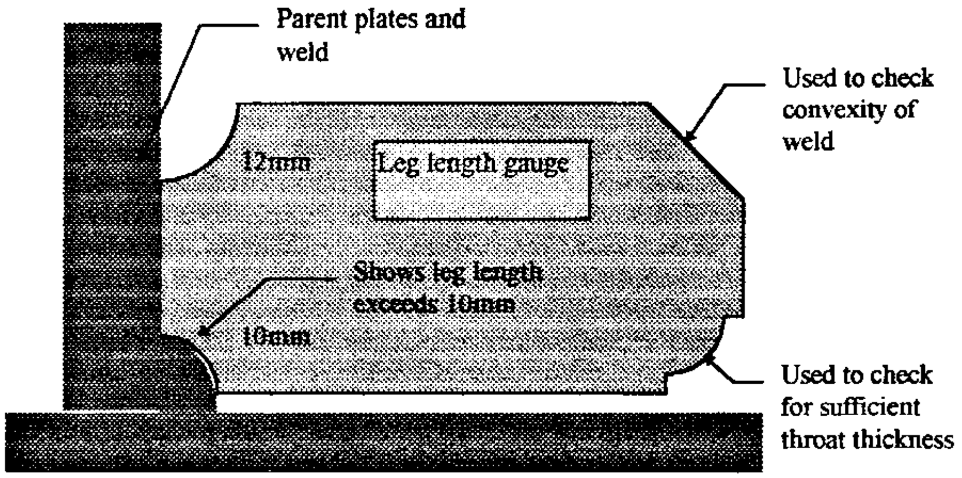


Figure 7.24 Leg Length gauge Showing leg length greater than 10mm

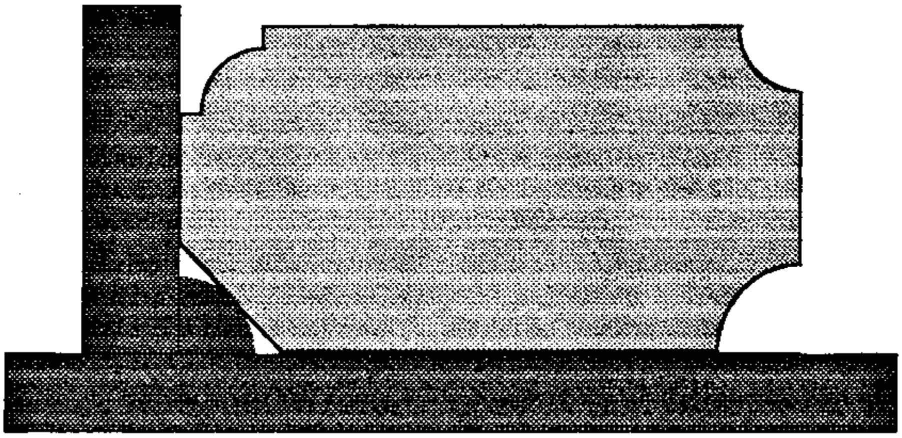


Figure 7.25 Leg length gauge showing Convexity not exceeding gauge

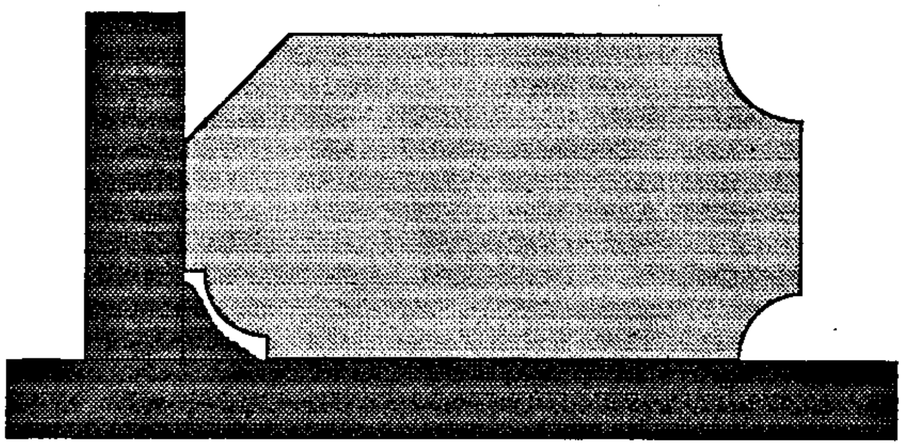
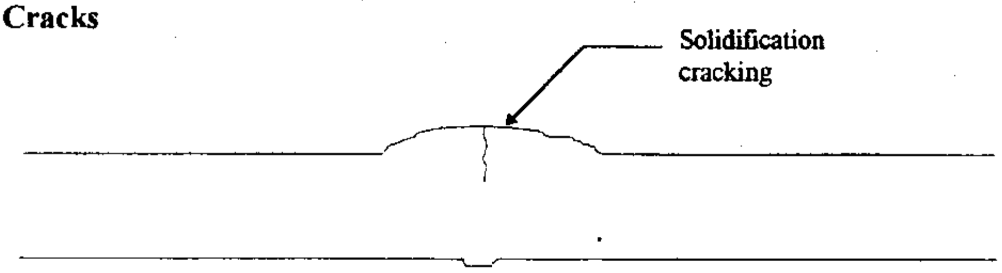
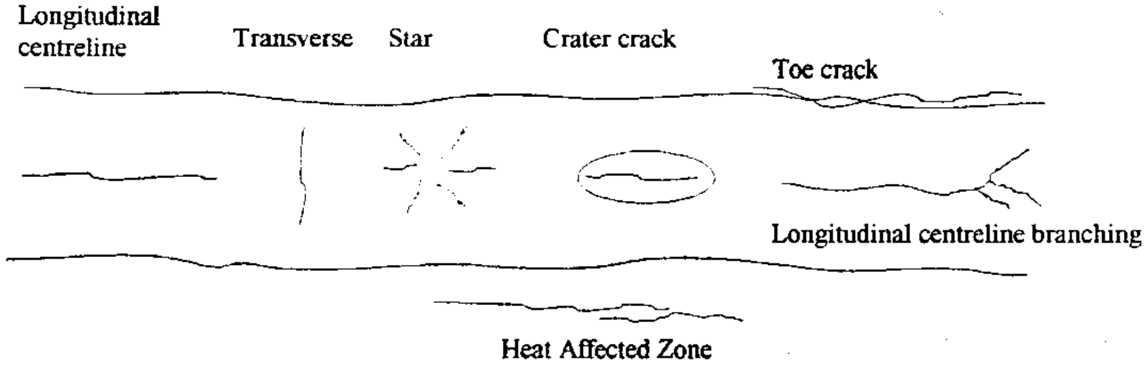


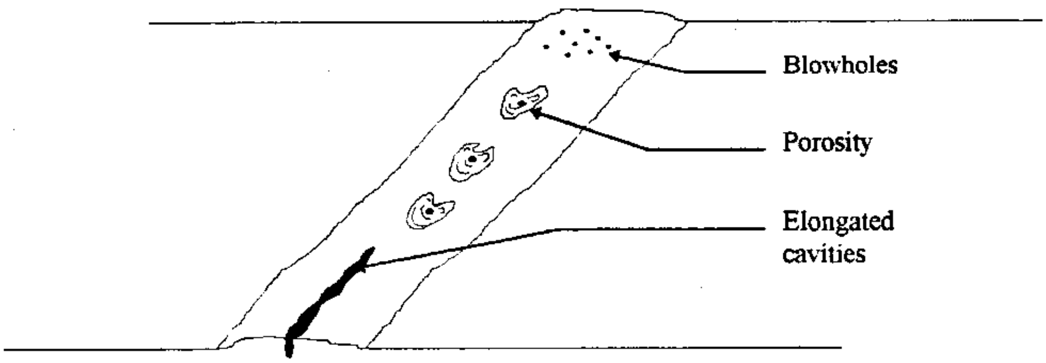
Figure 7.26 Leg length gauge showing Convexity exceeding gauge (Throat thickness too little)

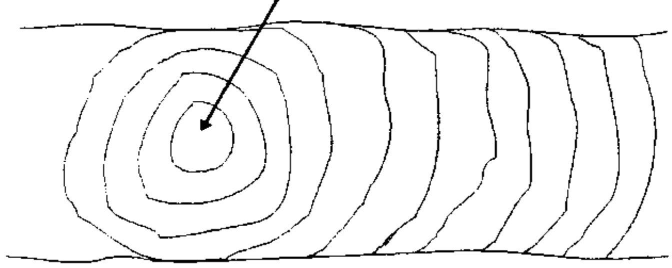
1 Cracks

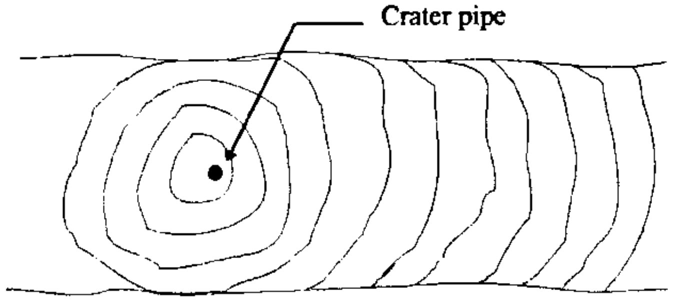




2 Cavities



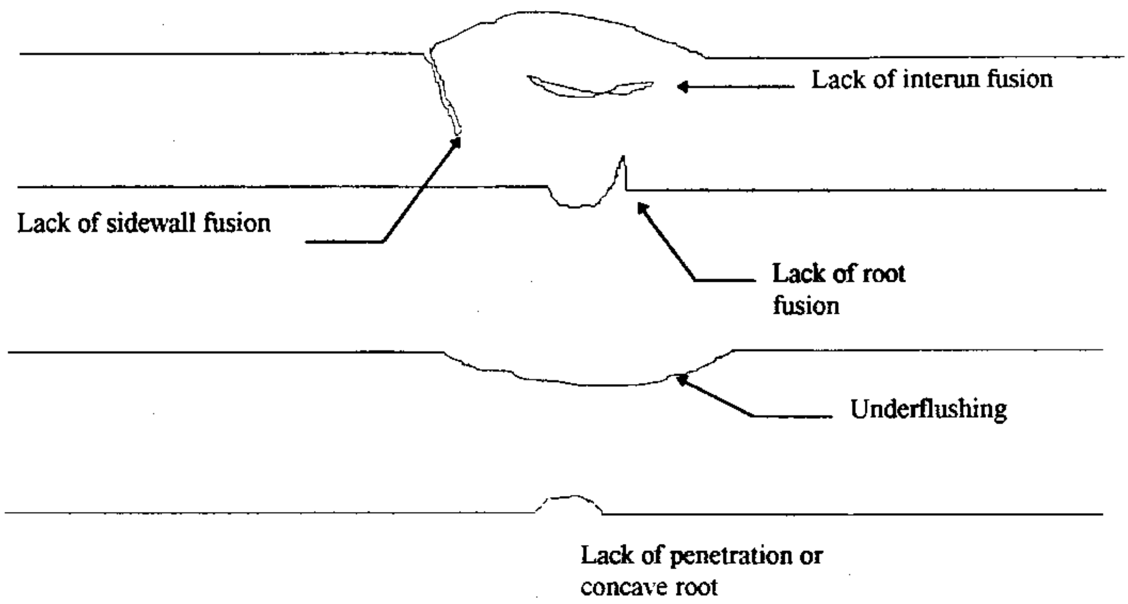




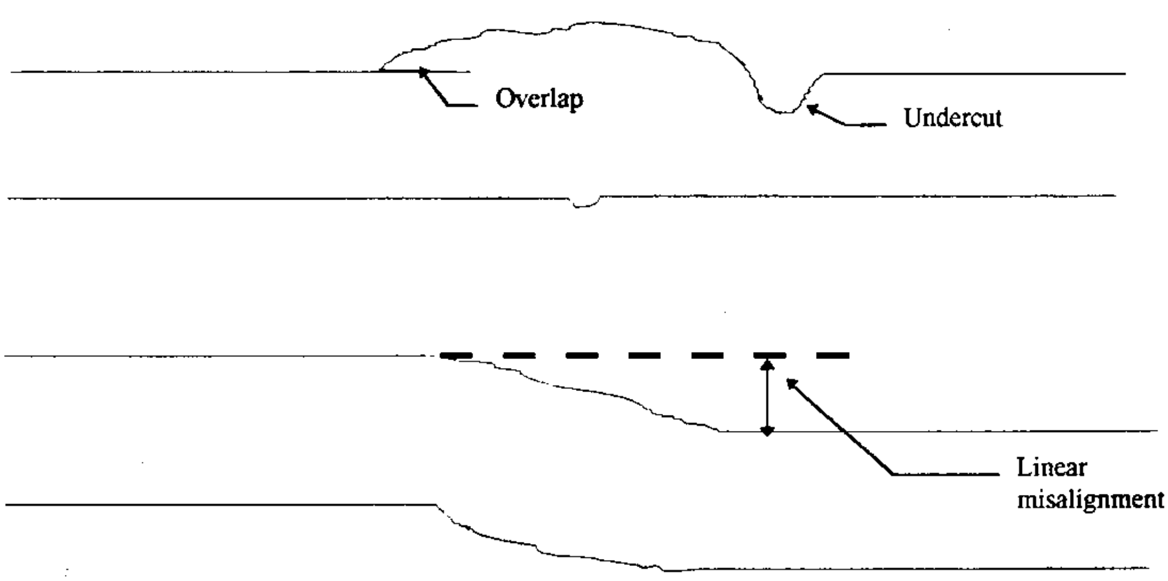
3 Solid Inclusions

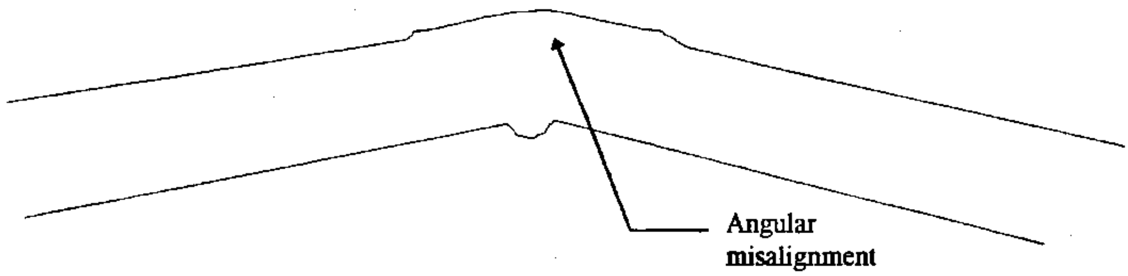
Solids trapped in the weld when the metal is still molten, from a visual inspection point of view, apart from slag inclusions these will not normally be visible.

4 Lack of Fusion and Penetration



5 Imperfect shape





6 Miscellaneous

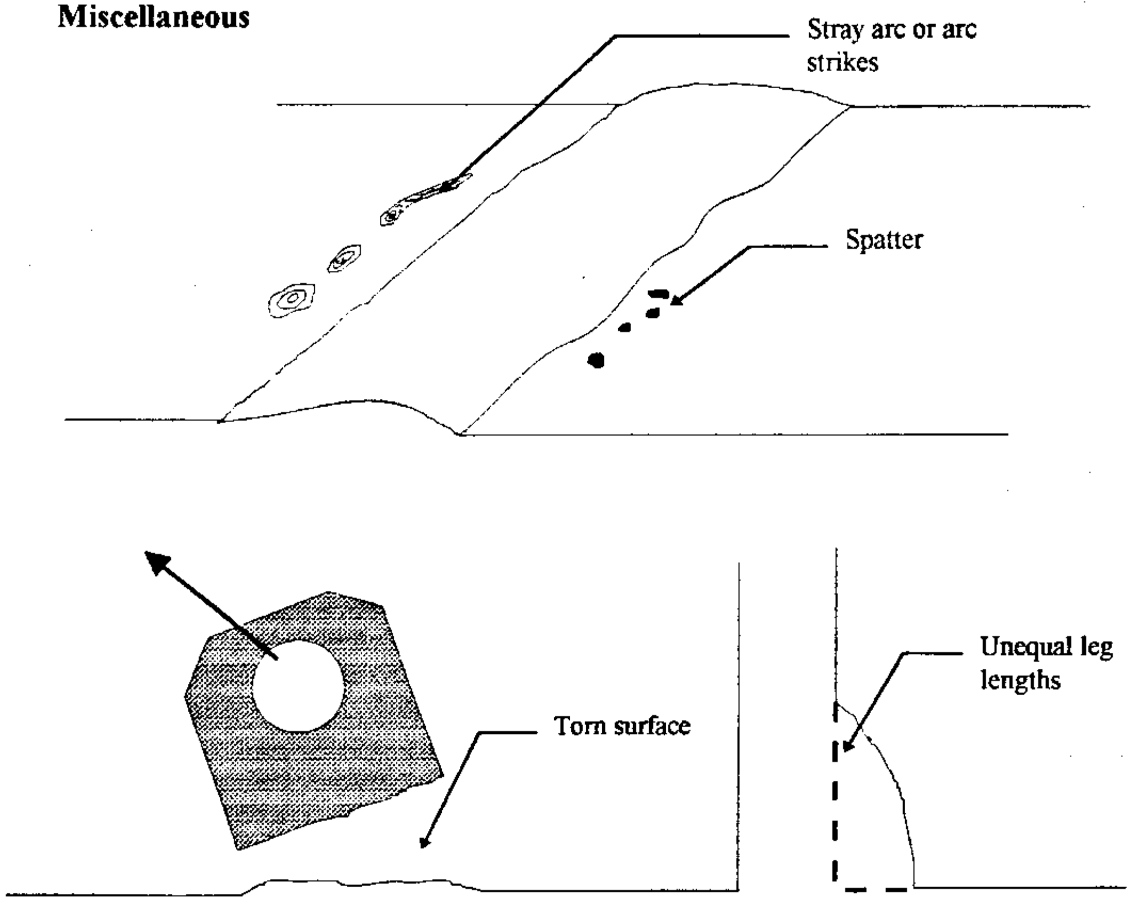


Figure 7.27 Weld Defects and Locations according to BS 499

NOTES

CHAPTER 8

DAMAGE

Because of the harsh environment in which the offshore structures have to exist and the high levels of stress involved it is extremely important that the structure is not damaged in any way.

As mentioned previously different materials react in different ways to stress, for example concrete is extremely resistant to compressive stress but weak in tension or shear stress, steel is very strong in tensile stress but relatively weak in compressive stress. In order to overcome this problem the designers make use of "form" to strengthen the structure. To demonstrate this if we take a sheet of paper and compress it along its long axis it will have virtually no compressive strength, but if we now roll the paper into a tube it becomes much more rigid. This technique is used in offshore tubular members. If the tube is subsequently deformed then it will lose some of this strength and tend to bend. This being the case we must ensure that the steel members of our structure are not deformed as can occur by impact damage.

Approximately 70% of all defects found offshore are primarily due to:

1. Collision by shipping.
2. Fatigue failure.
3. Dropped objects.

Of these 48% are discovered by routine inspection and 38% by post-incident inspection. This clearly shows the value of routine inspection.

DAMAGE SURVEY

The general rule of thumb must be that the inspection diver must always report **<u>anything</u>** that is not in an as made condition. The diver should be concise and objective when reporting, and correct terminology should be used at all times.

In order for the diver to know whether an object is damaged in any way he clearly needs to know how it should look in prime "as made" condition. Otherwise he can only guess as to whether it is damaged or not. The diver must make himself familiar with the object as far as is possible by looking at drawings, photographs and video footage of the object.

The most basic form of inspection is of course Visual Inspection. Sometimes this method of inspection is called the preferred method of inspection.

VISUAL INSPECTION

Advantages of visual inspection

1. Able to focus from a few inches to infinity.
2. The diver can see in three dimensions.
3. The diver can see in colour.
4. Always available.
5. Use other senses to back up visual.
6. Can give on the spot interpretation (commentary).
7. Need no other equipment (except maybe a light source).
8. Access is very good.

Disadvantages of visual inspection

1. No permanent record.
2. Open to interpretation.

Procedure for visual inspection

LOCATE AREA.

1. General visual inspection looking for gross structural damage and assessing marine growth.
2. Clean to SA 2.5 or SA 3 at least 75mm either side of the weld.
3. Establish the datum point (at 12 o'clock) and mark up the weld (using a tape and clock positions).
4. Measure and report complete weld length
5. Close visual inspection looking for fine defects.
6. Record and report defects relative to the datum point.
7. Back up the inspection with CCTV and photography.

The following is an example of a general inspection report sheet typically used for the recording of a visual inspection:

Visual inspection report sheet		Report sheet number:
Client:	Date:	Sheet: of
Dive spread:	Diver	Dive number:
Drawing sheet number:	CCTV log No:	Photo log No:
Inspection engineer:		Cleaning standard:
Equipment used:		
Detail:		
Signed:		
Supervisor:	Inspection engineer:	Client:

The basis for most inspections is accurate measurement of defects so we will now look at the ways and means of measuring and assessing damage in water.

SIZE REFERENCE AND MEASUREMENTS IN WATER

Size of defects and anomalies is of course of great interest to operators. There will be a number of reasons why measurements will be taken during an inspection, the following is a list of the major reasons:

i) To provide exact dimensions of areas of concern

ii) To accurately position any anomalies with regard to a fixed known point (Datum)

iii) Both of the above will allow accurate assessment as to the structures continuing ability to perform its design task

iv) Allow easy relocation of areas of concern at a later date for repair or monitoring

v) To allow fabrication of repair pieces which will fit properly

vi) To ensure construction is efficient

There are a number of different ways in which we can accurately assess the size of defects.

When we measure an object, we are assessing the distance between two points. We can do this either by directly measuring in a straight line or by using some other method which will require us to perform secondary measurements.

1. STRAIGHT LINE OR LINEAR MEASUREMENT

a) RULER

The simplest form of linear measurement is the ruler which is usually only used for small measurements such as the actual size of a crack or depth of a deformation. Possible accuracy is plus or minus 0.5 mm.

b) MAGNETIC TAPES

Magnetic tapes which are commonly used for the assessment of welds can be 1.5 or 3 metres in length. We can have an accuracy of approximately plus or minus 1.0 mm.

c) FLEXIBLE MEASURING TAPES

Flexible measuring tapes which can be used for large areas or long measurements, can be up to 100 metres in length. The possible accuracy can be plus or minus 5.0 mm, over a length of 1.5m

d) COMPARISON

Comparison to an object of known size such as a divers knife or “dymo” tape scales. There is no accuracy using this method but a good idea of the size can be obtained.

e) ELECTRONIC METHODS

Electronic methods such as sonar transponders which are usually used for large area mapping and wellhead location etc. This method can give an accuracy of plus or minus 10 mm over a range of up to 1000 metres.

2. CIRCULAR MEASUREMENT

a) CALLIPERS

Callipers can be used for both internal and external measurements of pipes and the like. They come in a variety of sizes up to about 2 metres across and their accuracy will depend on the procedure of use and measurement, however we can achieve an accuracy of plus or minus 0.5mm with smaller callipers.

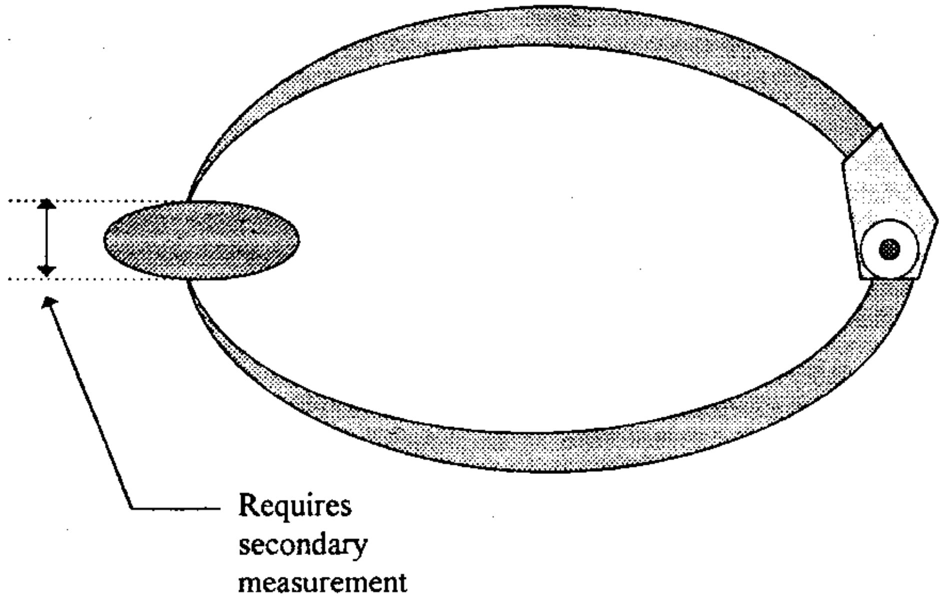


Figure 8.1 Callipers

b) VERNIER GAUGES

Vernier gauges are much more accurate than the above, however they are still callipers and will normally be used on smaller measurements. Accuracy can be plus or minus 0.1 mm.

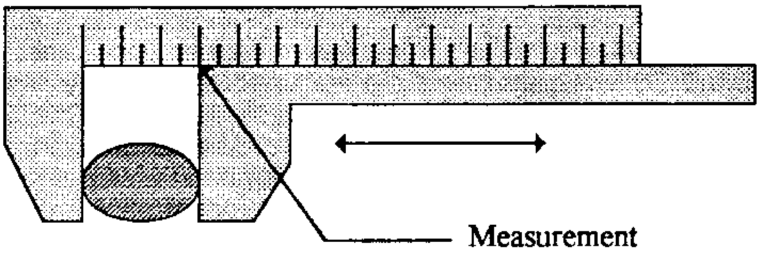


Figure 8.2 Vernier Gauge

c) SPECIALIST JIGS

Specialist jigs can be used to assess the shape of members with a view to their having changed shape. The accuracy will depend on the manufacturer of the jig and also how well it has been stored, but could certainly be plus or minus 5 mm.

3. ANGULAR MEASUREMENT

a) PROTRACTOR

Protractors of various sizes can be used to determine the angle of a component or defect.

b) PENDULUM GAUGES

Pendulum gauges (inclinometer) can be used to determine the angle of buoy chains and the like.

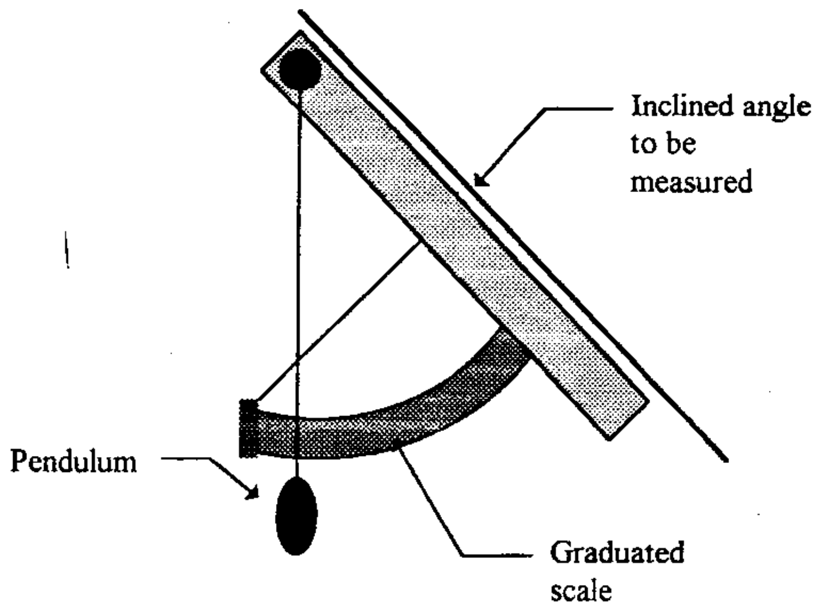


Figure 8.3 Pendulum Gauge

4. DENTS AND DEFORMATION OF MEMBERS

a) PROFILE GAUGES (Mimic Gauge) APPLY LONGITUDINAL TO TUBULARS

For small areas of deformation we can use a profile gauge, sometimes called a mimic gauge a series of moveable pins set in a bar. When the pins are forced into the defect a profile of the defect will be recorded which can be quite accurate plus or minus 0.5 mm. However the pins could move when the gauge is transported, so normally the gauge will be assessed while still on the site and maybe even photographed prior to bringing to the surface.

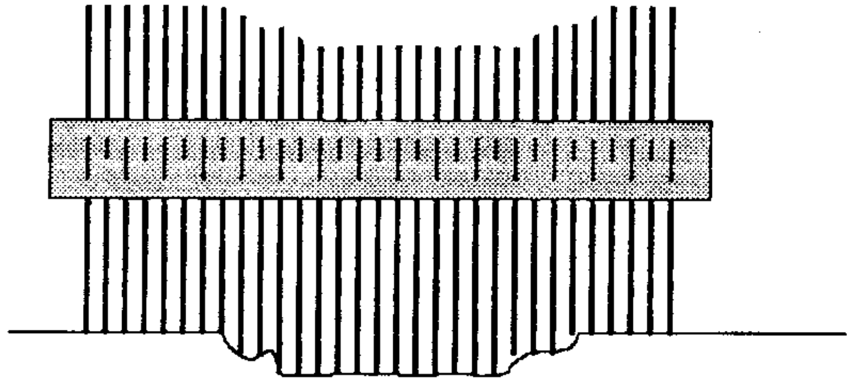


Figure 8.4 Profile Gauge

b) CASTS

There are a number of different materials which have been used to take casts underwater such as plastercine, putty and more commonly now two part rubber compounds such as "Microset". All casts act in the same way, that is to force a malleable material into the defect and then remove it so that it records the shape and size accurately. The problem with most materials is that they will tend to be deformed when they are removed from the test piece or under transportation to the surface.

"Microset" is a two part rubber solution which is applied to the workpiece by means of a pressurised applicator gun. Once applied it will cure in about 90 minutes in the North Sea, and then it can be peeled off. The cast will not be deformed as it will spring back to it's original shape and size, and so gives a much better result. The manufacturers say that microscopic defects can be located using this method. Mouldings and castings have a number of uses in the offshore industry:

- i) Recording of weld profile.
- ii) The recording of profile of defect grinding.
- iii) Recording the results of an M.P.I. inspection.
- iv) Giving an engineer a solid representation of a profile such as a propeller blade edge or the like.

There are a number of different substances which have been used in the past such as:

- i) Plasticine.
- ii) Putty.
- iii) Dental moulding material.
- iv) Two part plastic moulding material ("Microset" is one brand name for this type of material).

There are some problems associated with making casts and removing them to the surface:

- i) It can be very difficult to remove without distortion of the cast (except for the two part plastics which will allow a good deal of pulling about and still return to the original shape).
- ii) Possible damage of the cast during transport to the surface.
- iii) They all require secondary measurement.
- iv) The image that they record is a negative image (i.e. grinding of a component will appear as a raised section on the cast).
- v) They can be very difficult to apply properly (the correct technique must be followed when using the plastic mouldings).

All of this will mean that they are best used on relatively small defects and for weld profiles.

c) STRAIGHT EDGE

This can be used on small defects, it involves laying a straight edge across the defect and measuring from it down to the bottom damaged area. This can give a very accurate profile of the damage, plus or minus 1.0 mm.

d) TAUT WIRE SURVEY

A variation on the straight edge but used on larger defects. A wire will be stretched across the defect being careful to make sure that the magnets or securing clamps are on an undamaged member (this may involve stretching the wire from one vertical leg to another).

The wire should be graduated, (the more graduations the more accurate will be the result), and torqued up to a predetermined tension. The diver will then work along the wire taking measurements down into the defect at all of the graduations on the wire. When this is done properly the dent will be drawn in profile from the measurements taken. The wire can then be moved to another point of the defect.

The wire must lie longitudinal to the member in order for the readings to make sense, and another set of readings taken. Eventually a three dimensional image can be built up (see diagram). This should be done in at least two planes i.e. one at 12 o'clock and one at 3 o'clock. The following are some points to remember when employing taut wire survey:

CLEANED TO SA 2.5.

i) Clamps must be on undamaged member (take several measurements from the wire to the member close to the clamps and the measurements should be unchanging).

STANDOFF WIRE DIST MUST BE MEASURED & TAKEN AWAY FROM MEASUREMENTS.

ii) Wire must be graduated, the more graduations the better the accuracy.

iii) Wire must be at the correct tension.

iv) Wire must be in line along the axis of the member.

v) Wire must not be deflected in any way.

vi) All measurements must be taken perpendicular to the TAUT WIRE undamaged member, and the wire stand-off measurements must be subtracted from each of the readings.

vii) Measurements must be taken in at least two planes i.e. 12 o'clock and 3 o'clock, this will ensure that if the member has been deformed laterally it will be recorded.

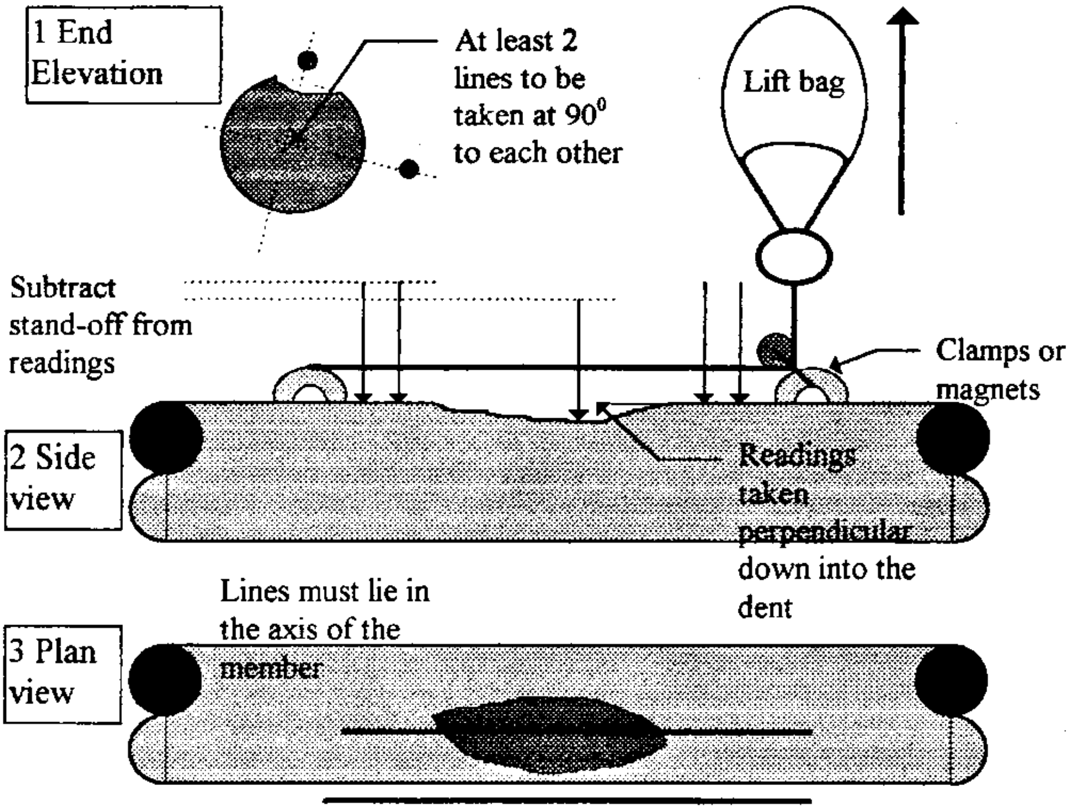


Figure 8.5 Taut Wire Survey

e) PIT GAUGE

Pit gauges will be used for the measurement of small pits and deformations in the surface of a structure. It will consist of a point which can be pushed into the pit and a scale from which an indication of the pit can be taken.

f) LINEAR ANGULAR MEASUREMENT (LAM) GAUGE

The linear angular measurement gauge is specifically designed for depth and angle measurement of remedial weld grinding, this will allow accurate stress analysis of the remaining ligament. In addition it can be used effectively for the measurement of the following:

1) Pitting depth
2) Angle of preparation
3) Misalignment
4) Fillet weld leg length
5) Fillet weld throat
6) Excess weld metal

7) Undercut
8) Indentations
9) Protrusions
10) Profile of damaged areas in members (using a steel straight edge)
11) Checking excavation depth in weld repairs
12) Linear measurement parallel to member surface (root gap)
13) Measurements taken from flat or curved surfaces.

The LAM gauge incorporates a sliding measure which is able to rotate in order to accommodate different angles, this rotation can also be measured thus enabling us to calculate the angle quite precisely.

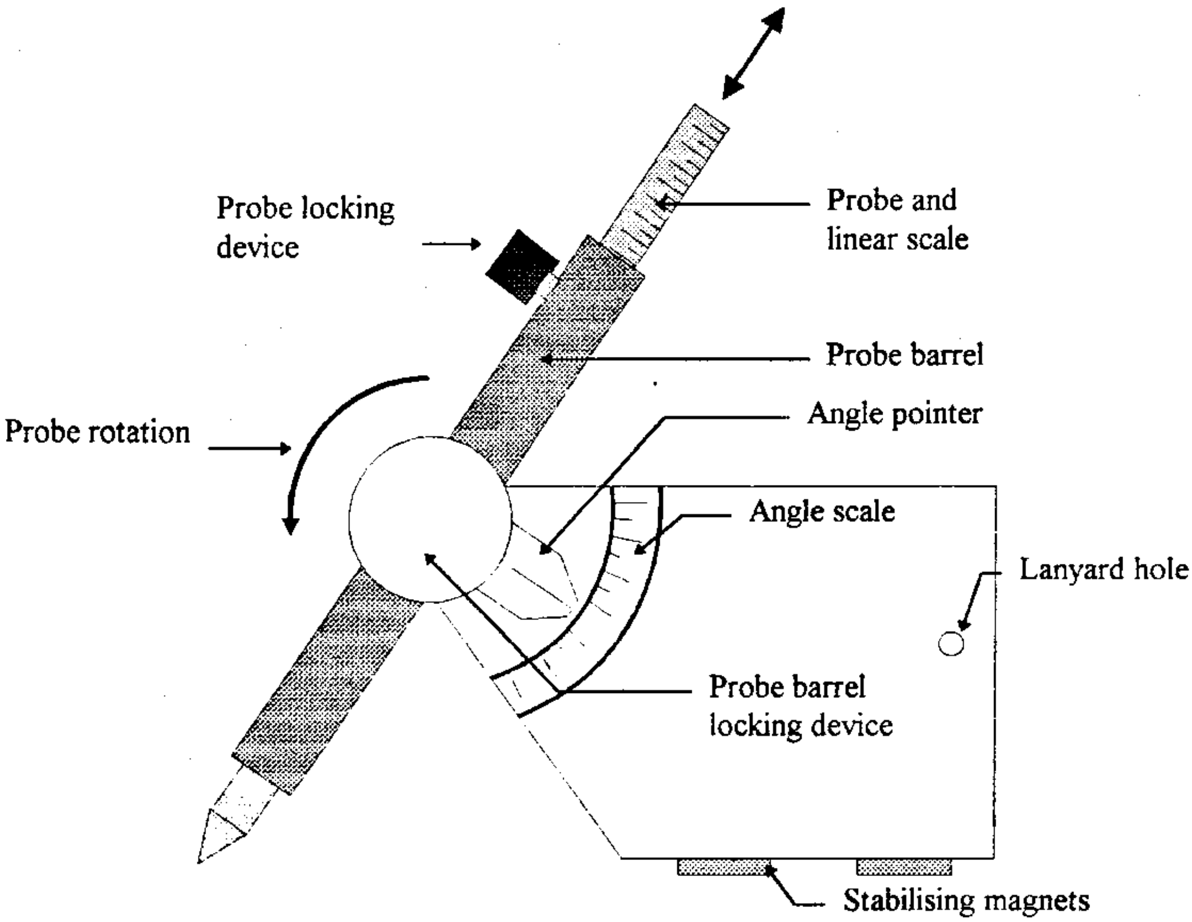


Figure 8.6 Linear Angular Measurement (LAM) Gauge

g) PHOTOGRAMMETRY

This is a method of taking a three dimensional photograph of the defect which can then be assessed very accurately using computers, accuracy of plus or minus 2.5 mm is not uncommon.

The method uses two cameras which are aligned on a frame in such a way as to take two pictures, simultaneously, or a single camera which has two lenses which are offset in order to take two exposures of the same object but from slightly different angles. The stand off of the cameras is exactly controlled and so will not change from one shot to the next. Also the lighting is controlled to give just the right amount of shadow to the image.

When all of this is correct the images can be evaluated by a computer, which can then assess the picture very accurately (see the section on photography).

NOTES

CHAPTER 9

THE IMPORTANCE OF DOCUMENTATION AND RECORD KEEPING

Operators keep extensive records for the following reasons:

GIVE REASONS WHEN REPORTING.

1. To provide documentation for Statutory Certification/Verification, insurance and operator in house purposes.

2. Records allow engineering assessments to be made regarding the structures ability to perform its designed tasks safely.

3. To provide a record of any existing defects or anomalies with exact locations, (the building up of a damage register).

4. To assess and monitor the extent of existing defects. The company engineering department will decide what is an allowable defect this will be expressed as the **criteria of non conformance**.

5. To provide the data from which an inspection, maintenance programme can be planned and implemented.

6. To evolve future structure design criteria.

7. PROVIDE MEASUREMENTS FOR REPAIR WORK.

Record keeping starts right from day one of the structure's life, when it is still on the drawing board. At this stage all of the individual components will be assigned unique reference numbers. These numbers will be used to keep a record of the component during future inspections and repairs.

When the design is finalised there will be some kind of Quality Assurance Certificate issued which will guarantee that the design is to the relevant standards. This could be said to be the structures first inspection record.

The design will call for materials of specific standards to be used in the construction. These will also come with a Quality Assurance Certificate. As the structure is fabricated each component will gain a series of records relating to the procedures, preparation, consumables used, and any inspection carried out. These will all be filed under the unique reference number for that component.

Once the structure goes into service any further inspections and repairs done to that component will be cross referenced. This allows all of the reports relating to that particular component to be held and therefore studied together. This information will be used to maintain a register of allowable anomalies relating to all of the components on the structure (The damage register).

The system works in that if any discontinuities are found in an inspection, then all of the previous records for that component can be retrieved for assessment easily and quickly. The records can possibly be accessed by the offshore personnel using a computer terminal situated at the offshore site.

In this way all platform and structure operators can keep track of each individual component on all of their structures.

NOTES

CHAPTER 10

General Overview of Inspection Methods Available to an Offshore Operator for the Assessment of Subsea Structures

An offshore operator will of course need to maintain all of the offshore structures in his system. If done properly it will ensure that there is the minimum of lost work time due to failure. If a failure occurs then the consequences can be very extreme; loss of life, damage to the environment and loss of production being the most major problems. In addition there is a need to maintain the confidence of the Independent Verification Body in order to prove the structures continuing safety.

For these reasons the operator will formulate a program using the most cost effective methods and procedures, while still ensuring that all defects will still be located. The program will dictate the equipment and the procedures used. This must take into account the capabilities of each method. A brief summary follows:

VISUAL

Can locate visible defects and discontinuities. Will be used to locate small defects in the case of close visual inspection of welds etc. This method has the advantage of the diver actually being there and so he will be able to back up his findings with his other senses. He can give an on the spot commentary with the benefit of his three dimensional vision and interpretation whilst still on location. The main disadvantage is that there will not be any permanent record produced, thus it is open to interpretation by the diver.

CLOSED CIRCUIT TELEVISION CCTV

This will be used in much the same way as visual inspection but will produce a real time permanent record of defects and discontinuities. The resolution is not as good as photography or visual inspection thus the defects detectable are going to be larger. When used with ROV the video image will of course be the only method that the pilot will have of visually inspecting the component although he may have the facility to photograph a defect once it has been located. PRODUCE 2 COPIES.

MC CAMERA CANNOT FREEZE MOVEMENT.

PHOTOGRAPHY

MC. Photography will be used to make a high definition permanent record of areas of interest, such as defects and discontinuities, as well as checking the location and security of components. It is not normally used for "blanket" coverage of a structure. Maybe it's main drawback is that there will be a delay in obtaining the results from a photographic inspection due to time needed for developing of the film.

CATHODIC POTENTIAL READINGS

This is a method that is used to assess the structures ability to withstand corrosion. It will do this only at the point of contact or in the immediate vicinity of the probe. The measurement taken is a measure of the structures potential relative to a known reference half cell.

H.C. NOT USED TO DETECT DEFECTS.

DIGITAL THICKNESS READINGS

The DTM measures the time of flight of an ultrasonic pulse made to travel in the steel of a structure. This method can assess the wall thickness of the structure and is used alongside C.P. readings to gain an idea of how much steel has been lost over time due to corrosion.

H.C. DIST TO MAJOR REFLECTOR ONLY.

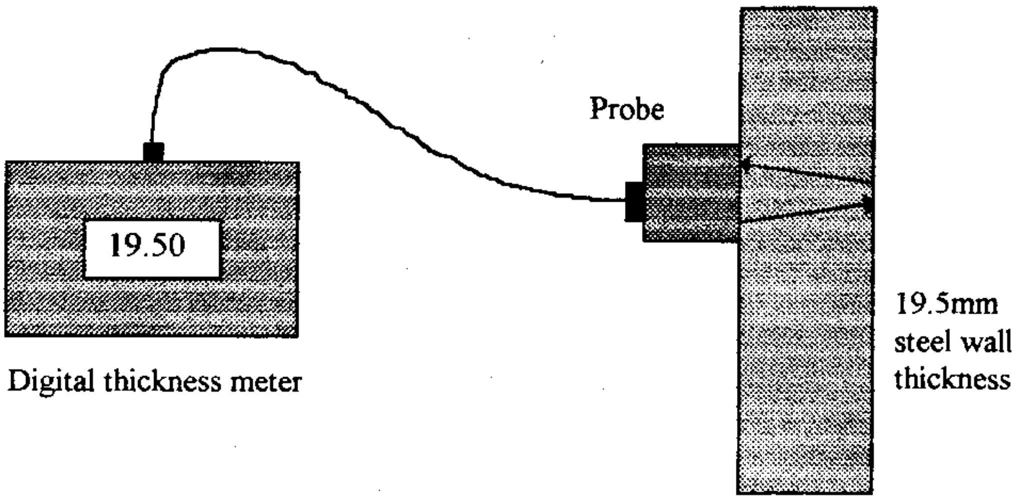


Figure 10.1 Digital Thickness Meter use

The above five techniques are all C.S.W.I.P. 3.1U techniques and as such the diver must be 3.1U qualified before the results he could obtain would be accepted. The following two techniques are covered in the C.S.W.I.P 3.2U syllabus:

MAGNETIC PARTICLE INSPECTION (MPI)

CANNOT ASSESS DEPTH OF DEFECT.

MPI can find fine surface breaking and slightly sub-surface discontinuities in ferromagnetic materials. By passing a magnetic field of sufficient strength across a discontinuity, ideally at an angle of 90° to the discontinuity. This will cause the discontinuity to polarize thus producing an area of "flux leakage" around the discontinuity. If we then apply an ink mixture containing ferromagnetic particles to the surface of the testpiece, the particles will be attracted to the flux leakage thus making the discontinuity visible to the naked eye.

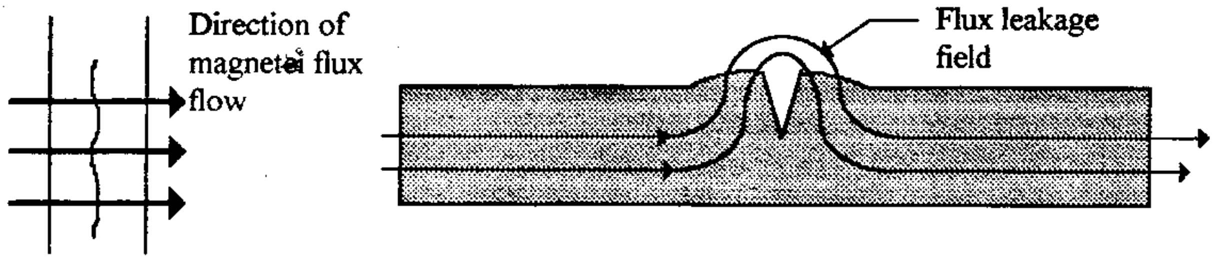


Figure 10.2 Magnetic Particle Inspection (MPI)

ULTRASONIC A'SCAN

FIND + SIZE SUBSURFACE DEFECTS.

Pre 1993 This method was included fully in the 3.2U syllabus, however since then students only get an appreciation of the technique and will not be qualified to use the technique offshore. A'scan can be used to both find and size sub surface defects. The method involves producing ultra sound which is then transmitted to the testpiece. The A'Scan flaw detector will then measure the time taken for the sound to return to the probe. This is then displayed as a "peak" on a cathode ray tube. The axis of the A'Scan display correspond to the following:

1. The Y-axis (Vertical) will be a measure of the returning sound intensity.

2. The X-axis (Horizontal) is a measure of the time of flight of the pulse in the material, because the velocity of the sound in the material is known this will give us an indication of the depth or thickness of the material.

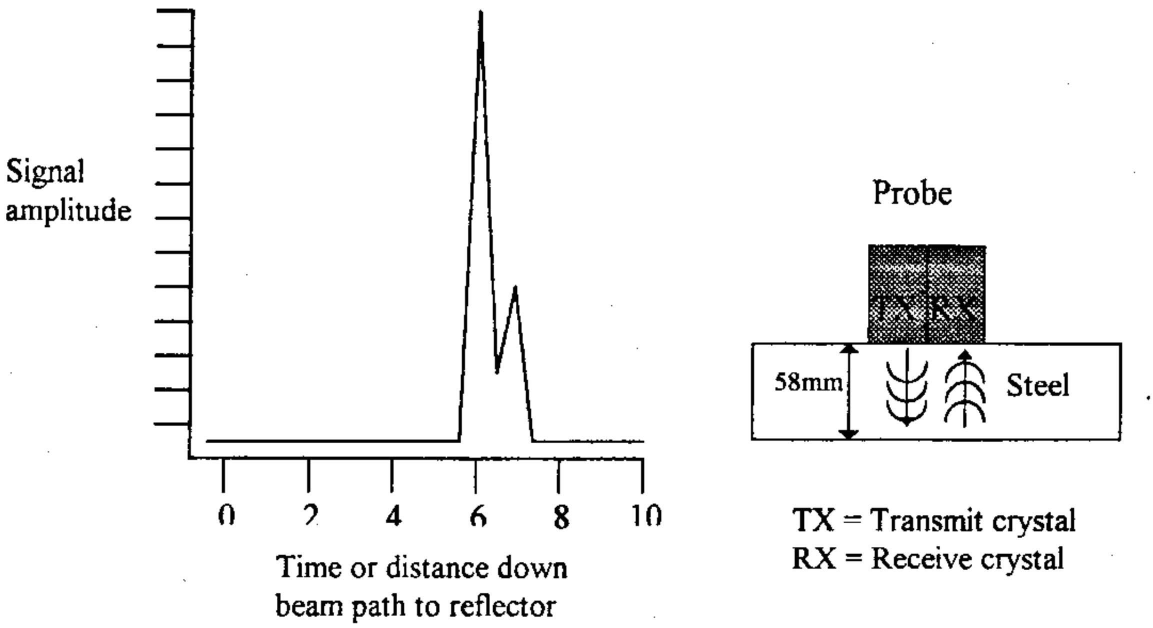


Figure 10.3 Ultrasonic A'scan

The above are widely used in the offshore environment. The operator will also have other methods which are not covered in the C.S.W.I.P. Phase 7 scheme available for use in his inspection program, the important ones to date are as follows:

RADIOGRAPHY MAINLY RELIABLE VOLUMETRIC DEFECTS MAINLY FABRICATION DEFECTS.

Radiography can be used to find and size sub-surface defects. Because this method uses absorption of radiation to locate defects it is important that the defect will significantly change the absorption rate when the radiation passes through the defect as opposed to when the radiation passes through undamaged metal. The amount of radiation that can penetrate the undamaged material will be registered on the film by a certain shade of grey, i.e. high levels of radiation hitting the film plane will produce darker areas than will be produced when lower levels of radiation hit the film plane.

If the radiation does not have to travel through steel for the whole distance then the amount of radiation reaching the film plane will vary, depending on whether the discontinuity is more or less dense than the surrounding steel. If it is less dense then the radiation reaching the film will be increased over the undamaged part. If the discontinuity is more dense then the radiation will be more effectively blocked, thus seeing a lighter image on the radiograph.

Subsequently, radiography is best used on defects which have a volume (volumetric), as they will always change the radiation absorption significantly (see diagram). Planar defects may not always significantly change the amount of radiation reaching the film. This will mean that Planar defects may not always detected.

MC Since radiation is used, the most important factor to consider when using radiography will be **safety**, the minimum exclusion zone from an exposed source will be **8 metres**, this being for the most common source used offshore today which is **Iridium 192**.

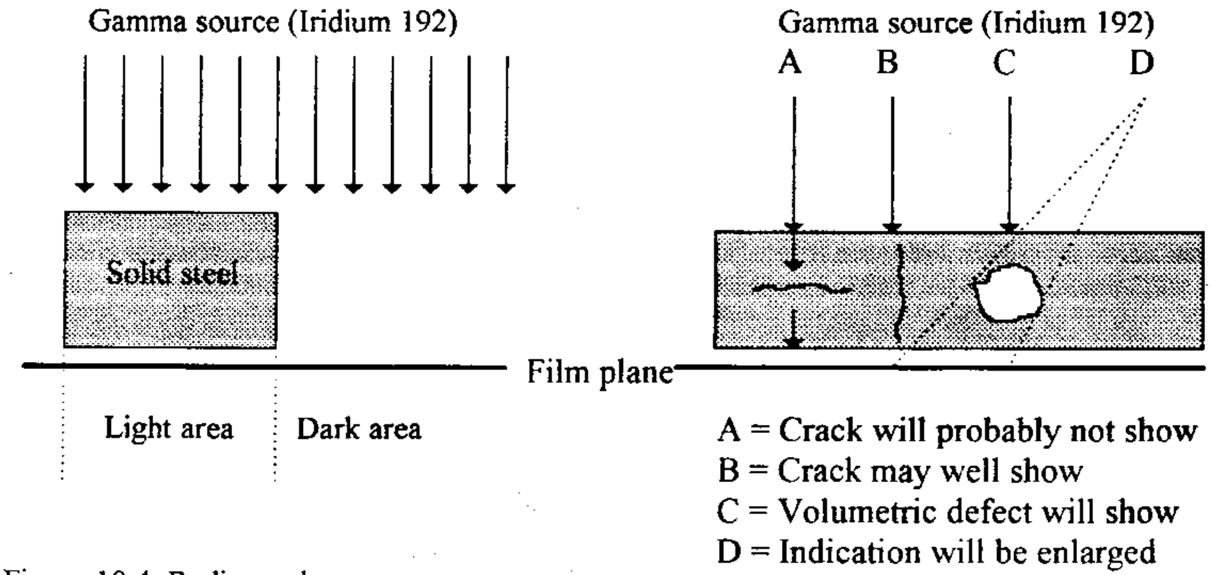


Figure 10.4 Radiography

ALTERNATING CURRENT POTENTIAL DIFFERENCE (ACPD)

MC. Alternating current potential difference can be used to assess the depth of a surface breaking defect. The method will not normally be used as a detection device, rather it will be used to explore a defect previously found by some other method. As current flows through a conductor there will be a potential drop from one end to the other. So, if we pass current over a weld the resulting drop can be measured. If we then put the measurement probe over a defect the electricity will have to travel further, it cannot jump across the defect so will be forced to flow around or below it. This will demonstrate a greater potential difference, thus the machine can give us an indication of crack depth.
ONLY ON CLEAN SURFACE.

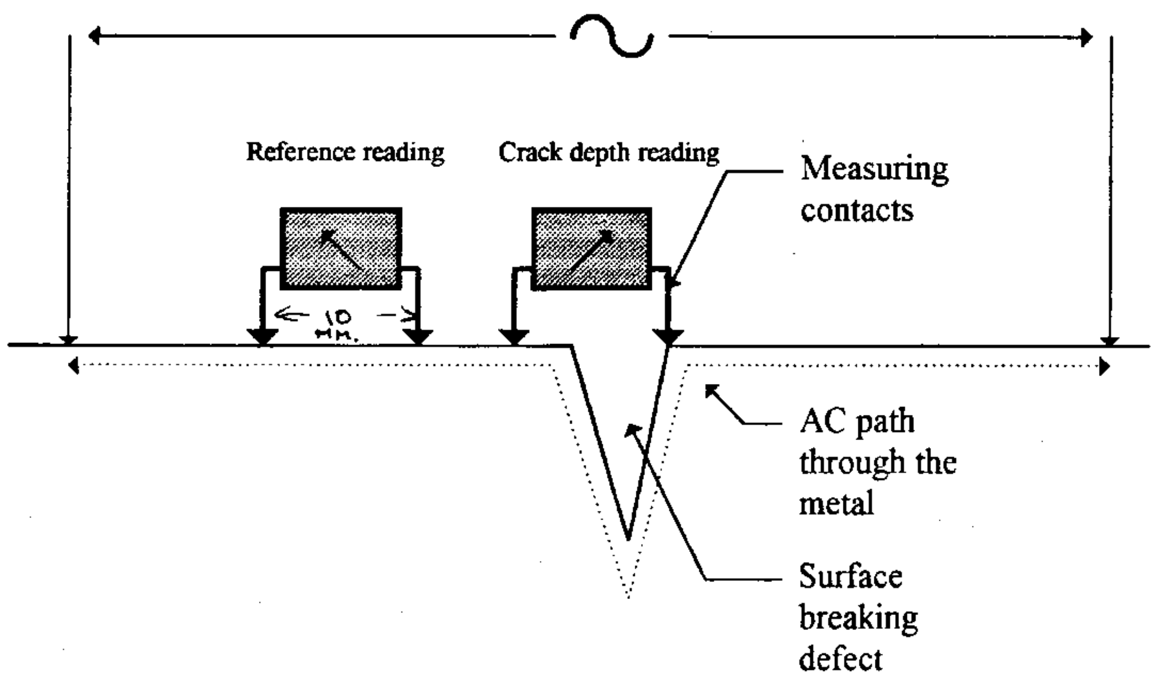


Figure 10.5 Alternating Current Potential Drop (ACPD)

ELECTRO MAGNETIC DETECTION TECHNIQUES (EMD or EMT)

Commonly known as **Eddy Current** or **ACFM**, these methods of detection can find fine surface breaking defects through non conductive coatings. In addition they can be used to size defects both for length and depth. Some of these techniques can also be used to sort materials and measure the thickness of coatings.

A brief description of eddy current is as follows: An alternating electric current is passed through a coil in a probe. This will create an alternating magnetic field running longitudinal through the coil, if this field is passed through a conductor, such as a testpiece, then there will be small current of electricity produced in the material (Eddy Current). If these small currents of electricity encounter a discontinuity in the material then they will be diverted in some way. This will cause a change in the primary coil and it is this change which is measured.

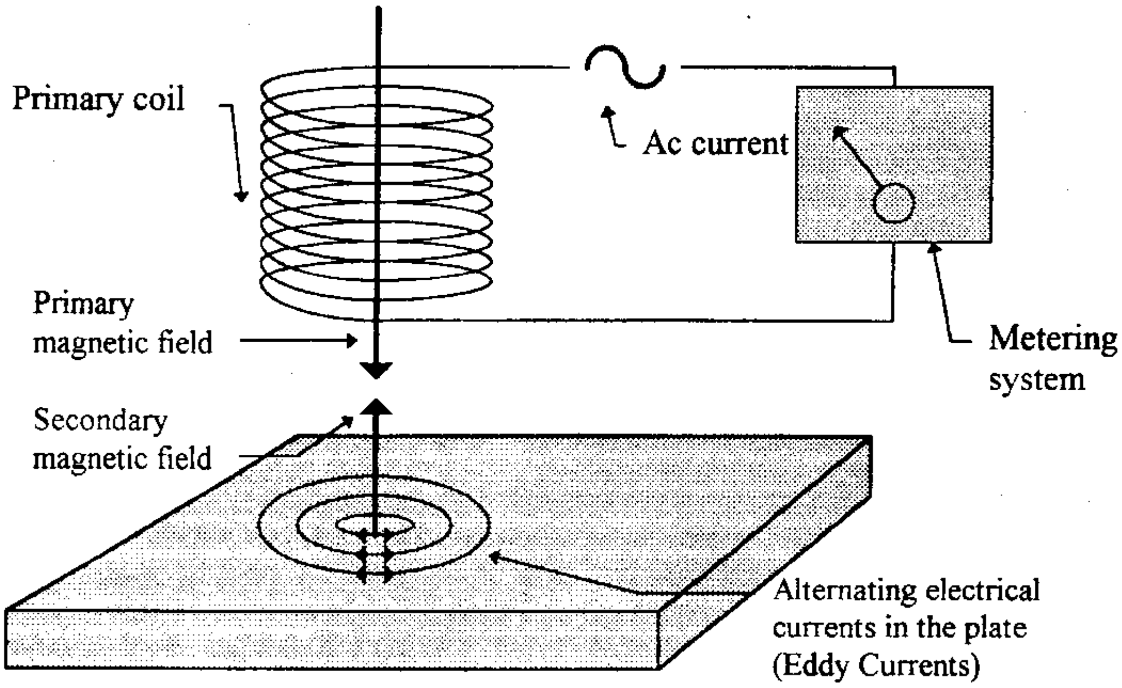


Figure 10.6 Electromagnetic Detection Technique (eddy current)

ALTERNATING CURRENT FIELD MEASUREMENT (ACFM)

As mentioned above this is another electromagnetic technique which is also capable of finding and sizing for length and depth very fine surface breaking defects, it can also do this through non conductive coatings. It differs from eddy current machines, in that it measures changes in the magnetic fields produced in the material by the eddy currents generated by the probe. These magnetic fields will be significantly altered by the presence of a defect or discontinuity (see the chapter Alternating Current Field Measurement).

FLOODED MEMBER DETECTION (FMD)

USUALLY BY DIVER ALL 3 ROV.

FMD is used to assess the integrity of members in the offshore structure. It can be achieved by the use of ultrasound, radiography or thermal methods. In the case of radiography the film would be placed on the opposite side of the member to the source and then exposed for a given time. The shade of grey produced is varied according to whether the member is air or water filled. The thermal method will involve placing a probe onto the surface of the member, this will heat up the member to a given point, once reached the heating element will switch off and the machine then times how long the member takes to cool a certain number of degrees, if the member is air filled it will take longer to cool than if it is water filled. The previous methods are most likely applied by ROV, as far as divers are concerned the most common method will be the ultrasonic method which uses an A'Scan presentation to show if the member is flooded. If it is air filled then the sound will not penetrate the member and so the resulting single peak on the timebase (X-axis), the postion of this peak will correspond to the probe standoff distance (A). If the member is flooded then some of the sound will penetrate the member, this will result in the presence of two peaks on the timebase, the left hand one will again correspond to the probe standoff distance as before (A), but the amplitude will be reduced. This is because the peak height is related to the intensity of returning sound and as some of the sound will be transmitted into the water-filled member there is no longer enough sound being reflected back from the first wall of the member to push the peak up to full screen height. The sound which enters the member will then be reflected back from the back wall of the member (or perhaps the surface of the water if the member is not fully flooded), so producing a second peak on the timebase, corresponding to the diameter of the member (B).

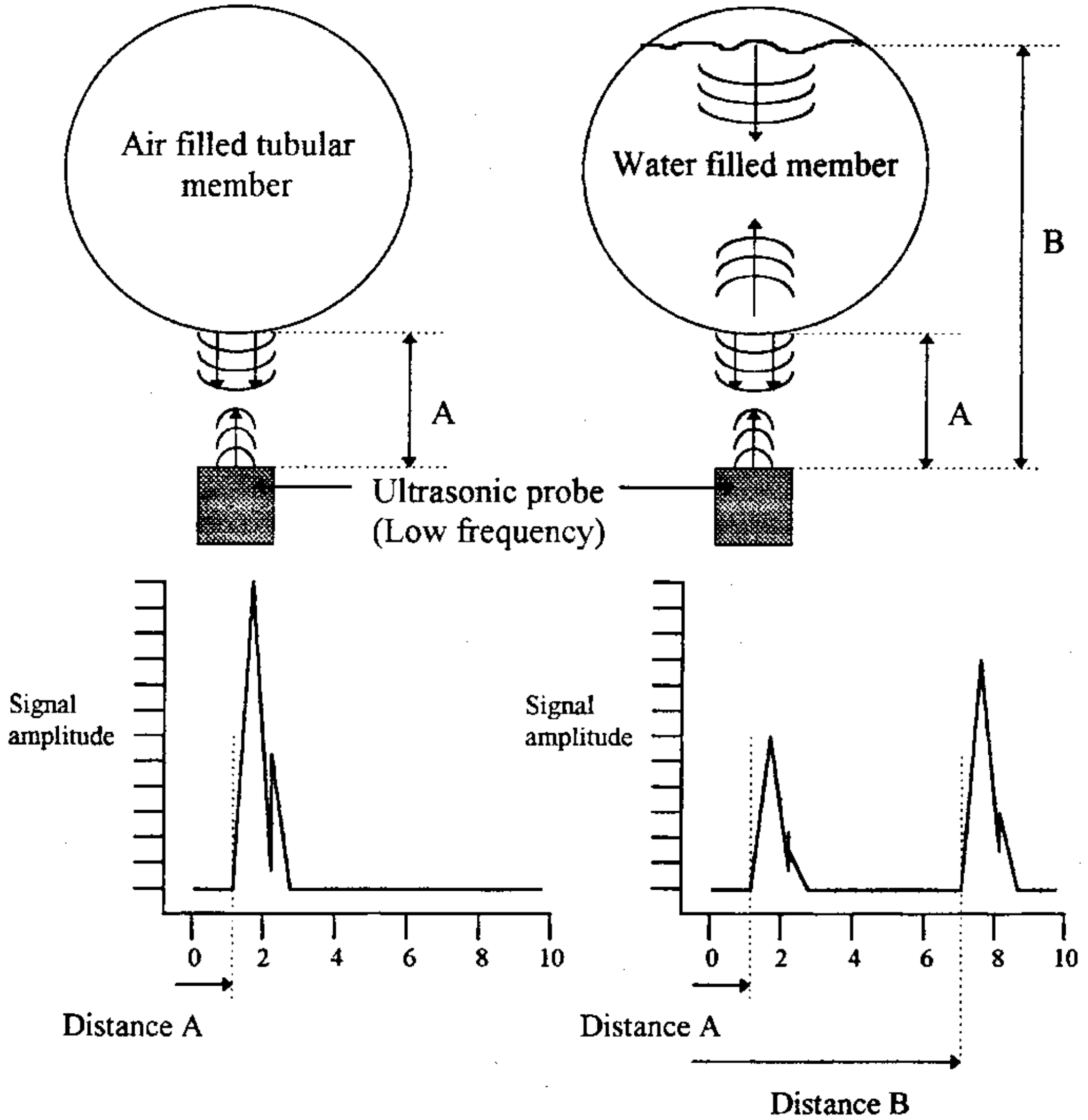


Figure 10.7 Flooded Member Detection (FMD) using the Ultrasonic Method

NOTES

CHAPTER 11

WRITTEN AND VERBAL REPORTING

No matter how detailed the initial inspection, nor how thoroughly any anomalies found are investigated, if there are no records then you have **NOTHING!**

1. RECORD KEEPING

Initial data from the diver or ROV relating to the inspection site will be the first record completed for any inspection carried out. Any anomalies will be followed up separately and will generate their own reports. Normally all data will be recorded on data acquisition forms (Perhaps these forms will now be supplied via a computer). These data acquisition forms will enable efficient recording to be carried out quickly and easily. They will normally be supplied as a pro-forma from the client. If the system adopted is an anomaly based system the information will usually be recorded direct onto a computer at the surface control point of the dive. Reports will then be drafted from the raw data. Record keeping and effective cross referencing is crucial as there may be a need to refer back. If the recording is not carried out efficiently, then this may not be possible.

2. DOCUMENTATION

Documentation will form the basis of the following:

a) Reports required for presentation to Independent Verifying Body, with respect to satisfying the criteria for continued use of the structure.

b) Reports required to formulate future structural inspection, maintenance and repair programs as well as long term trend analysis of the structure.

c) Further routine or follow up inspections will be generated as a direct result of reviewing current reports.

d) New structural designs will be evolved indirectly from the reports.

e) Confidence in the structure is maintained and enhanced by this historical record

3. DAMAGE REGISTER

With both anomaly based and full reporting systems a damage register will be maintained. This will be a record of all known damage on the structure, pipeline, risers etc. All documentation will be crucial to:

1. Update register with previously undetected damage.

2. Monitor and "manage" existing damage and anomalies, to reassess it with a view to ascertain whether repair is now required.

3. This will provide confidence in the structures ability carry out its designed function safely, imperative with the system as it now is with the emphasis on Verification rather than Certification.

NB

WRITTEN REPORTS

Written reports will form the basis of the operators Independent Verification plan, as such they are very important. The format of a report will normally be dictated by the clients requirements the following is how a written report should be laid out and shows the points that should be included., typically it will have the following components:

1. Title - This should be as short and as descriptive as possible, it is usually presented as a front-piece with the title, author, project and the date.

2. Signing off sheet - Signatures of those involved.

3. Table of contents - Should show the pattern of the report at a glance, it should be on a separate page.

4. Introduction - Gives brief details as to the purpose of the report and the background, it may define the terms of reference for the report. The following will normally be included in the introduction:

TEAM INVOLVED.

a) Geographical location
b) Component reference WO.
c) Client CSWIP
d) Diving company
e) Divers name ROV
f) Inspection controllers name
g) Task undertaken CP. CCTV, STILLS ETC.
h) Equipment used ROV USED. CONTACT OR PROX. CP. PROBE.
i) Date of inspection

5. Summary - Should be a highly condensed precis of the report to enable the engineer to skip reports which do not need his attention. In the case of an anomaly based system, the summary may be the most important section of the report. The summary should indicate the following:

a) The extent of the report.
b) The findings of the writer.
c) If appropriate, proposed action. RE FURTHER INSP. IE CLEANING.

6. Results - The main body of the report. This should be concise but clear and include all photographs, readings, relevant data and any cross references etc. CP, CLAMPS, LIMITERS ETC.

MAKE SURE YOU HAVE INFO TO BACK UP CONCLUSION

7. Conclusions - May not be required, if they are required they should follow & RECOMMEND from the facts logically. Opinions can be include but it must be clear that they are just personal opinions.

8. Recommendations - Again not always needed but if required they will be derived from the conclusions. They should be practical and within the confines of the report.

Note: - It is very important that if giving conclusions or recommendations, they should always be limited to our particular field, in other words do not conclude or recommend anything outside the scope of your experience and qualifications.

9. References - Should list all material relevant to the report which has been IE CJI to BS 499 drawn on to provide additional background data or support. WORKSCOPE NO.

10. Glossary - A list of technical or special word or definitions used in the report.

11. Appendices - Should contain material which is secondary to the report:

a) Copy of the workscope
b) Raw data sheets
c) Sketches
d) Calculations
e) Printouts FROM ACPD ETC.
VIDEO LOG - LOG EVERYTHING.

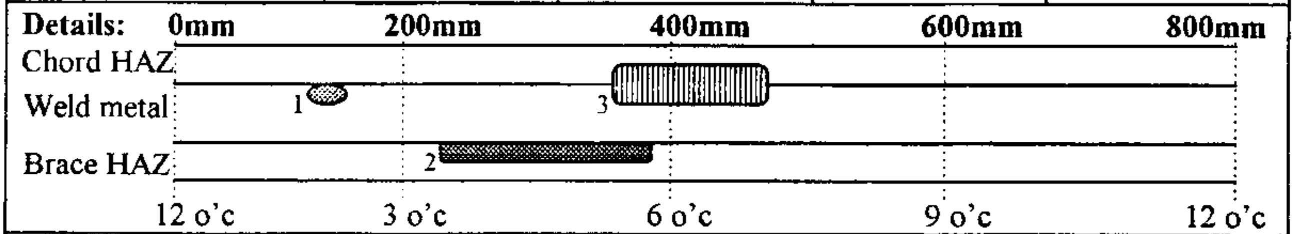
Most clients will of course supply inspection report sheets, which must be filled out correctly. It is of absolute paramount importance that the sheet is filled out in the proper manner using correct techniques, if this is done the report sheet will draw attention to all of the relevant points quickly and easily. Each contractor will vary slightly but in general the report will be easier if graphics are employed. A great deal of information can be conveyed by the use of sketches and graphics, such as type of defect, size, location and orientation. An example of a how a visual report sheet for a weld could be used follows in figure 11.1:

Platform:	**Weld reference:**	**Date:**	**Data sheet No:**
Highland "A"	NJ14/MJ24	02/06/97	0448/9

Dive No:	**CVI:**	**MPI:**	**CCTV:**	**Photography:**
44	23	31	N/A	N/A

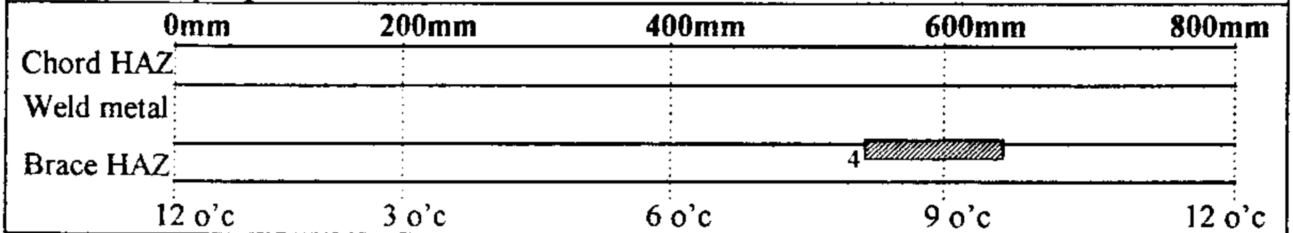
CP readings:	**12 O'clock**	**3 O'clock**	**6 O'clock**	**9 O'clock**
	-0.95V	-0.93V	-0.90V	-0.93V

Details:



Feature number	**Feature type**	**Visual inspection report description**	**Distance from datum**	**Max depth**
1	CR	Crater in the weld	147mm	2mm
2	UC	Undercut in the brace toe	220 - 380mm	3mm
3	GR	Grind in chord toe	360 - 440mm	3.5mm

MPI anomaly report:



Feature number	**Feature type**	**MPI report description**	**Distance from datum**	**Max depth**
4	CK	Intermittent cracklike indication in the brace toe	550 - 630mm	Unknown

Figure 11.1 Written Report Sheet

The report sheet shown in figure 11.1 can be used to best effect if graphics are employed as shown, these graphics would be used to illustrate defects and anomalies on the weld, they should employ shapes and shading and not colour as at this time it is still unusual to have a colour photocopier and the reports will need to be copied. Figure 11.2 shows how a weld can be described using draw 4 horizontal lines, these lines would indicate 1, the outside of one heat affected zone 2, the upper toe of the weld 3, the lower toe of the weld and 4, the outer edge of the lower heat affected zone. The area between lines 1 & 2 would show the upper heat affected zone, the area between lines 2 & 3 would show the weld cap itself and the area between lines 3 & 4 would show the lower heat affected zone. In addition the clock positions and/or tape reference scale can be illustrated as shown.

DONT USE COLOUR. USE GRAPHIC TECHNIQUE

When graphics are used it will be of prime importance to include a Key to explain what the different graphics that have been used actually relate to, the graphics should be unambiguous in that they should all be sufficiently different so as to avoid any sort of confusion regarding the type of anomaly reported.

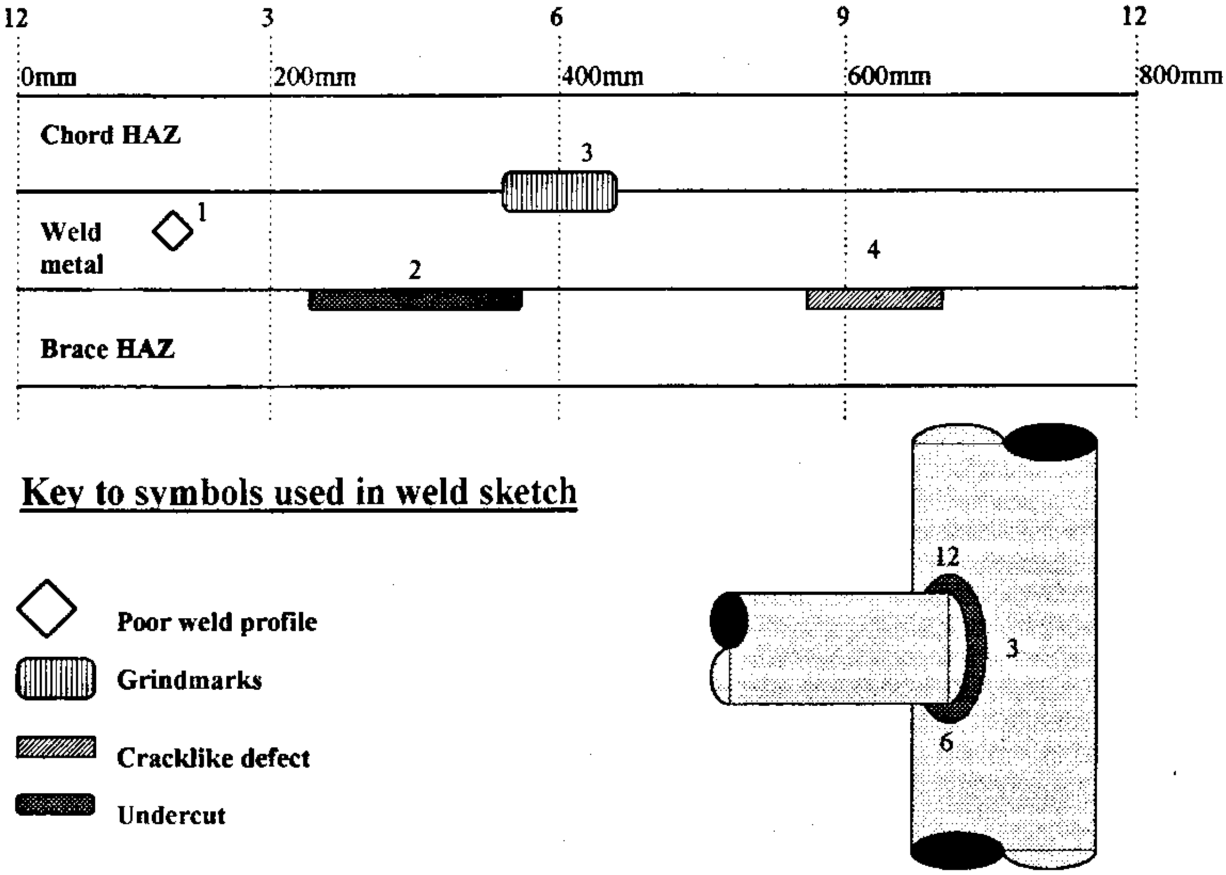


Figure 11.2 Weld Reporting using Graphics

VERBAL REPORTING

Most reporting is now carried out over the divers communications, this means that several points must be noted by the diver in order for the report to be useful:

1) Correct terminology must be used at all times.
2) The commentary must be fluent.
3) An introduction must be given, the following should be included in the divers introduction:

   a) Who is carrying out the inspection (~~Diver~~ inspector). SELF.
   b) Where the inspection is being carried out. COMP. REF NO & IDENT.
   c) What is to be done (General or close inspection).
   d) When the commentary is being done. PLUS DATE OF EXAM.

Additionally when a diver is required to complete a commentary the following should be borne in mind:

USE WORKSCOPE CP DIST. AS PROMPT STOPS.

1) Always attempt to keep a rhythm going, this means that there should be no gaps or "um...er" in the commentary.
2) Try to maintain a relatively slow speed of speech, do not rush or the words may not be understandable.
3) Volume, do not shout or mumble, and ensure the topside operator can easily understand before starting.
   RECORD STOP & PLAY TO CHECK VOLUME.

For more information see the section relating to CCTV, (video inspection).

NOTES

CHAPTER 12

RECORDING METHODS USED IN WATER

The whole reason for being on site to carry out inspection is to prove the structure is seaworthy, and to detail any defects which are found. In order to assure the quality of results and to make them more acceptable to the various Independent Verification Bodies we must record the details of the inspections, there are several methods currently in use offshore they are:

1. SCRATCHBOARDS

A scratchboard is a piece of rigid plastic which the diver will take to the job site with him and on to which he can write the information that he needs to record. This method will therefore call for the diver to record all of the readings and information while he is still on the job. The advantage is that **there is no requirement for communications**, to or from the diver. The main drawback is that the report will be just a representation of the divers interpretation as to the condition of the item under inspection.

2. SKETCHES AND WRITTEN REPORTS

A) Sketches

Can be extremely important as a way of conveying information regarding damage etc, **they enable the diver to convey information which he would find very difficult to put into words**.

B) Written Reports

Most of the information from an inspection program will ultimately be presented to the client in the form of a written report. In terms of a recording method the information can either be given by the diver over the communications and written down on data sheets on the surface this is the most common method. Or the diver could transfer the information from his underwater scratchboard on to paper in order to make a written report of the inspection when he returns to the surface.

3. PHOTOGRAPHY

Both of the above methods have relied exclusively on the divers interpretation during the inspection. Photography is a method of backing up the visual inspection and of making **a very high definition permanent record of an area of interest**. It allows the clients engineers to view a good quality visual representation of the defect, thus removing much of the responsibility for the diver to make accurate assessment of the damage.

4. CLOSED CIRCUIT TELEVISION (CCTV)

Closed circuit television is a method of **recording the inspection in real time**. This means that the topside engineers can view the inspection either as it occurs or at a later date, providing that the inspection is recorded on videotape. It is widely used for the recording of general visual inspections and close visual inspections, being able to include a vast amount of information on the screen, such as time, date, depth, heading and cathodic potential readings etc. With hat mounted video cameras now almost universally fitted, and remote operated vehicles becoming widely used, most tasks and inspections will be recorded on videotape.

5. RADIOGRAPHY

All of the above methods have been recording information about the surface of the component. Radiographs will **give a permanent record of sub surface defects** included in a material. It is principally used for the inspection of welds after fabrication or repair. The reason being, it works best on volumetric defects but is not reliable for the detection of planar defects.

6. CASTS

Casts are used to **record the contour or profile of small defects or welds**, usually after the weld has undergone some remedial grinding. They are formed by forcing a malleable material into a defect to form an impression, there is a risk of distortion when the cast is removed. Most commonly the cast is formed by the use of a two-part epoxy compound such as "Microset" which will not be deformed on removal, or transportation to the surface. This method is especially good for recording the profile of grind-out marks and recording the depth and profile of corrosion pits. It can also be used to record the results of a magnetic particle inspection by trapping the particles in the cast, enabling the results to be studied at a later date.

7. ELECTRO MAGNETIC DETECTION TECHNIQUES INCORPORATING HARD COPY FACILITIES

Most oil companies and offshore operators are keen to take the onus off the diver with regards the interpretation of weld inspection. The route that seems to be most likely is to use electro magnetic methods, these will involve the topside operator in both the recording and interpretation of the inspection. Sometimes the information will be recorded on computer and thus the information can be manipulated, interpreted and printed out at a later date, maybe even ashore in better conditions. This leaves the diver as little more than a probe pusher however he will inevitably need to have some background in visual inspection as he will need to inform the topside operator of visual imperfections and features. Some of the systems are very likely to be deployed by ROV in the near future if not already.

8. SAMPLING

This is usually employed with marine growth and seabed surveys. It will involve recovering small amounts of material from the location, these will then need to be properly labelled, logged and referenced according to the clients requirements.

NOTES

CHAPTER 13

PHOTOGRAPHY

Photography is an extremely important technique for the recording of defects and anomalies in the offshore environment. The advantages are as follows:

1. Permanent record.

2. High resolution (compared to CCTV).

3. Scale and information can be included; very accurate measurements and assessments can be made employing stereo and photogrammetry.

4. Cheap.

5. Readily available.

6. Adaptable.

* SCALE MOST NB IN PHOTO.

7. Proven technique.

8. Easy to deploy and equipment is readily available.

9. Magnification is possible.

10. Time lapse photography is possible.

There are also some disadvantages, especially over CCTV, the following are considered to be the major ones:

1. There will be time needed for development of the film, this will mean that the diver or ROV and maybe even the ship carrying them may have left the job site before the results are known.

2. Complex lighting and camera settings may be needed in order to gain the correct exposure.

3. Trained personnel and a fair amount of equipment will be needed to carry out the developing processes.

Photography is the recording of reflected light onto a photo sensitive surface, it is always dependant on the amount of light available.

FILM STOCK

The first thing that we should look at is the film stock, as this is the photo sensitive part of the process, the factors which affect the selection of the film used are as follows:

1. SLIDES (positives) OR PRINTS (negatives).
2. COLOUR OR BLACK AND WHITE (monochrome).
3. FILM SPEED.
4. FORMAT.

If we now look at these in more detail one at a time:

1. POSITIVE OR NEGATIVE FILM

SLIDE FILM (POSITIVE FILM)

Advantages	Disadvantages
Quick developing time	Not tolerant to exposure errors
Little equipment needed	Poor for inclusion in reports
Little skill needed for developing	Difficult to produce prints
Viewed with only one process	

For some clients or job sites the advantages may well out-weigh the disadvantages and so slide films will be chosen. This is especially true for the one-off job or the quick "look see" type of job. It may well be that the client is "geared up" to the use of slides in his reporting procedure and so he may well insist on them.

PRINT FILM (NEGATIVE FILM)

Advantages	Disadvantages
Tolerant to exposure errors	A lot of equipment needed for developing
Good for inclusion in reports	Skill is needed for developing
Easy to study fine detail	
Easy to print reprints	
Easy to print enlargements	

Most clients will prefer the use of print film and the advantages it brings; especially the tolerance to exposure error, as this will ensure a good result in even difficult conditions.

2. COLOUR OR MONOCHROME

Photography is the gathering of an image by the use of photo sensitive chemicals and as such is dependant on the amount of light available, this being the case there is almost always a trade off with regards the desired picture and the settings which must be used.

The photo sensitive part of the photographic emulsion are the **SILVER HALIDE** crystals. They will react with the light which is admitted to the camera and will form a latent image, this image will become visible only after the film has been developed.

If the film is a monochrome film then the silver halide crystals will form grey dyes when they have been exposed to light and developed.

In colour positive film (slide film) the silver halide crystals will form true colours when developed.

If colour negative film is used then the silver halide crystals will form colour opposites e.g., something which is green in the picture will appear purple in the negative when developed.

In a monochrome film there will be a layer of plastic film base which will have an emulsion containing the silver halide crystals on one side only; unlike a radiographic film which will be coated on both sides (see figure 13.1).

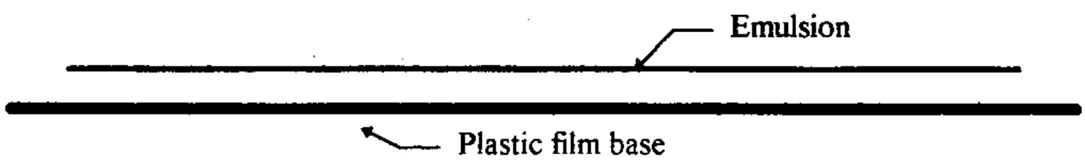


Figure 13.1 Monochrome Film

In the case of a colour film the emulsion is more complicated in that it will have a number of photo sensitive layers. Each of which will react with a different wavelength of light to produce a dye in one of the complimentary colours; magenta, cyan or yellow. These are the three colours which are opposite to the primaries on the colour circle. As such they only absorb light of approximately one third of the spectrum, so allowing the other two thirds through to the layers sensitive to the other wavelengths. The primary colours cannot themselves be used as they absorb two thirds of the spectrum and thus would block the light from the other layers of the film. The result will be to form a picture containing all of the possible colours (see figure 13.2).

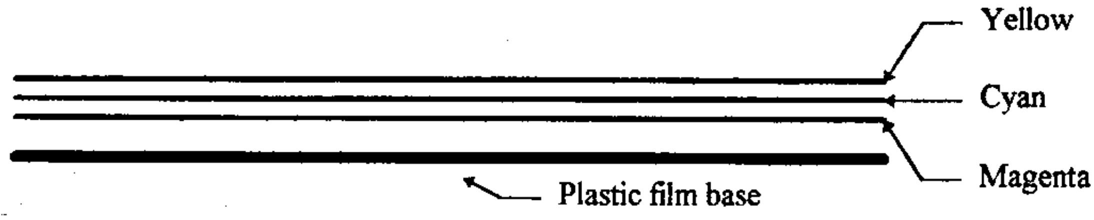


Figure 13.2 Colour Film

Monochrome or Black and white film does not give a life like image and as a result can be said to lack the contrast needed offshore. It will in fact have a greater contrast than colour film, however, colour adds a further "dimension" to the picture and makes the picture easier to interpret. This is especially true as far as marine growth and concrete inspection are concerned; so colour film is therefore preferred. **FOR THE REASONS STATED THE MOST COMMON FILM USED OFFSHORE WILL BE COLOUR PRINT FILM.**

3. FILM SPEED

One other factor is affected by the silver halide crystals and this is the sensitivity of the film to light. The size of the crystal is the deciding factor in this, the larger the crystal the faster the reaction and vice versa. So, if you use the largest crystal then little light is needed, however the larger the crystal the more visible it will become in the finished print. Again we have a trade off, this time between the picture quality and the speed of reaction to light, or to put it another way the amount of light needed to create the image, so in summary:

SMALL CRYSTAL - SLOW REACTION - GOOD QUALITY.

LARGE CRYSTAL - FAST REACTION - POORER QUALITY.

The crystals can be grouped onto the film by size which enables us to give the film speed a numerical value, in doing so we can use the film that is appropriate to the amount of light available. There are three systems used for the marking of film speed these are:

1. **A.S.A. - AMERICAN STANDARDS ASSOCIATION.**

2. **D.I.N. - DEUTSCH INDUSTRIES NORM.**

3. **I.S.O. - INTERNATIONAL STANDARDS ORGANISATION.**

System	Slow			Medium		Fast	
A.S.A.	25	50	100	200	400	800	1600
D.I.N.	15	18	21	24	27	30	33
I.S.O.	25/15	50/18	100/21	200/24	400/27	800/30	1600/33

Each step is equivalent to either doubling the speed of reaction or halving the speed of reaction to light, therefore I.S.O. 100/21 is twice as fast (and so will need only half as much light to ensure a correct exposure) as I.S.O. 50/18, but only half as fast as I.S.O. 200/24, and so on.

The system which should now be used on all film is the International Standards Organisation (I.S.O.) number.

4. FORMAT

The format of the film may well be dictated by the camera which is available. If there is a choice, then there will be certain factors to consider. Underwater there are two formats which can be used they are:

SMALL FORMAT (35mm cameras).

MEDIUM FORMAT (70mm cameras).

Although these two formats are available, it is probable that these days the most common camera and film combination used will be small format, this is due to the following reasons:

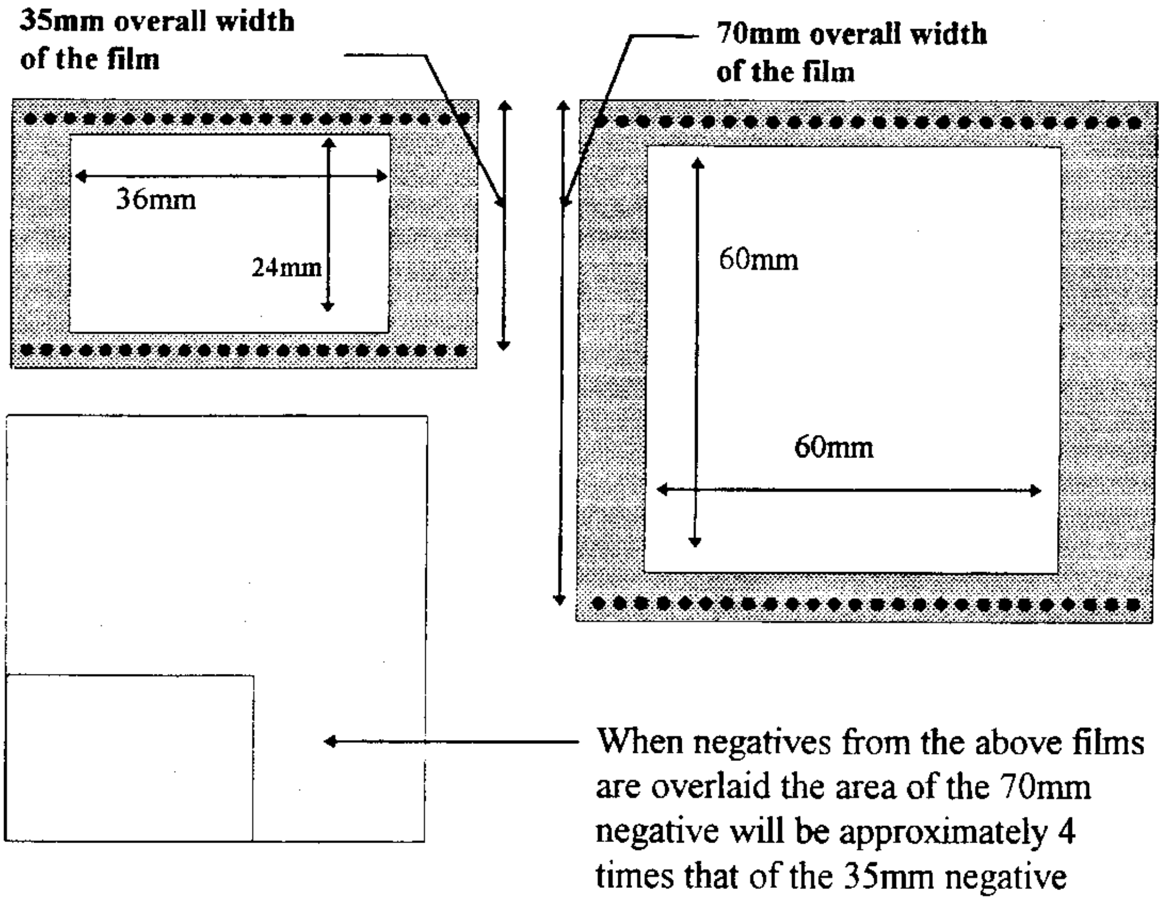


Figure 13.3 Small and Medium format Film

The difference then is the size of the film. In the case of the small format, the negative size is 36mm x 24mm, these cameras are termed 35mm cameras, the 35mm measurement comes from the overall width of the film including the perforations (see diagram). In the case of the medium format film the overall width of the film is 70mm (see diagram), the frame size can vary slightly according to the camera but will be either 60mm x 60mm or 60mm x 70mm.

So what advantage is there to be gained? The final print quality is dependant on the size of the grain in the emulsion as we have said before. During the printing process we will enlarge the negative to the size of print that is needed, so if the negative is already large then we will not have to blow it up so much in order to achieve the print size needed. Therefore the larger the negative the better the quality of the finished print.

70 millimetre film has a frame size (negative size) which is **approximately four times larger than that of the 35 mm film**, so giving four times the print quality accordingly.

THE CAMERA

The choice of camera is determined by:

1. The type of inspection required - a quick stand off shot or a detailed weld survey etc.

2. Physical constraints of the worksite - the best camera in the world is no good if it cannot gain access to the worksite.

3. Picture quality - if very good quality is needed medium format should be used.

4. The number of photographs required - some cameras can take up to 250 shots before requiring reloading which is an obvious advantage with ROV applications or weld inspections.

5. Type of format - by this we mean the format may be dictated by the client and his special needs.

6. The cost - if the client just wants a quick shot solely to ensure that a component is still there he will not want to pay £30,000 for a camera set up.

The camera is a light-proof box which will allow light to fall on to a photosensitive surface in a controlled fashion. In its simplest form a light-proof box with a small hole in one end. Although this will work we need more control over the finished product. We achieve this control by the use of the following:

1 A lens is used to improve the focus and field of view of the photograph.

2. Control of a variable aperture.

3. Control of the time that the light is allowed to pass through the aperture.

1. THE LENS

The lens is used to provide an image which is in focus, that is to say an image which is sharp. Also, the lens will give control over the field of view, that is the angle across which the camera will record an image.

FOCUS

Focus is the point at which the optical image is clear. When we focus a camera on to an object we measure the distance from the object to the film plane and set this on our lens focusing ring.

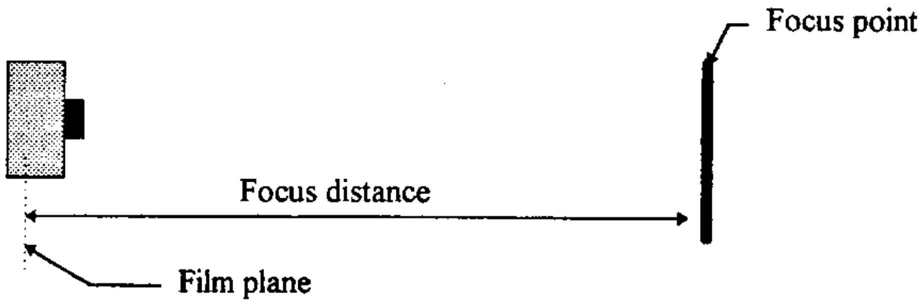


Figure 13.4 Focus

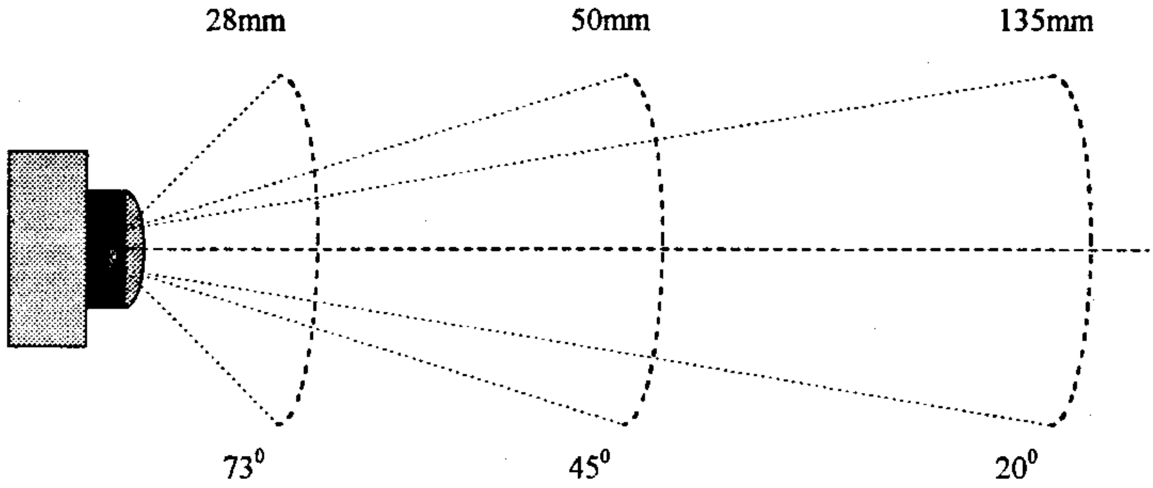
FIELD OF VIEW

The field of view is controlled by the focal length of the lens. This is the length of the light path, measured from the optic of the lens to the film plane, the shorter the focal length the wider the field of view.

In the case of a 35mm camera used in air the "standard" lens has a 50mm focal length. This lens will have approximately the same angle of view as we do and so will record an image similar to that which we are accustomed to seeing with our own eyes. If we use the camera in water, and the lens has a flat port, then the object will appear nearer and larger so a wider lens will be needed to achieve the same "normal" result. As a consequence, in water using a 35mm camera a standard lens will have a focal length of 35mm (this effect can be reduced by the use of a domed port).

A 28mm lens or short lens is termed a "wide angle" lens and as such will have a wider field of view than normal. A 135mm lens or long lens, is termed a "telephoto" lens and will have a narrower field of view. It will thus not record as much of the area to be photographed as we would normally see.

The following sketch shows how the field of view will be affected by choosing various lenses when using a 35mm camera in air:



All the above angles assume a standard 35mm camera used in air

Figure 13.5 Field of View

As we are trying to record an image of a structure in a medium which is at times somewhat less than clear it is an advantage to be as close as possible. Therefore a wide angle lens is preferred for underwater work.

DEPTH OF FIELD

The depth of field is the distance either side of the focus point, (foreground and background) which is also sharp and appears in focus. There are several factors which will contribute to the size of the depth of field these are:

i) The distance from the subject:

The further the camera is moved away from the subject the greater will be the depth of field produced.

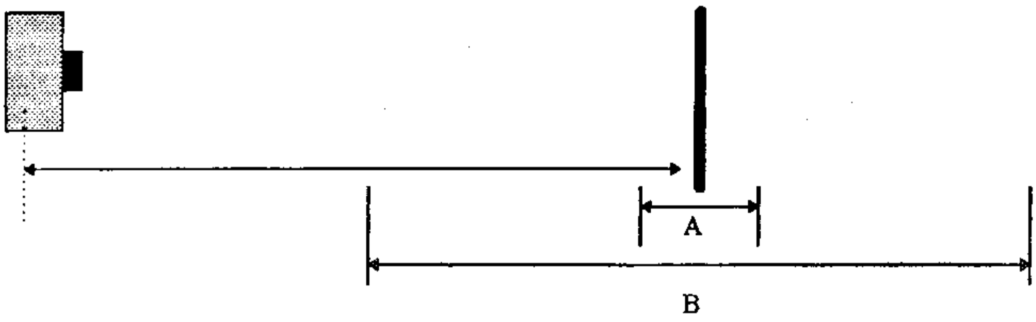
ii) The focal length of the lens:

The shorter the focal length of the lens used the better the depth of field will be.

iii) The amount of light available:

The light level will affect the size of the aperture which can be set on the lens, since the aperture is the hole through which light can enter the camera. The aperture has a great influence on the depth of field as will be shown in the following section:

Basically, the smaller the aperture diameter (large "f" number) the bigger the depth of field, this means that more of the foreground and background will be sharp. So if we use f 22 (small hole) we will have a very large depth of field and f 2.8 (large hole) will have a very small depth of field in fact probably just the point of focus will be sharp. Consequently, when using photography underwater we always try to use a small aperture or high f number in order to maximise the depth of field.



A = Small depth of field (Wide aperture)
B = Large depth of field (Small aperture)

Figure 13.6 Depth of Field

2. APERTURE

The aperture is the hole through which the light is admitted to the film plane, it is a part of the lens arrangement. The size can be varied and will be determined by the "f" stop f stands for factor and is worked out as follows.

$$\text{"f" stop} = \frac{\text{focal length}}{\text{aperture diameter}}$$

For example if we take two lenses with different focal lengths i.e. 100mm and 40mm:

$$f\ \text{number} = \frac{100}{10} = f10$$

$$f\ \text{number} = \frac{100}{5} = f20$$

$$f\ \text{number} = \frac{40}{4} = f10$$

$$f\ \text{number} = \frac{40}{2} = f20$$

As can be seen from above the "f" number f10 means that the aperture is in fact one tenth of the focal length of the lens and f20 is one twentieth of the focal length and so on.

So it can be seen that although the "f" numbers may be the same, the size of the aperture will not be if the focal length of the lens has changed. Both lenses have f20 but the aperture is only 2mm for the 40mm lens whereas it is 5mm for the 100mm lens. Bearing in mind that the smaller the aperture the bigger the depth of field this will mean that the 40mm lens will give a better depth of field as well as a wider field of view.

For these reasons **the preferred lens for underwater stand off photography offshore is the short focal length wide angle lens.**

The relationship of the "f" numbers is not at first obvious but can be shown as follows:

"f" Stop	2.8	4	5.6	8	11	16	22
Light units	32	16	8	4	2	1	½

Note: the light units used are purely arbitrary and are only used to illustrate the point as to the relative amounts of light which could travel through to the film plane in a given time.

So as with the film speed numbering system the effect of moving one step is to double or halve the amount of light which the film needs, as far as the aperture is concerned moving one step will either increase or decrease the amount of light allowed to enter in a given time i.e. f4 will allow twice the amount of light to enter than f5.6 will allow in a given time.

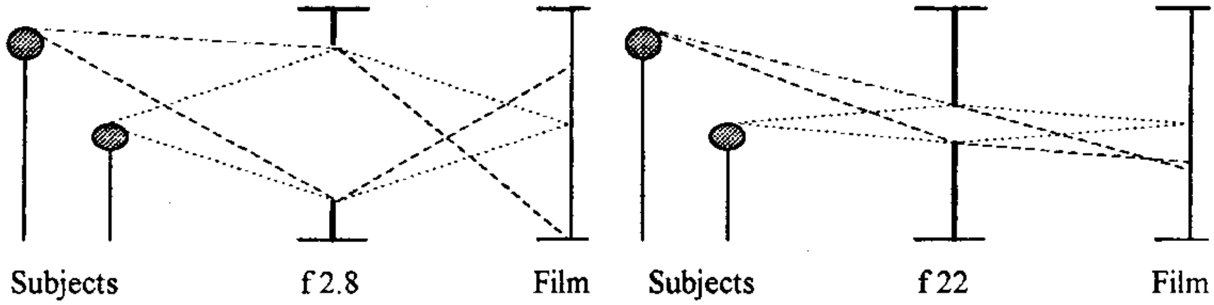


Figure 13.7 The Relationship of Aperture to Depth of Field

In both of the above, the lens remains focused for the subject, but at different apertures. The amount of the subject that is sharp on the film plane changes. At a wide aperture the far object comes to focus in front of the film plane and so would record out of focus. The foreground would record behind the film plane and so would also be blurred. By reducing the aperture the cones of light become narrower; the result is that the foreground and background now form smaller circular patches of light and so give a more acceptably sharp image on the film plane.

3. SHUTTER SPEED

The second way in which we can control the amount of light reaching the film plane is by controlling the time we allow the shutter to remain open, this is called the shutter speed.

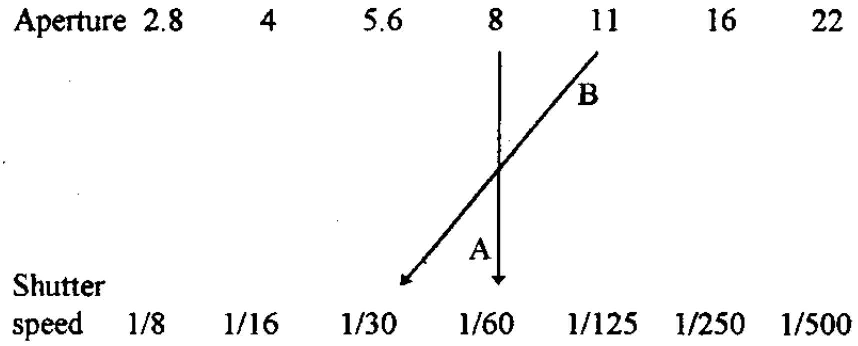
The relationship is much more obvious, this is because we are all used to dealing with time, typically the speeds will be as follows:

Seconds	1	½	¼	1/8	1/16	1/30	1/60	1/125	1/250
Light units	32	16	8	4	2	1	1/2	1/4	1/8

Therefore, the shutter is open for either twice as long or half as long depending on which way the speed is altered.

It should be obvious that all of the factors involved, the film speed, shutter speed and the f stops are all calibrated to affect the image by the same amount. So, if we alter the "f" stop one step one way, all we have to do to compensate is to alter either the film or the shutter speed one step the other way. We would not normally alter the film speed as this involves changing the film in the camera so we tend to use the shutter speed.

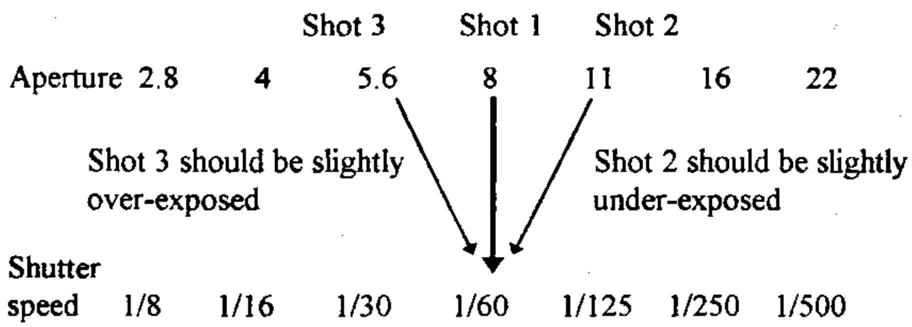
Relationship between Aperture and Shutter Speed



As can be seen from the above diagram the correct exposure was perhaps f8 at 1/60th of a second, however, if we want to increase the depth of field we will need to use a smaller aperture. So we move to f11, this will tend to under expose the film unless we compensate by using a slower shutter speed i.e. change from 1/60 to 1/30th of a second. Indeed, if we had gone up to f16 all that need have been done to compensate is to move the shutter speed the same number of stops, to 1/16 and the exposure would also then be good.

BRACKETING THE EXPOSURE

Most of the time in our situation we will not have the control of shutter speed, as this will be fixed because of the need to synchronise the flash to the shutter, so we will have to use the aperture to control the exposure. When we are taking photographs in water we need to ensure a good quality result. To make sure of this we "bracket" the exposures. This means for example, that if the exposure we should use to achieve a good shot were for arguments sake say f8 at 1/60th of a second. In order to make sure that we achieve a good result we would bracket this exposure, meaning that we would take one shot on f8 at 1/60th and then one on f11 at 1/60th and finally one shot on f5.6 at 1/60th as shown below. Having done this at least one, and possibly all three will give us a good result which is, of course, what the client is paying for.



CAMERA TECHNIQUES

FOCUSING SYSTEMS

There are two main systems in use for the focusing of cameras they are:

1. SINGLE LENS REFLEX

This method of focusing involves the operator looking through the same lens as the camera will use to take the picture. There are obvious advantages to this system, principally what you see is what you get. In addition some cameras will also measure the light through the lens (TTL metering).

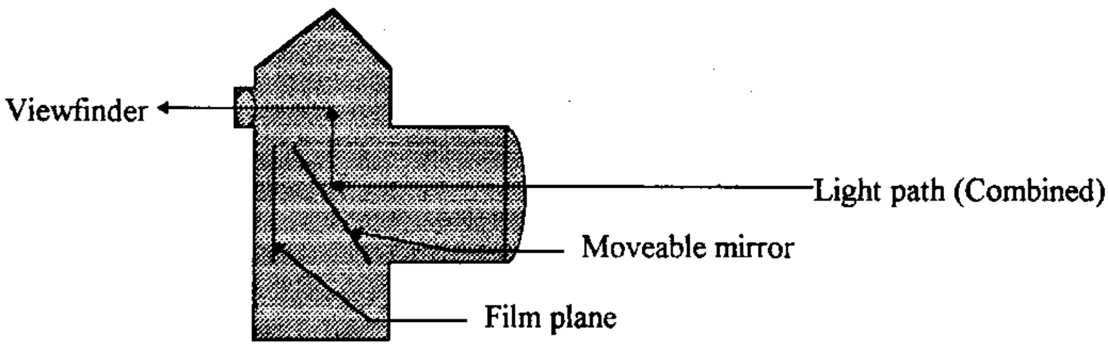


Figure 13.8 Single Lens Reflex Camera

The main problem from the underwater photographer's point of view is that he either cannot see the viewfinder at all because the camera is in a housing, or if he can see it, his eye is a good distance from the viewfinder, making it very difficult for him to focus accurately. This method is widely used for land cameras but at the present time there is only one purpose built SLR underwater camera on the market, so usually any SLR cameras that the diver will come across will be in housings such as the Olympus OM2 in a Scoones housing which does not allow the operator access to the viewfinder.

Through lens vie

However some ROV systems will use a derivative of the above, this is the **TVP or TLV** camera, with these cameras there will be a CCTV camera which is arranged to view through the lens of a photographic camera all of the time. When a still picture is required the operator can fire the camera and will capture whatever was being viewed by the CCTV camera at the time.

2. PARALLAX

This method relies on the operator looking through a separate viewfinder in order to compose the picture. This means that he will be looking along a parallel path to the lens which will ultimately take the picture. This may not be a problem with stand off shots but as the camera is brought nearer to the subject the problem is accentuated, the camera can see some of the subject which the viewfinder cannot and vice versa. Some cameras have a moveable viewfinder, others have a highlighted area in the viewfinder. This is the area that the subject must lie inside, it is the camera to subject distance is less than approximately 4 feet.

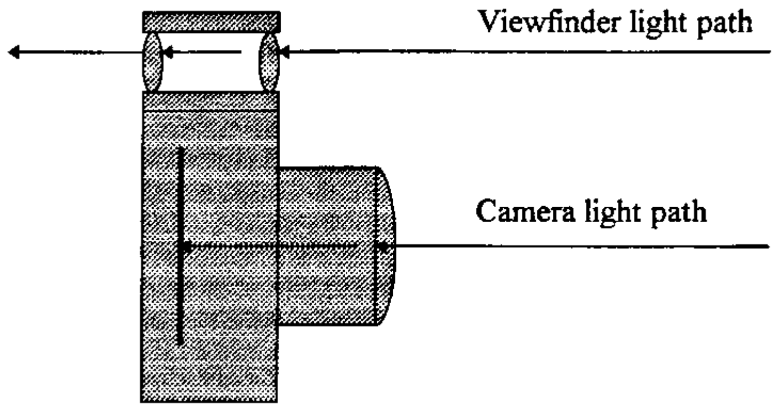


Figure 13.9 Parallax Camera

When the camera is being used for stand off photography it is important to never stand off more than **1/3 rd of the visibility**, this is to cut down on the effect of suspended solids in the water, such as plankton and silt etc. As far as focusing is concerned with this kind of camera the distance will normally be measured and then will be set on the lens focusing ring. This can cause problems as the assessment of distance in water is not always easy, if this is a problem then use a tape and magnet as an aid, place the magnet on the surface of the structure and read off the measurement to the camera this takes the guesswork out of the picture.

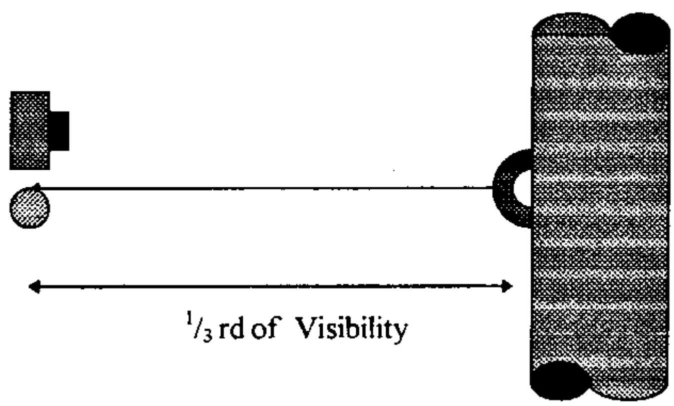


Figure 13.10 Visibility and Distance Assessment in Water

CLOSE UP PHOTOGRAPHY

When taking close up photographs there are two problems. The first is that the area of the subject recorded will be very small, typically approximately 100mm X 70mm with the Sea and Sea Motormarine 2 camera. The second is that the depth of field will be minimal, no more than a few millimetres. Because of these factors we must use some form of focusing aid, there are commonly two types used offshore:

i) Close Up Frame

The frame is designed to be at the centre of the depth of field but slightly out of shot so that whatever the frame is placed onto will be in focus. With the Nikonos there are normally three frames supplied one for each of the lenses, 28mm, 35mm and 80mm. They have the advantage that the frame shows the diver exactly how much of the subject is being covered in the shot. The disadvantage is that the frame cannot be located onto a weld so that it remains flat, this can result in the subject being out of focus, thus the frame is best suited to photography of flat surfaces such as concrete and marine growth surveys.

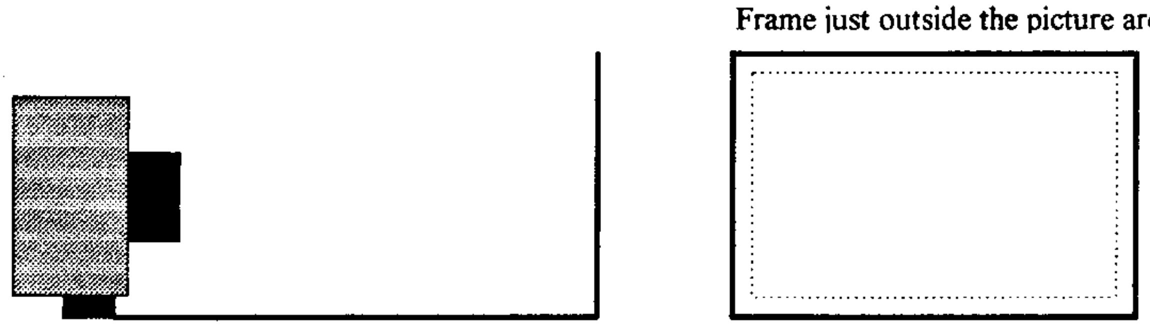


Figure 13.11 Close up Frame Attachment

ii) Close Up Prods

The prods are again designed to be at the centre of the depth of field and slightly out of shot. They will also be centre frame with respect to top/bottom orientation. They have the advantage of being able to be located on a weld so that the weld is in the centre of the depth of field thus maximising the available field. The diver should ensure that the angle between the components is bisected so that if the joint being photographed is a 90° node the camera should be held at 45°, or if the weld to be photographed is on a flat plate then the prods should be held perpendicular to the surface, this will again maximise the use of the available depth of field.

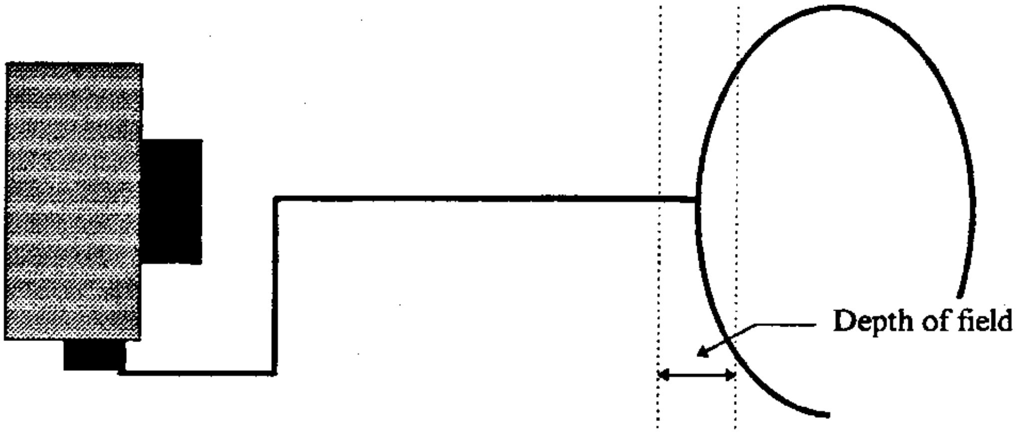
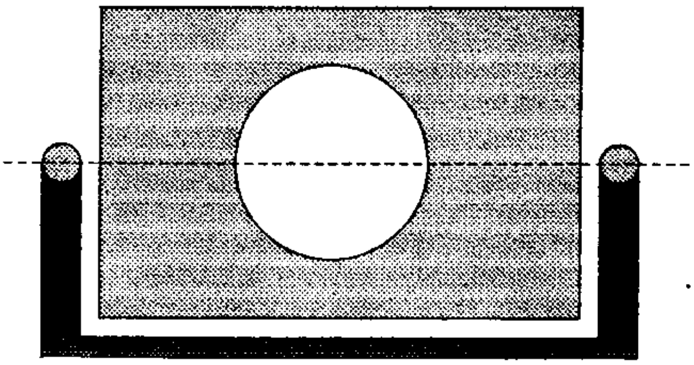
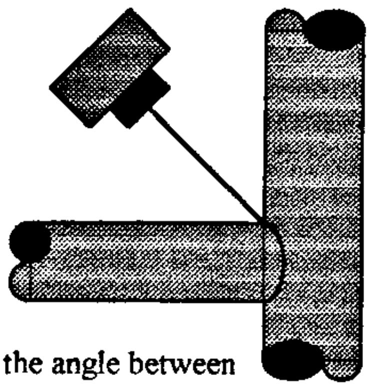


Figure 13.12 Close up Prods





Bisect the angle between the components

Figure 13.13 Prods Bisect the Angle Between the Components.

When using prods or frame the area of the structure recorded will be relatively small, in order to achieve results the diver will have to **mosaic** the subject. To mosaic a subject it will be photographed in such a way as to overlap the pictures, a complete record of the subject can be built up. When doing a mosaic the diver should aim for approximately a **30% - 40% overlap** of the pictures, this can be achieved by a 50% overlap of the prods (which are slightly out of shot). When carrying out NDT photography there must always be a **SCALE** provided in every shot, this is because it is possible to enlarge or reduce the image by using different methods thus making an included scale imperative. In addition each shot should be identified with clock positions and the member identification.

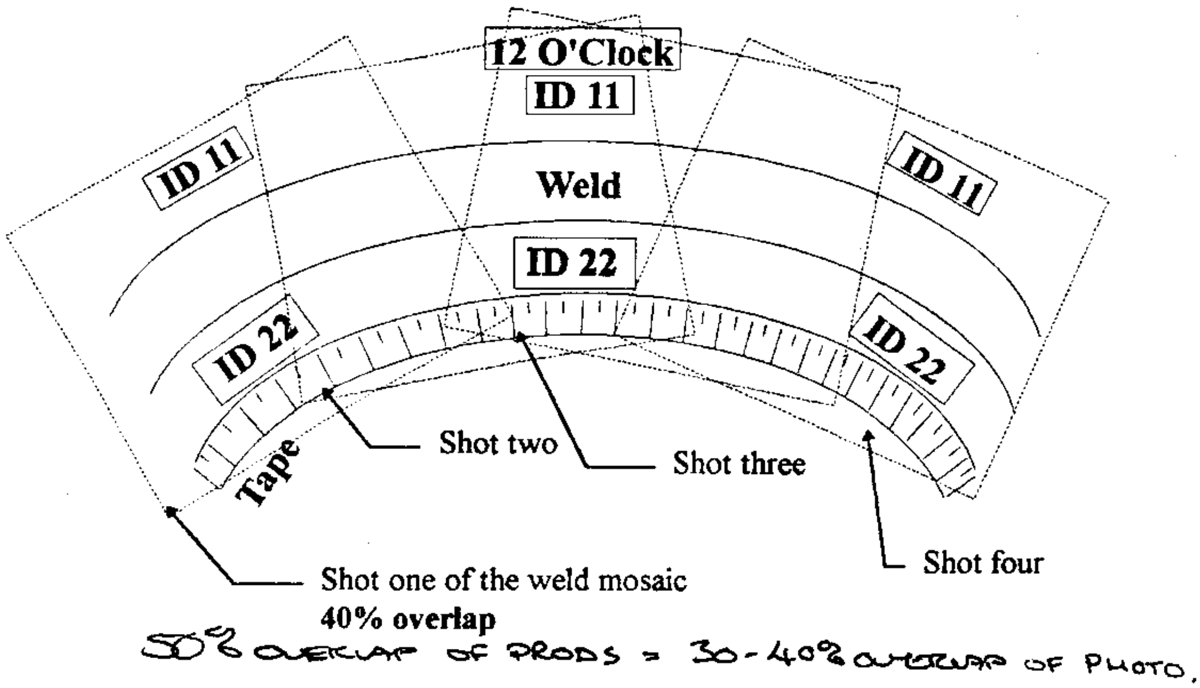


Figure 13.14 Weld Mosaic Showing 40% Overlap, Scale and Identification included

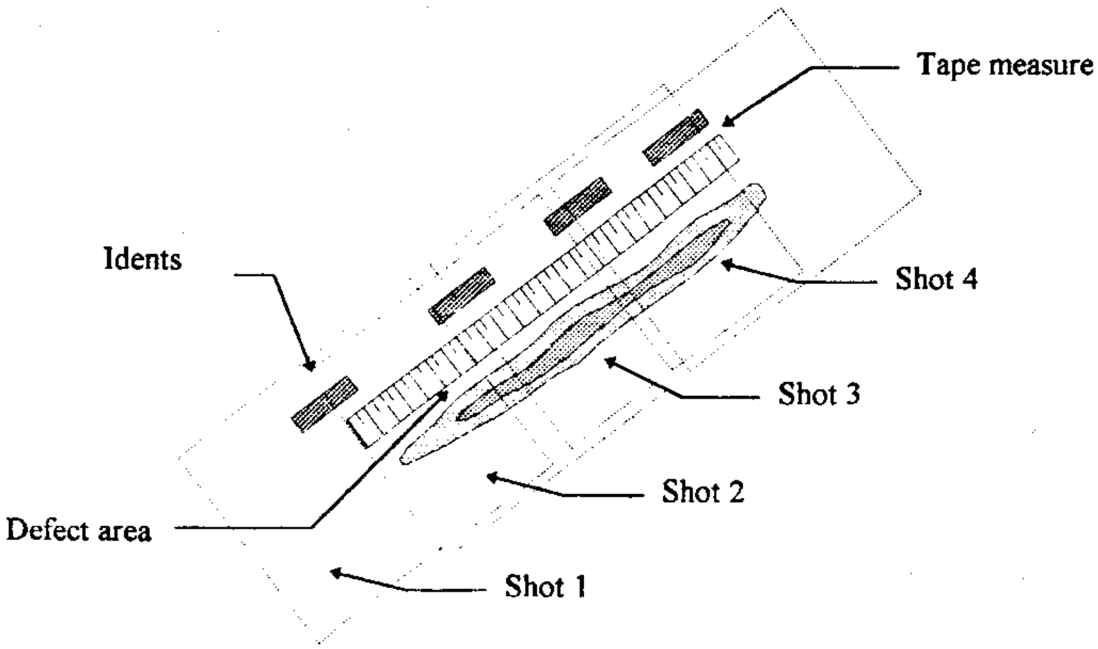


Figure 13.15 Defect Mosaic Showing Scale and Identification

Identification Boards

In most cases there will be a need to include some kind of Identification Board in some if not all of the shots. This board will normally be designed with regards the task to be undertaken, and the particular photographic equipment being used both of which will influence the size and makeup of the board, it is quite possible that there will be a number of boards carried to cater for different types of scenario i.e. close up and stand off photos. The following is an example of how an Identification Board may look:

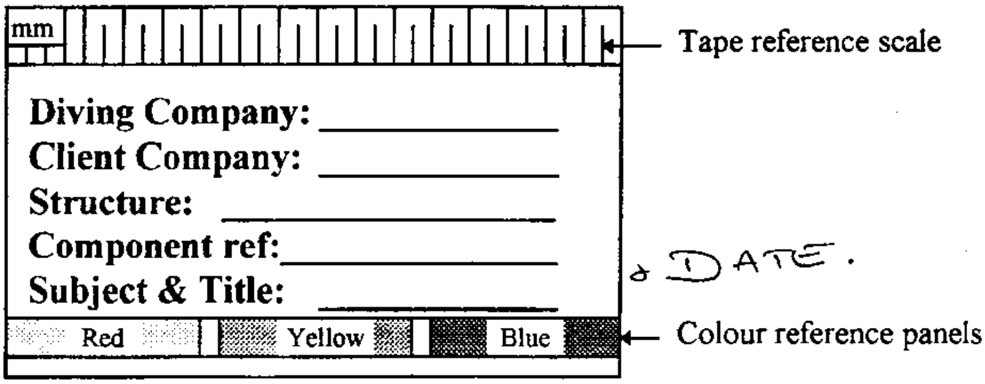


Figure 13.16 Photographic Identification Board layout

In summary the following points should be noted in order to ensure quality results:

1. EVERY location should be identified and a SCALE must be provided.

2. Ensure the field of view is not obstructed in any way (umbilicals, soft line, anodes and exhaust bubbles. When ready to take a shot the diver should hold his breath until the bubbles have cleared the field of view.

3. Make sure that each shot is centred correctly, at the correct angle (bisect the angle if possible) and that the correct overlap has been maintained.

4. Avoid camera shake by squeezing the shutter release, do not jab the button.

5. Place the lighting to avoid backscatter (to be explained in the next section) and ensure the strobe is not obstructed.

6. If in doubt take another shot (bracket the exposure). Film is cheap compared to the cost of returning to the location just to retake a picture.

LIGHT AND PHOTOGRAPHY

As photography is recording light reflected from an object we must look at how light is affected by travelling into and through seawater. There are three laws of light, they are as follows:

i) REFLECTION

The angle of incidence equals the angle of reflection. This will occur at the air water interface and also when suspended particles are present in the water (plant and animal as well as sediment). It will reduce the intensity of light and produces bright spots on the picture termed backscatter when it occurs.

ii) REFRACTION

The bending of light at an interface, occurs as the light passes form one medium to another such as air to water. Light is bent as it passes from water to glass/perspex camera housings. Refraction causes the image to appear closer and larger.

iii) ABSORPTION

SCATTER. - RED. AMOUNT OF LIGHT PENETRE DEPTH.

Different wavelengths of light will penetrate further through water so colours disappear at different depths. The colours will tend to disappear according to wavelength as they appear in a rainbow:

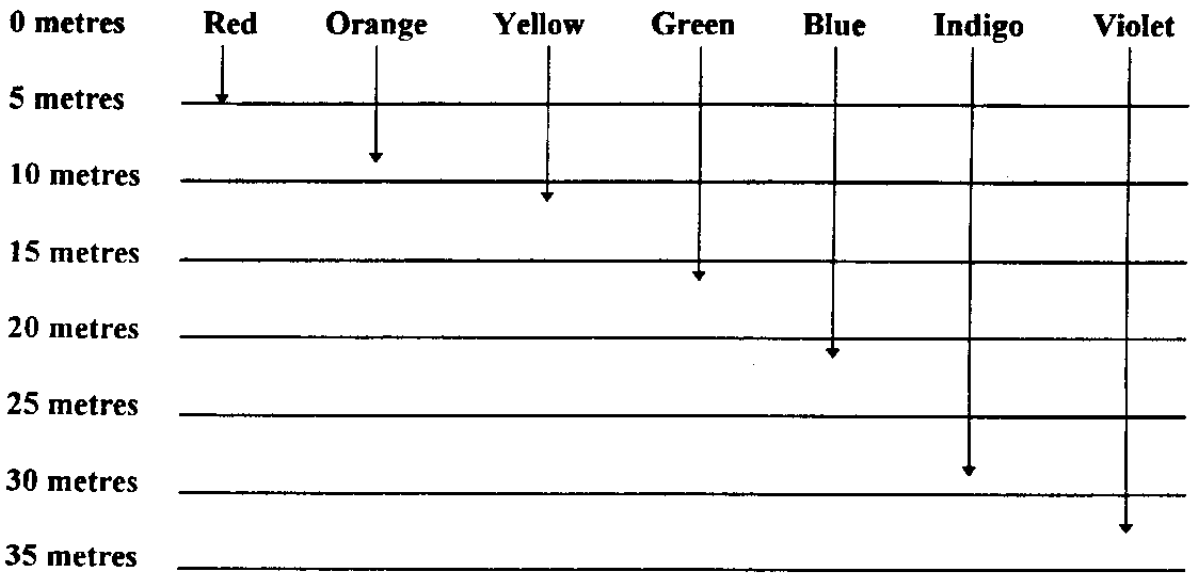


Figure 13.17 Absorption rates of light in seawater

As can be seen from the above diagram at depths below about 35 metres only grey will be evident with virtually no colour will evident.

Although visibility is not a law of light it will have a great bearing on the amount of light available for photography. This is because the light will reflect off of the particles in the water and so will be prevented from penetrating, this is normally referred to as "Scatter".

In the U.K. we are at a latitude of approximately 50° North, this means that even in the summer the incident angle is going to be such that a good deal of the light will be reflected back away from the surface of the water and will not penetrate. Even in the tropics the sun is directly overhead only at noon.

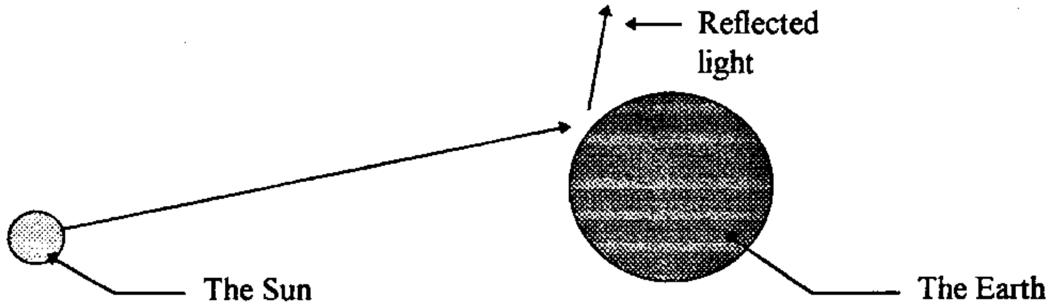


Figure 13.18 Reflection

The light which does penetrate will be subject to refraction and so will be bent as it crosses the interface.

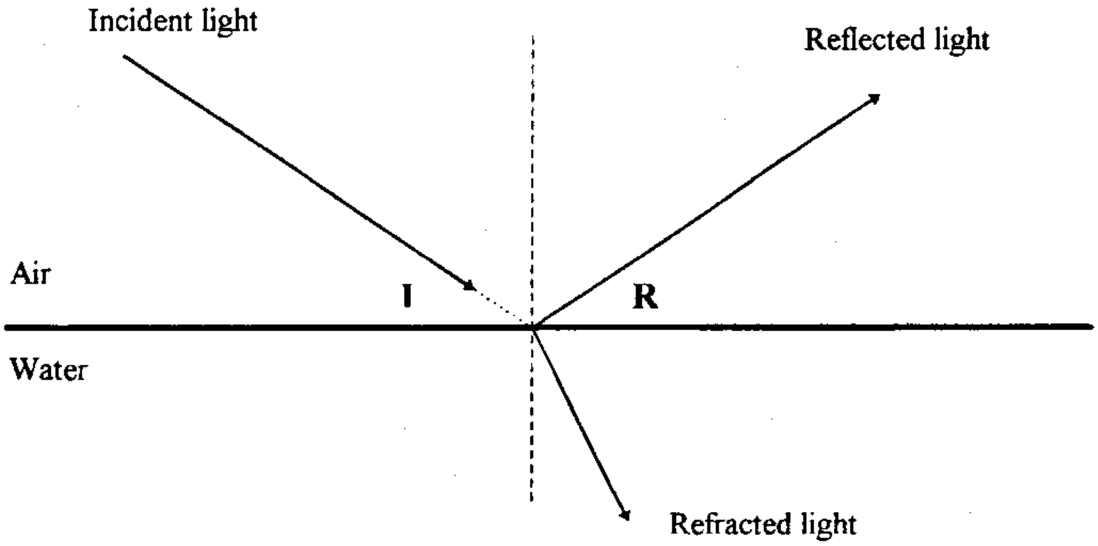


Figure 13.19 Refraction

The fact that the light is not travelling directly down will also mean that for every 1 metre depth, the light has to travel somewhat further and so will suffer more absorption.

The above laws are going to mean that even on a sunlit day in the middle of summer if the diver sits with half his face mask above the water and half below, the underwater section will be significantly darker. Even if there is a lot of light in a shallow area the component will only be lit from above and so there will be shadows at the 6 o'clock position which will be an area of significant importance. This means that the majority of underwater photographs will need artificial lighting to ensure adequate results.

ARTIFICIAL LIGHT

There are several ways in which we can take light with us when we go to take photographs underwater they are as follows:

i) Bulb Flash

This kind of light involves the use of a "once only" bulb, this means that after each exposure the bulb must be replaced, it gives a warm incandescent light, there are obvious disadvantages in this method and so it is not widely used offshore.

ii) Electronic Strobe

The electronic strobe uses a capacitor discharge to produce a vast quantity of harsh white light which will produce abrupt shadows. The advantages are that it will recycle a large number of times without the need for changing bulbs or recharging, also the duration of the light is very short (typically 1/1000th of a second), this will help to reduce "camera shake" as the camera will be set for the strobe exposure and any ambient light will not significantly affect the picture.

The output of an electronic strobe is normally given by the **GUIDE NUMBER**. This number will be quoted to be used for the calculation and setting of the f stop. Normally there will be one number for underwater and one for use in air. The underwater number may be expressed for metric and imperial distances and would relate to the film speed used. For an example we will assume the metric guide number in water is 22, for a film speed of ISO 100/21 this would mean the imperial equivalent would be 72, the exposure is calculated by using the following formula:

$$\text{f stop} = \frac{\text{Guide number}}{\text{Distance to the subject}}$$

If we assume we have a subject to camera distance of 2 metres then the formula would look as follows:

$$f\ stop = \frac{22}{2}$$

<u>f stop to be set will be f11</u>

It is not unusual for the strobes to have a half power and quarter power settings, if these are used then the guide number (22) would be either divided by 2 or 4, and then the resulting number inserted into the formula.

It's possible that the Guide number quoted is for one speed of film, i.e. Guide number of 50 for a 200 ASA film. But the film available is only 100 ASA, this would require that there be some adjustment to the exposure as the film is only half as sensitive, in this case the original guide number is divided by 2 in order to compensate therefore giving a useable guide number of 25, when this is used in the above formula the "f" number which results will give a good exposure (Note* Always bracket the exposures to ensure a good result).

When using any of the above the shutter speed of the camera will have to be set in order to "synchronise" the strobe to the camera, thus ensuring that the strobe fires while the shutter is open. This will limit the versatility of the camera as the speed set is likely to be 1/60th, 1/90th or 1/125th of a second, but the short duration of the strobe tends to make up for this somewhat.

iii) Photo Flood Lights

Photo flood lights are not widely used as the amount of light involved will require either large battery packs or a cable to the surface thus reducing the manoeuvrability, the advantage is that the camera can be used as a full function camera meaning that the shutter speed does not need to be set, the camera can be used as a land camera using available light, focusing is also going to be much easier as the light is there all the time.

LIGHT PLACEMENT

With all of the above there is a need to ensure that the subject is illuminated from the right angle, in order to reduce the effect of suspended solids (backscatter) and ensure the subject does not fall in shadow.

Backscatter:

Backscatter is the presence of isolated suspended solids which will cause bright white dots to be visible on the picture. If there is a lot of solids in the water then the picture will lose contrast and tend to take on a milky hew; for this reason we limit the stand of to no more than 1/3rd of the available visibility. A second way to alleviate the problem is to place the flash in such a way as to prohibit the reflected light from finding its way into the camera lens.

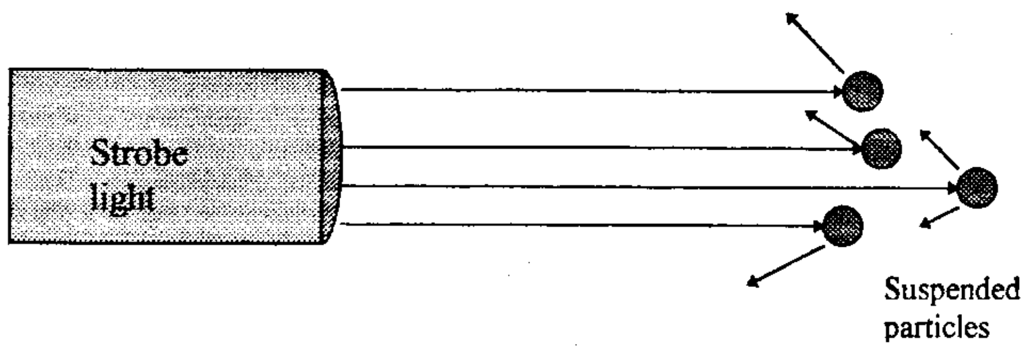


Figure 13.20 Backscatter

We have all seen the results of photographs taken of animals with small pocket cameras incorporating built-in strobes, in these photographs their eyes look like two bright lights. Professional photographers prevent this by moving the strobe away from the camera lens and putting it onto an arm. We to can use this technique to avoid the backscatter caused by suspended solids by placing the strobe on the end of an arm away from the camera. The distance does not have to be great, and all it does is to place the strobe so that the light reflected back from the solids will not enter the camera.

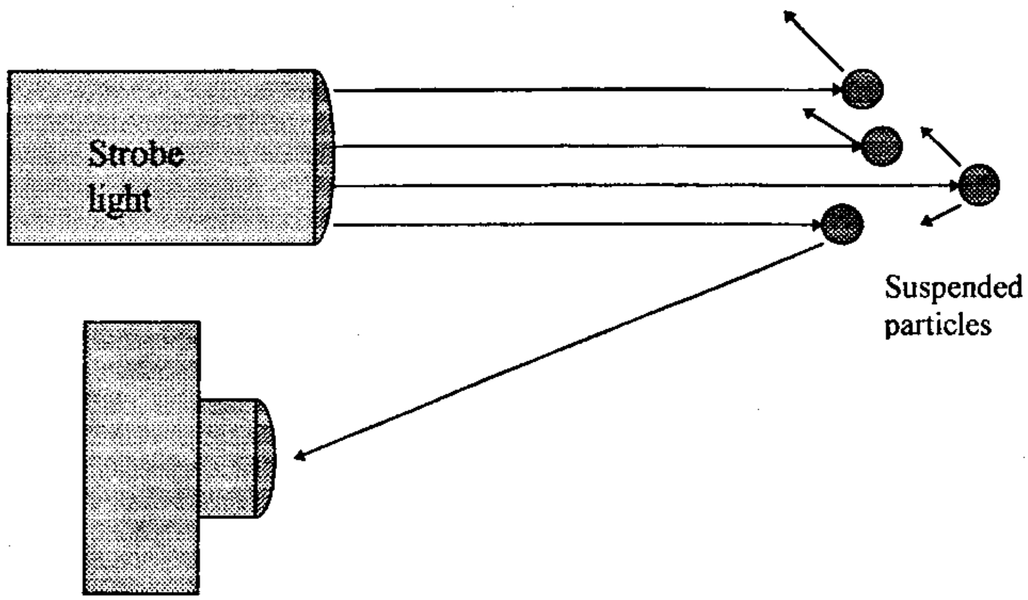


Figure 13.21 Backscatter the reflected light can enter the camera lens.

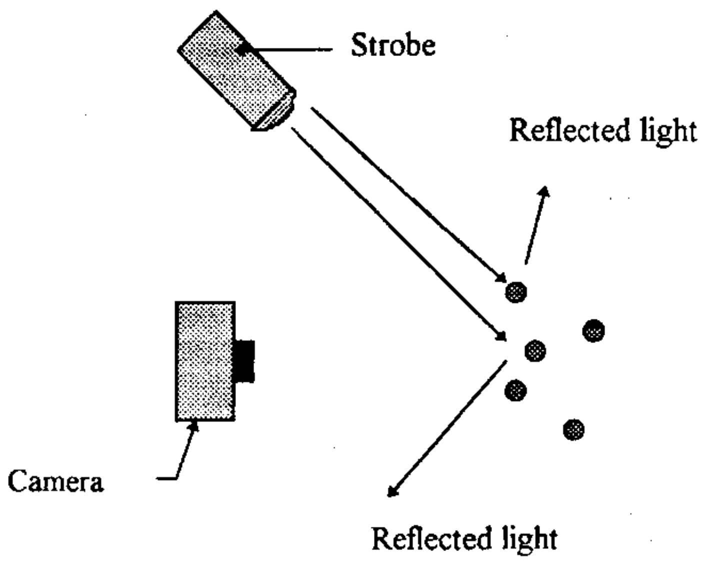


Figure 13.22 Avoidance of Backscatter

In figure 13.22 the light does not enter the camera and so the backscatter will not be a problem.

Angling the strobe to effect the best lighting can also be a problem. The strobe gives an illumination for such a short period of time that the strobe could be shaded from the subject at the time of firing, or the strobe could cast a shadow from the prods. However the diver may not realise that this has occurred, focusing lights will help to remove this possibility. A focusing light is a small light which may be built into the strobe or could be strapped to the outside of it. The light will be on all of the time and will be angled so as to be pointing in the same direction as the strobe, this will enable the diver to see whether the strobe is obstructed or not. It will also help in the focusing and composure of the picture.

MAGNETIC PARTICLE INSPECTION ULTRAVIOLET LIGHT PHOTOGRAPHY

One of the main drawbacks of MPI is that there is no permanent record of the indications, leaving interpretation entirely to the diver, this is no longer acceptable to a number of clients who require something more.

Photography is one way in which MPI indications can be recorded. This is accomplished by either using visible light inks, or if Ultraviolet inks are to be used then either a fixed ultraviolet lamp and a standard camera can be used with a timed long duration exposure, or by the use of a strobe light fitted with filters to allow only ultra violet light to be emitted. While the first is not difficult there are obvious problems of keeping all the components still enough. Ultra violet flash photography overcomes this by producing enough ultra violet light over a very short period of time, thus removing the risk of movement. Electronic strobes with special filters are used. This method can be difficult to achieve as most strobe lights are designed to cut out as much ultraviolet light as possible, so very powerful strobes will be needed.

Using this method a good record of the indication can easily be made, the scale is again very important as this will be used in the assessment of the indication by the topside personnel.

PHOTOGRAMMETRY

Underwater Photogrammetry is currently being used to carry out very accurate measurements in a variety of applications, both for inspection and engineering purposes, these tasks include:

i) Inspection Tasks

- a) Corrosion assessment
- b) Weld defect analysis
- c) Areas of damage
- d) Marine growth assessment
- e) Anode size and wastage assessment
- f) Scour survey

ii) Engineering Tasks

a) The compilation of plan and engineering drawings of subsea components.
b) The measurement of ovality in tubular members.
c) The measurement of damaged physical structures to allow accurate assessment of the damage and fabrication of a repair piece.
d) The measurement of distances and relative positions to allow the installation of risers and clamps or spool pieces.
e) The evaluation of complete node geometry.

Photogrammetric cameras are constructed and calibrated to very high specifications. They must be stable and in addition, to ensure the highest possible image quality they normally use 70mm film. The film will be held flat between the pressure plate behind the film and a **Reseau plate** (Fig 13.23) in front of the film, the Reseau plate is a glass plate which will have small crosses etched onto the surface, these can be used as reference points in the subsequent analysis. There will be computer analysis of the results to enable a high degree of accuracy to be achieved, although for normal stereo systems this is not necessary and there are several 35mm systems available. The cameras are fragile and care must be taken with them.

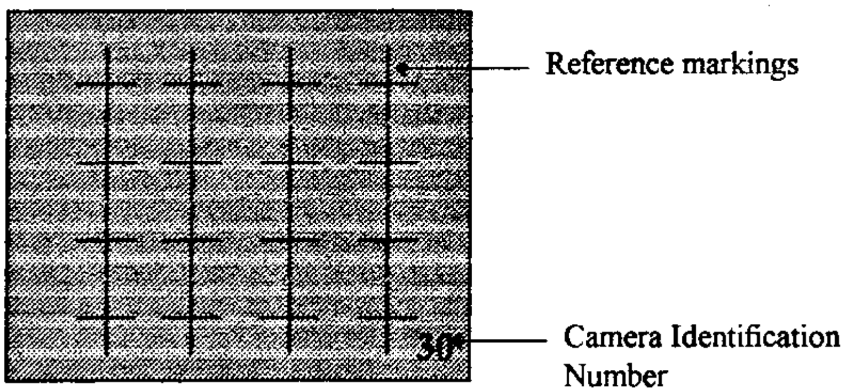


Figure 13.23 The Reseau plate, note that sometimes the plate may even have a scale printed on it to aid referencing

Stereo photography is a method of taking two pictures simultaneously of the same subject but from slightly different angles. This is much the same method as we use for our assessment of distance, our eyes see the same object from two slightly different angles allowing us to see a three dimensional image. In order for it to be useful we have to make sure the cameras are held rigidly, at the correct angles, with the correct stand off and that the lighting of the site is adequate. Normally this will mean the cameras will be mounted on a frame with prods to maintain the stand off, stereo photography can be achieved by the use of two cameras or one camera with two correctly angled lenses.

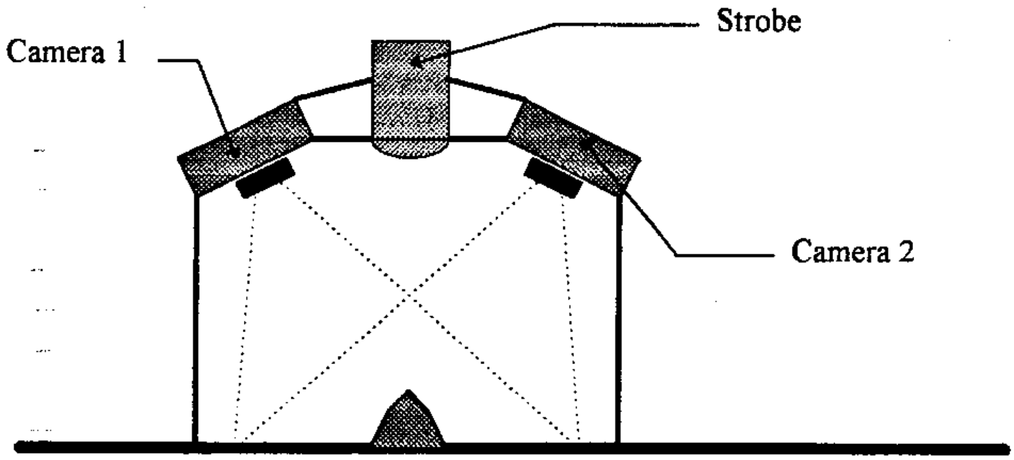


Figure 13.24 Photogrammetric Camera Arrangement

Regardless of the type of photography it will be imperative that an accurately completed photographic log sheet be supplied to the client. This will be used to record the basic information of the frame, with details of the dive and location etc, figure 13.25 below is an example of a photo log sheet:

Company Name:		**Structure Id:**
Client Name:		**Film No:**
Date:	**Dive No:**	**Task Group No:**
Location:		**Dive spread/Diver name:**

Task list code:	**Counter:**		**Task, Description, Comments (Scale, Position etc)**
	From	**To**	

Signed:	**Client:**	**Controller:**

Figure 13.25 Photographic Log Sheet

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Care of a camera for in water use

Prior to use:

1 Charge batteries and fill out any charging log sheets
2 Select film IE 100 ASA 35mm ETC. SPECIFY.
3 Inspect and maintain all camera and strobe seals and sealing faces
4 Ensure a photolog sheet is in place and ready for use
5 Load film
6 Choose suitable lens for task to be undertaken
7 Close camera and strobe and ensure watertight integrity
8 Pre set camera as required ("f" stop, Shutter speed & Focus)
9 Set up Data chamber (Day, date etc)
10 Take test shots & log them of photo board with colour reference etc
11 Fit to vehicle as required
12 Switch on as required

Post Dive:

1 Switch off strobe & camera
2 Rewind
3 Wash in fresh water
4 Dry thoroughly
5 Open & remove film LABEL.
6 Lightly grease O'rings (Silicone grease)
7 Store in a clean dry environment
8 Process film
9 Complete photolog sheet

NOTES

CHAPTER 14

STRUCTURAL MARKINGS AND SIZE REFERENCES.

In order for individual components to be easily located and relocated it will be very important that each component be uniquely identified. This means that the structure will have a set of unique numbers assigned to it's components at the design stage, this will enable a complete history of the structure to be kept and related to during the life of that structure.

With all aspects of inspection the client will need to know the exact location of any defects or anomalies found. In addition the divers and ROV, will also need to know the exact location of any component or item in order to ensure that all items are inspected in a useful manner and that nothing is missed. In short it is imperative that each component has a unique identification number or letter.

All operators have their own system for the marking of the structures they are operating. It is very important that everybody involved is familiar with the system in use, this will avoid any inconsistency or ambiguity in reports.

The following is an example of a numbering system used offshore today, but it must be stressed that it is the duty of all concerned to make themselves familiar with the system in use on the platform at the time of the inspection.

Each structure will have a unique code (maybe a number or a letter). Each component will also have a unique number and each level will be also be uniquely identified.

Structure number	Component Ident	Level	Number of component
013	12	03	04 NORMALLY FROM NW OF PLATFORM.

So this number may appear as 013/12/03/04.

The 013 identifies the structure.

The 12 identifies the component in this case 12 is a horizontal brace.

The 03 relates to the level on which the anode is located.

The 04 relates to the fourth horizontal brace on that level.

So we can now see that we are to look at an the fourth horizontal brace on the third level on the structure 013. Figure 14.1 is a diagram of this type of numbering system:

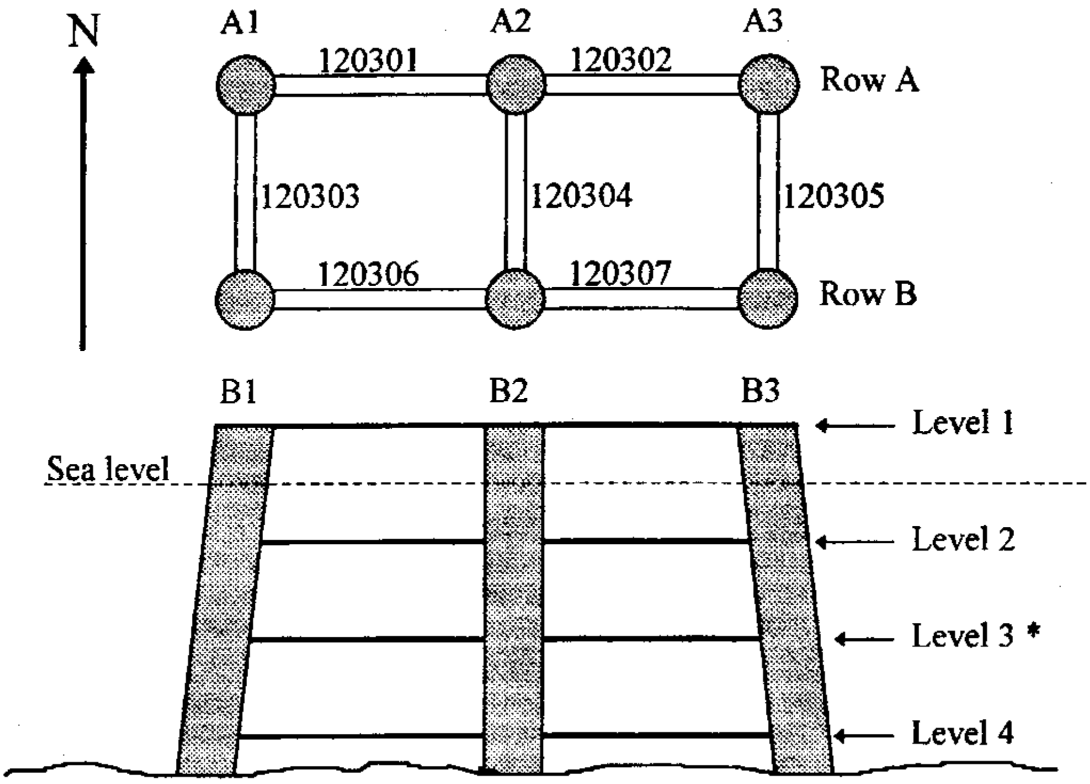

Figure 14.1 Structural Numbering Method

Normally the numbering is related to platform North or platform West i.e., if the diver is sitting on a horizontal member then he will be instructed to look towards platform North and then use clock positions for the inspection of that member. So three o'clock will be to his right and nine o'clock will be to his left.

If the inspection is to be on a vertical diagonal then the diver will be instructed to sit on the member and look upwards and then three o'clock will be on his right and so on.

On vertical sections the diver would normally be instructed to look upwards and the twelve o'clock will be at the platform North, three o'clock will be on the West side of the vertical.

On a weld the diver will sit on the minor member (Brace) and look towards the major member (Chord) and twelve o'clock will be uppermost, three o'clock will be to his right and so on.

When inspecting a structure it is normal to include the risers and flow lines to a distance of approximately **twenty metres** from the base of the structure. When the diver is on a flow line he will look towards the structure (or possibly he will look in the direction of flow) and the top of the line will be twelve o'clock, to his right will be three and so on.

If there is any doubt as to the marking of a component then the client will be able to give guidance on how it should be marked.

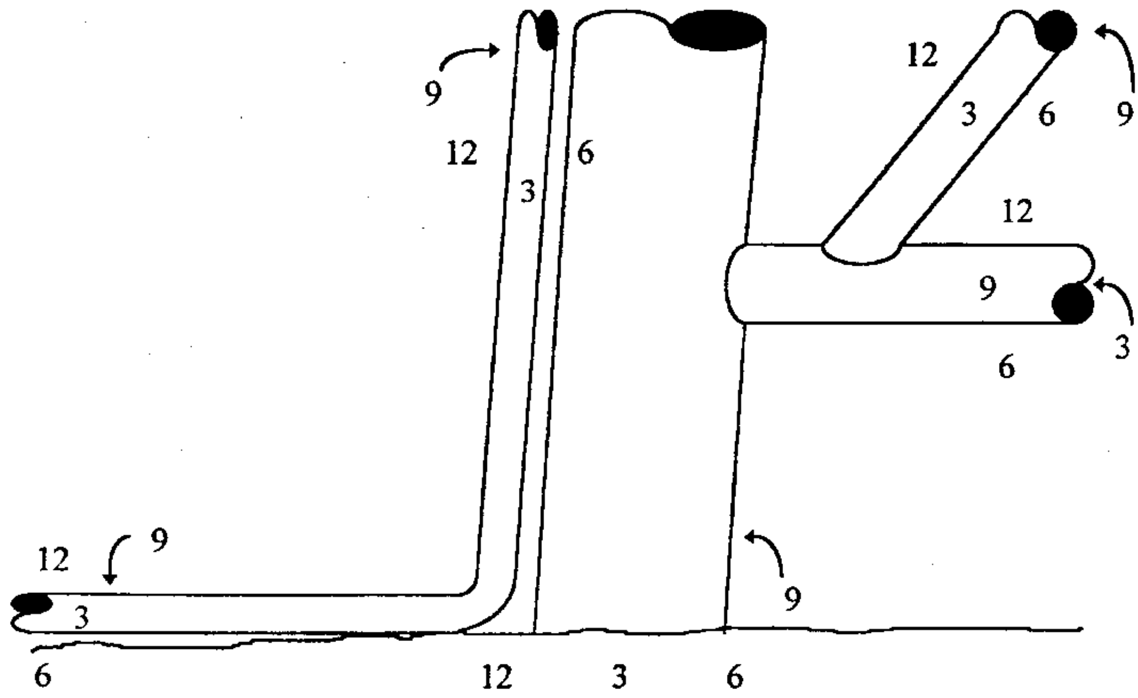

Figure 14.2 Typical Clock Position Markings

THE GRID SYSTEM

In order to make location of individual components easy most companies will grid their structures, this system will of course become as complex as the structure to which it is applied requires.

Shown below are two more systems which may be adopted:

a) The Alpha Numeric System

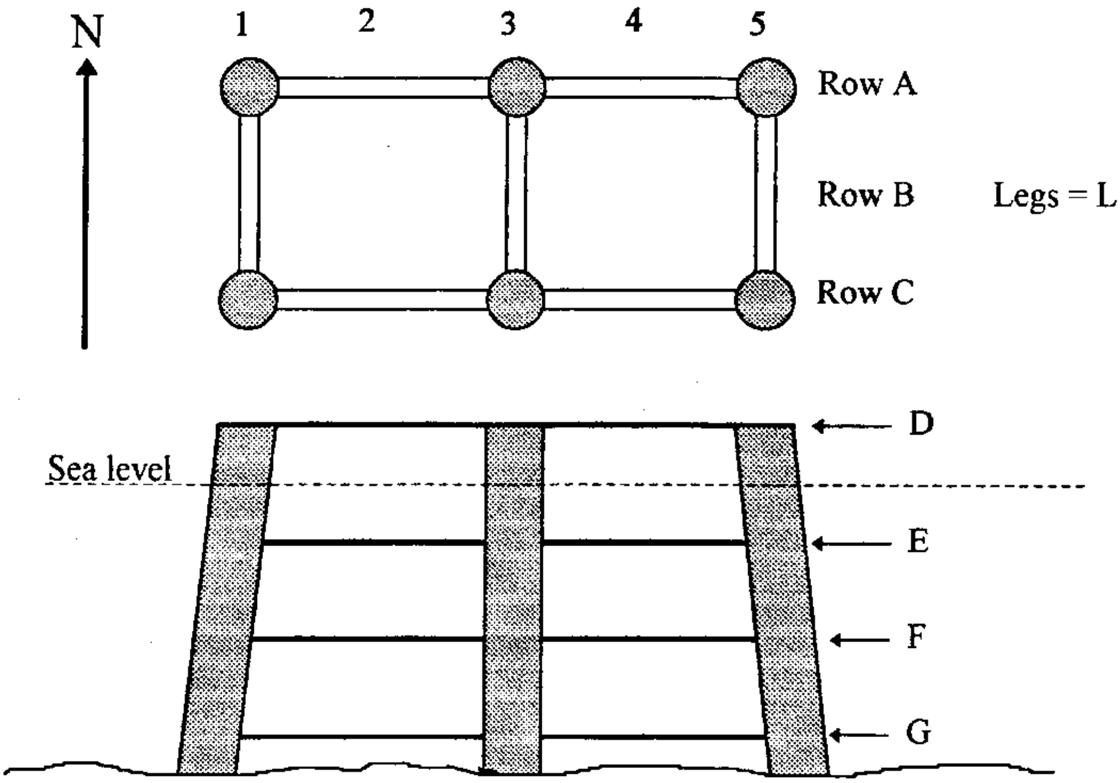

Figure 14.3 The Alpha Numeric Numbering System

It will be relatively easy to locate a component, for instance LB3 will be a leg on side B row three, if there is a number D34 then this will be a member on level D, and so on, the key being that each component will again have an unique reference number.

b) The second system commonly used is to divide the structure into levels and create a matrix on each level. This will mean that all components can normally be located using a four figure reference number as can be seen from the following:

Each component will have a letter to denote its type, this may be as follows:

M - Member
F - Diagonal
N - Node
R - Riser
C - Conductor
P - Pile guides
A - Anodes

The list will of course be as long as needs to be in order to cope with all of the different types of components on the structure.

The box matrix system may well look as figure 14.4:

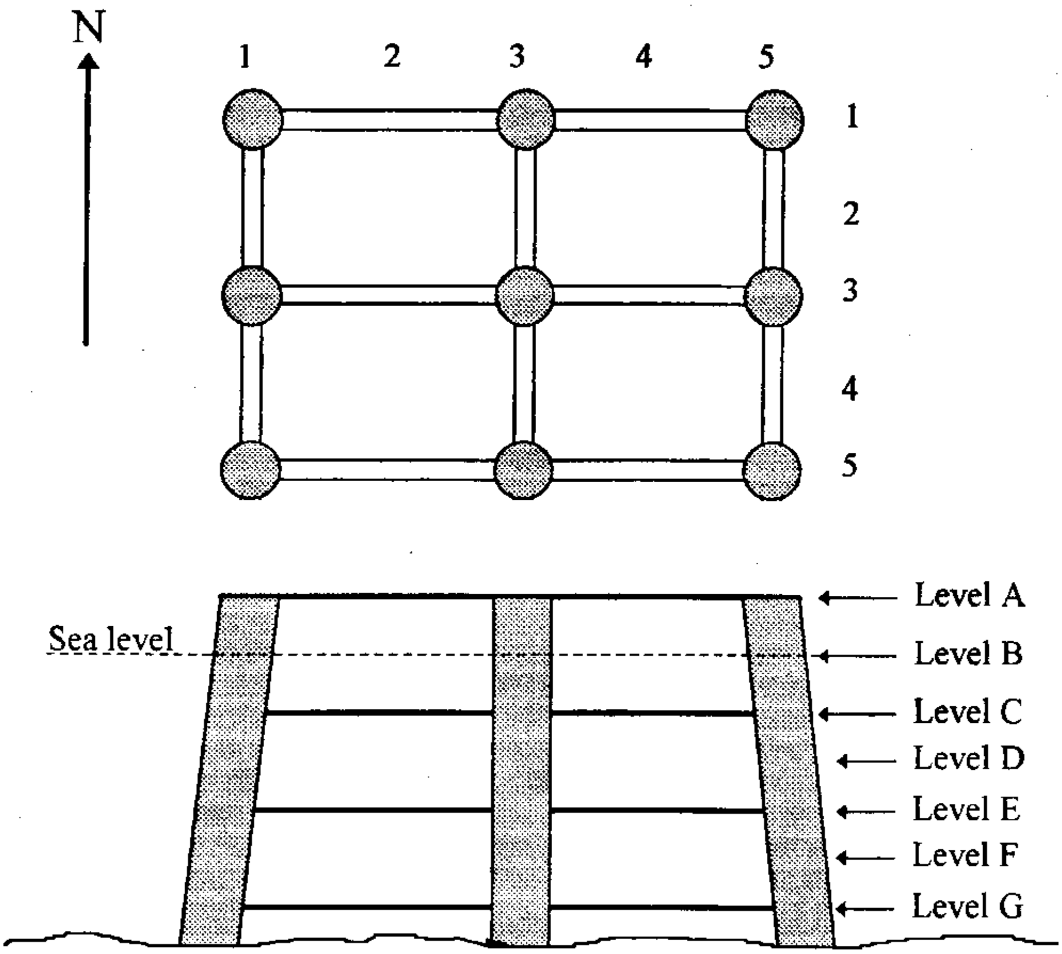

Figure 14.4 The Box Matrix System

So, if we are told to look for the component ME45 then this will be a Member on level E. To find the exact location we would use the co-ordinates, in this case the four and the five, the first number will be the East/West co-ordinate and the second number will be the North/South co-ordinate. Therefore ME45 is the member on the level E fourth to the east and fifth to the south.

Whatever system is used there will always be a need for all concerned to have a thorough knowledge, this will make location and relocation of components easy.

CONCRETE LOCATION TECHNIQUES

Concrete structures will of course create unique problems, this is largely because whereas when the diver is working on a steel structure he will normally have a series of steel tubulars which can be used as a kind of street map, if the diver is working on a concrete structure he will in effect be diving on a largely featureless wall. There are two main methods in use offshore today, they are as follows:

1. GRID SYSTEM

When the grid system is employed it will involve marking the structure with a series of numbered boxes. The diver or ROV would then be directed to box number ***. This is a good method certainly in the structures early years, although in later life some of the markings may well be at the very least difficult to find, this will then involve the diver having to replace the markings which is very time consuming and for an ROV virtually impossible.

Each box would have a unique number which could be located on a series of drawings, this will normally be instigated at the time of construction and may look as in figure 14.5 below:

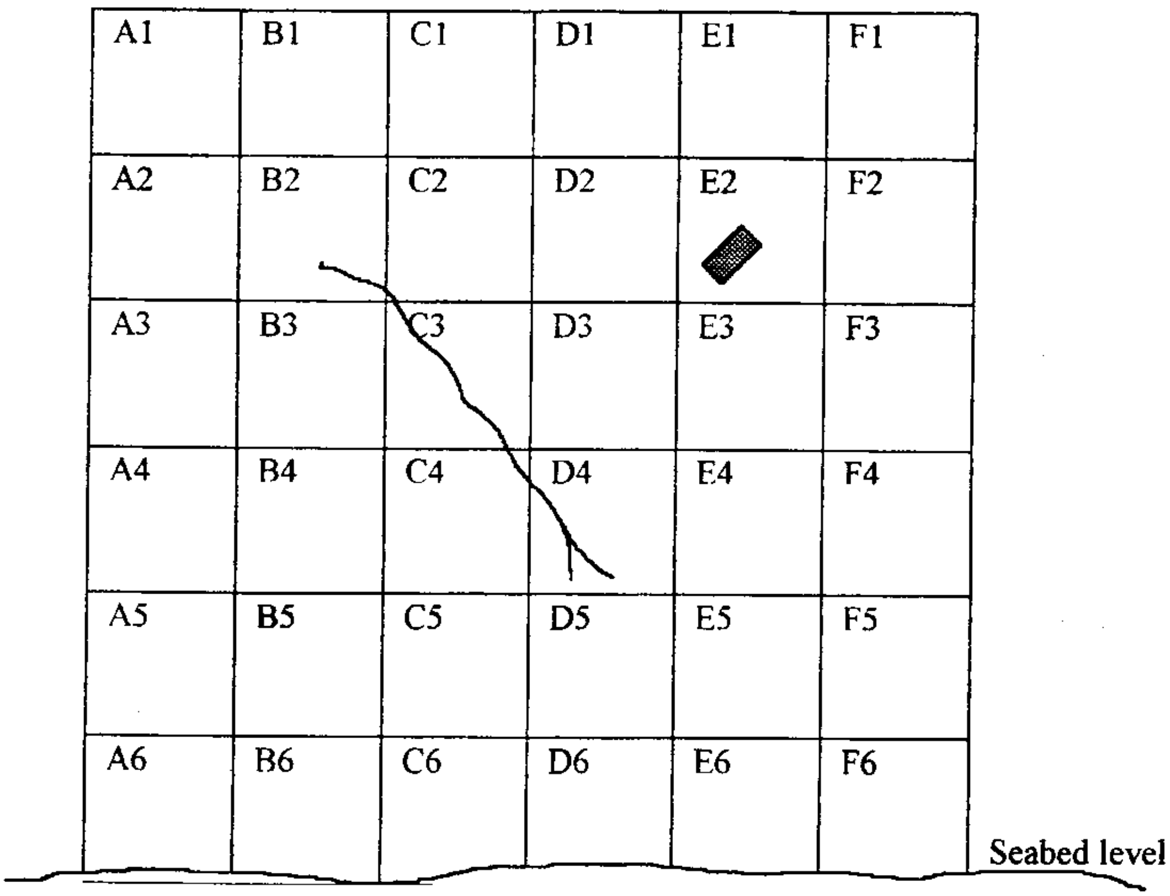

Figure 14.5 The Grid System

2. SHOT LINE AND TAPE

This method is taken from the archaeological method of laying a graduated line straight across the area and running another line off at ninety degrees. Offshore the straight line would be a graduated shot line from the surface placed at the correct vertical location. From this the diver would take a tape measure and run it out horizontally across to the point of interest, thus fixing it in two dimensions as shown:

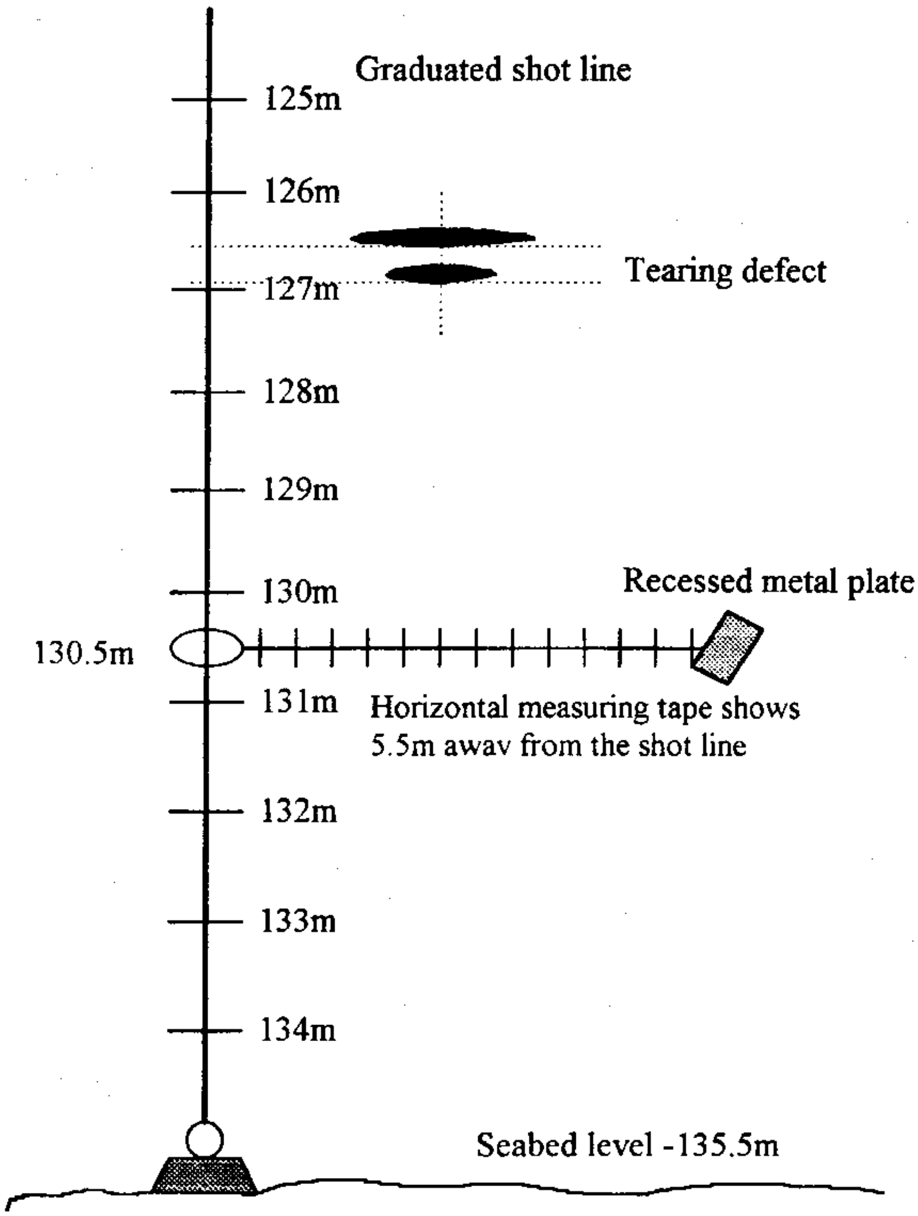

Figure 14.6 Shot Line and Tape System

THE USE OF STRUCTURE MARKINGS

Structure Identification, Petroil Charlie	Component Ident Number	Level	Member number
012	13	4	14

DIAGONAL - 13.
HORIZONTAL - 12.
ANODE - 15.

All of the above would relate to schematic diagrams in the "standard specification instructions" for inspections.

JOB NUMBER

Some companies will employ a Job Number, this will be used to reference a complete years inspection, thus enabling all relevant data to be kept together, the system may look as follows:

Year	Structure	Type of task (1)
88	**PCU** Petroil Charlie Underwater	1 41 Number of task 41 possibly CCTV survey

COMPONENT TASK SHEET (CTS)

The component task sheet will be used for the identification of the tasks to be carried out on the particular component.

i.e. CP SURVEY, VIDEO SURVEY ETC.

The component task sheet will include the extent, limits, specs (the depth from and to) and also the members involved.

The co-ordinator will get operational procedures with all CTS's in it and will work out a program for work i.e. all at -50m maybe CTS 4 (CCTV survey) and CTS 24 (MPI) may well be done at the same time as they relate to components at the same or similar locations. In this way all will be done together, it may be that all on the east side will be done at the same time thus ensuring that nothing is forgotten it will also limit the number of vessel moves. Also the diver/ROV interaction can be better planned from them.

NOTES

CHAPTER 15

VIDEO INSPECTION

Advantages and Disadvantages of Closed Circuit Television (CCTV) as an NDT Technique

Advantages:

1. CCTV will give real time pictures.

2. Will also be a permanent record.

3. Plenty of additional information can be included in the frame, this can include C.P. readings, depth, time and so on, can also have written information with the employment of a video typewriter.

4. Instant playback (no time is needed for developing).

5. Safety - if there is a camera on site then the diver will be monitored more easily and so will be safer.

6. Can include an on the spot commentary, if the camera is carried by a diver then he will be able to comment on the item under inspection with the benefit of actually being on the spot, thus being able to back up his assessment of the situation using his other senses and brain.

Disadvantages:

1. Cannot freeze fast movement.

2. Poor resolution compared to photography.

3. Gives a two dimensional image.

4. Can cause diver fatigue.

Video inspection or more correctly, closed circuit television CCTV is the process of capturing reflected light from a subject converting it into an electrical impulse which can then be relayed to another location, whilst remaining in the same time scale as the original (in real time). The term "closed circuit" means that the signal will not be transmitted, rather it will rely on a cable to relay the signal, all of the systems used offshore today have basically four components:

i) **Camera:** Used to convert the reflected light into an electrical signal.

ii) **Umbilical:** To relay the electrical signal from the camera to the surface control unit.

iii) **Surface control unit:** Used to control the camera for focus, light etc and receive the signals from the camera.

iv) **Monitor:** To decode the signal and display it as a picture relating to the subject under inspection.

In addition there may be a number of other input and recording systems, such as:

i) **Video typewriter** - to be used for the input of information such as title and subtitles etc.

ii) **Video cassette recorder (VCR)** - to enable the image to be re-run at another location.

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Types of Camera in use Today

1. Tube camera

These can be further broken down into the following:

i) Monochrome tube camera.

ii) Colour tube camera.

Both of the above are delicate and can easily be damaged by either impact or the introduction of to much light. For this reason the camera should not be pointed directly at a strong source of light and should always have a lens cap in place when not being used, this will avoid the target becoming scarred. They will also not work if there are strong magnetic fields, and so cannot be used to monitor MPI operations. They do however give a relatively good depth of field when operating underwater.

2. Silicone Intensified Target Camera (S.I.T.)

This is a low light monochrome camera which tends to be quite bulky, normally used on ROV and submarines, for navigation purposes. The SIT camera will not give a very high resolution image and it is also Monochrome, thus SIT cameras are not normally used for close inspection, only debris surveys and the like.

3. Charge Coupled Device (C.C.D.)

This relates to a very compact high quality solid state (no moving parts) colour camera (or possibly Monochrome). Most underwater colour cameras will now be C.C.D. They are widely used for hat mounted cameras because of their size and low weight. As they are solid state they tend to be more robust than tube cameras and should last longer. In addition they are not so susceptible to damage from bright light, they can be used for monitoring welding and will not be affected by strong magnetic fields so can be used to monitor MPI operations. The only real disadvantage as far as we are concerned is that they may not give quite such a good depth of field as a tube camera will.

Video Standards

There are several different video standards used throughout the world, the difference from our point of view is the picture quality. The video picture is made up of a number of lines which trace across the screen at intervals, thus building up the picture, the more lines the better quality the image will be, the following are the most common video standards in use today:

NTSC: This is the American system which uses 510 lines on the screen
Pal/Secam: This is the European system which uses 625 lines, this should give a slightly better quality image.

These systems will be recorded on VCR, these will cause a loss in quality, also they will not normally have as many lines as the above systems produce, the two which are common are:

VHS: This is the normal system used in the home and will use 200 lines
Super VHS: This is a professional system which uses 400 lines, this will give a much better picture quality and allow better quality of subsequent copies made from the original recording.

METHODS OF DEPLOYMENT

The following are the methods of deployment and their advantages and disadvantages.

i) Diver Hand Held.

Advantages	Disadvantages
Easy access to tight locations	Two umbilicals
Good for close inspections	Only one hand is free
Diver can give on the spot commentary	Diver will only have the light when carrying the camera
	Difficult to swim with

ii) Diver Head Mounted.

Advantages	Disadvantages
Safe	Heavy load on the divers head
Can be used for help in diver location	Not so good for close inspections
Can be used to assist the diver to perform tasks	Will suffer from parallax problems
Diver can become the engineers hands	Can be hard for the diver to assess defects when the camera is used for close work
Diver always has light on the job	
Only one umbilical	
Always available (if fitted)	
Diver can give on the spot assessment	

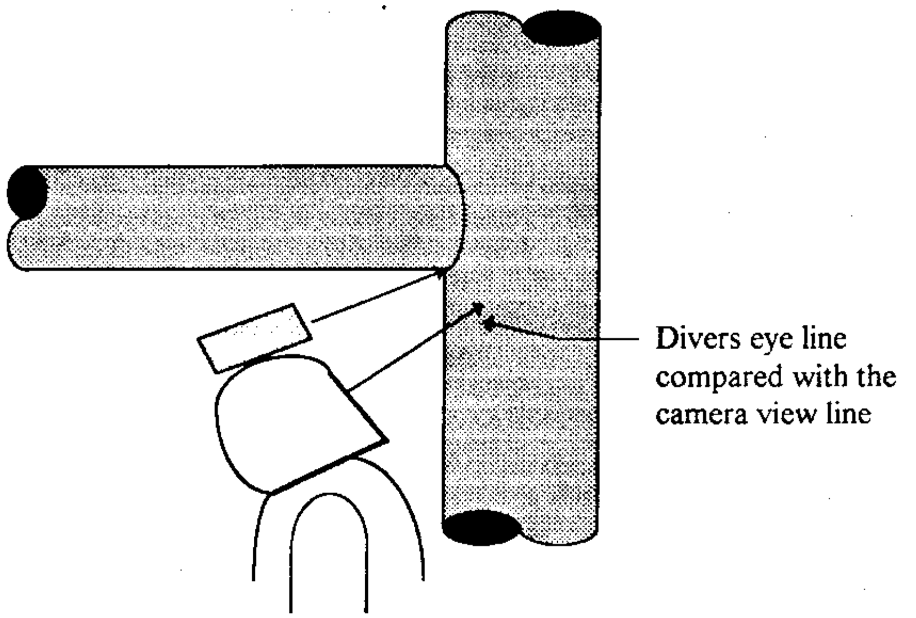


Figure 15.1 Hat Mounted Camera used for Close Work showing the problems of Parallax with close inspection using hat mounted cameras.

iii) Remote operated vehicle (ROV).

Advantages	Disadvantages
Safe	Access can be limited
Endurance is unlimited	Operator may not see all that a diver could
No decompression	Small defects may be missed
Plenty of light available	Cost may be prohibitive
Plenty of power	Complex system
Can work in high current states	Human is remote from the job
Can carry several specialist cameras	
Can carry many specialist sensors	

iv) Fixed location.

Advantages	Disadvantages
Good for monitoring	Limited movement
Safe (no human in the water)	Not versatile
Always available	Needs cleaning regularly

COMMENTARY

When carrying out a commentary we must ensure that at all times we remain fluent and use the correct terminology, in order for this to be achieved some basic rules must be followed:

Rhythm - Should be kept and steady.
Speed - Should be slow but not stagnant.
Volume - Should be checked prior to commencement.
Pitch - If the diver has a very deep voice he may have to pitch it up slightly, check before starting.

INTRODUCTION

An introduction will be necessary in order to accurately place the object under inspection and the inspection details, it will need the following information:

Who - Give the name as, diver inspector ******.
Where - Give the location, on leg number ******.
What - Give the task, doing a close video inspection.
When - Give the date and time.

TERMS

When cameras are being used there must be a standard terminology used for camera movement in order to minimise the ambiguity of commands given, the terms used should be as follows:

Pan - Diver stays still and moves the camera right of left.
Tilt - Diver stays still and moves the camera up or down.
Move - The diver moves to left or right and keeps the camera pointed directly at the object of interest.
Come - The diver moves the camera into or away from the object.
Follow - Diver moves the camera along the pre-arranged inspection area.
Rotate - The camera is rotated about its axis clockwise or anticlockwise.

Always bear in mind when doing a video survey that the commands from the surface will apply to the cameras orientation, i.e. the topside controller will tell you to move left if he wants the camera to move left regardless of where you are in relation to the camera. This is because the only point of reference that the topside personnel have will be the picture on the monitor produced by the camera.

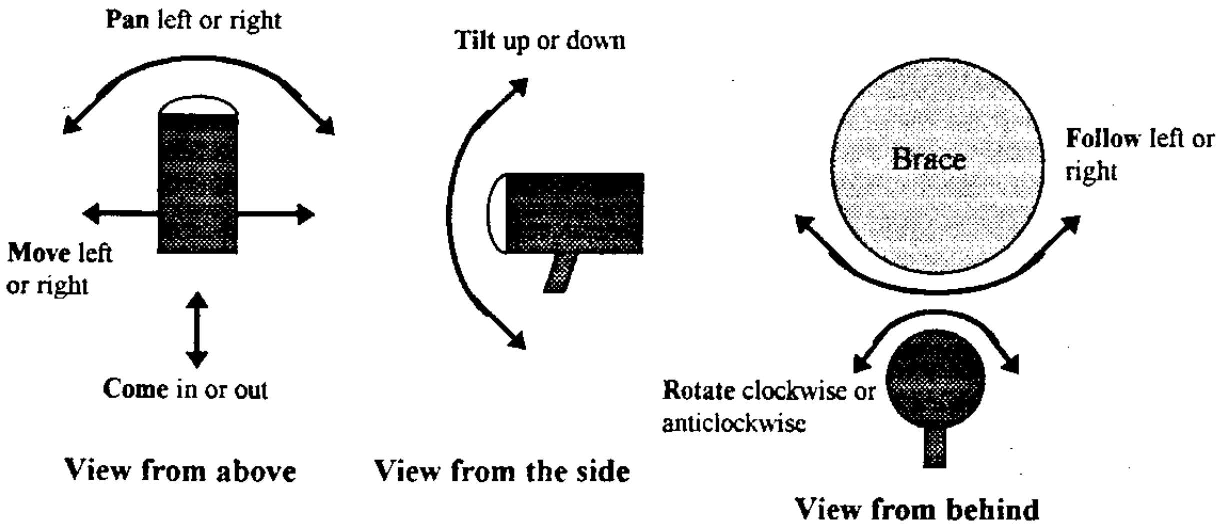


Figure 15.2 Camera Movement Terms

SHOTS

To begin with the diver will normally be asked to aim the video camera midwater, the topside operator will then superimpose an overlay on the screen carrying the introduction information, which will then be read onto the audio track of the VCR.

Then the diver will carry out the following:

Long shot	-	Used to establish the general inspection area.
Mid shot	-	Divers introduction and general video inspection.
Close shot	-	Close video inspection.

As with all other types of inspection there is a need for a video log sheet in order to keep track of the inspected items and the location etc.

Figure 15.3 Is an example of a video log:

Company name:			**Structure Id:**
Client name:			**Video tape number:**
Date:	**Dive No:**		**Task group number:**
Location:			**Dive spread/Diver name:**
Task list code:	**Counter**		**All times and pauses must be logged**
	From	**To**	**All CP measurements etc to be logged**
	TITLE ON	SCREEN	[illegible] SIGNIFICANT [illegible] & [illegible] ETC.
Client signature:			**Controller signature:**

Figure 15.3 Video Log Sheet

NOTES

CHAPTER 16

CORROSION, CORROSION PROTECTION AND CORROSION PROTECTION MONITORING

Almost all materials can be said to react with the environment in some way. When this is happening in metals we call it corrosion, if it were happening in plastics then it would be termed degradation and in concrete it is called weathering.

In this chapter we will be dealing with corrosion (see the chapter on concrete for a reference to weathering). Corrosion can be termed an electro-chemical form of reaction which can have one of the following results:

1. **REMOVAL OF METAL.**
2. **FORMATION OF OXIDES.**
3. **THE FORMATION OF OTHER CHEMICAL COMPOUNDS.**

Because of the above, corrosion can have a very significant effect on the structure in an offshore environment. The result will be either a general thinning of the metal which should give a predictable lifespan for a structure, or pitting of the metal which could cause stress concentration points and so possibly an unpredictable and catastrophic failure of the structure. It should be noted that most offshore structures were built with a safety factor so that they could cope with a small amount of wall thinning. However, as most structures have been overloaded owing to the introduction of new production methods which were not in use when the structure was designed, this will to an extent erode the safety margin, making it all the more important to be aware of any corrosion that has taken place.

THE CHEMISTRY OF CORROSION

When sea water is present corrosion is an electro-chemical process. In order for this to occur there are two basic factors which will be involved these are as follows:

i) AN ELECTRICAL POTENTIAL (VOLTAGE).
ii) AN ELECTRICAL CIRCUIT.

First the potential, the metal which we use to build our structures is normally steel, which is an alloy made up of iron and carbon and some other trace elements. Iron exists in its natural state as iron ore which is made into the metal which we can use by means of the smelting process. During this process there is a substantial amount of energy added, it is this energy which forms the corrosion potential.

The other factor which will affect the potential of the metal is the electrolyte in which it is immersed both its chemical and physical characteristics.

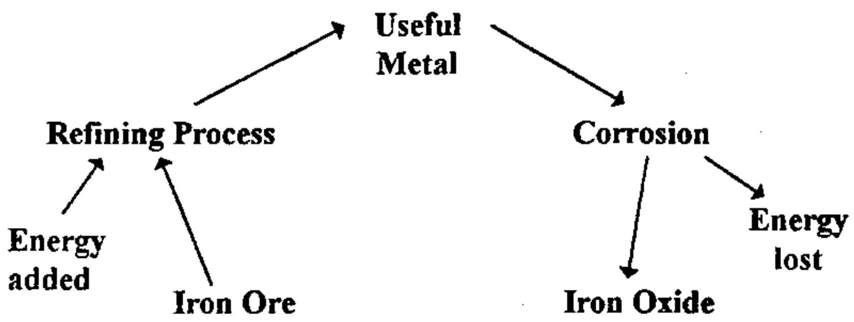


Figure 16.1 The corrosion circuit

In order to properly understand the corrosion process we must look at the metal on an atomic scale. All materials are made up of atoms and in turn the atoms are made up of smaller charged particles called, the **nucleus** which has a **positive** charge, and a number of smaller particles in orbit around the nucleus called **electrons** which will have a **negative** charge. Now when the material is in equilibrium then the overall charge will be zero, i.e. the negative electrons will exactly balance the positive nucleus. If for some reason the balance is upset by the adding or removing of electrons then the atom will become unbalanced and so will take up a charge, either positive if the atom has lost some electrons, or conversely it will become negatively charged if it has gained some electrons. Either way the atom can then be said to have become an ion of the material i.e. a zinc atom will then be termed a zinc ion.

AN ION IS AN ELECTRICALLY CHARGED PARTICLE

We should first look at how this will affect the metal in our structure at the anode. (The reasons for a part of the structure to become the anode will be discussed in a later section).

THE ANODIC REACTION (CORRODING SURFACE)

TRIES TO REVERT TO NATURAL STATE.

When the metal is actively corroding the atoms that make up the metal will start to break down. They do this in order to supply the electrons that will be needed for the chemical processes taking place. For the atoms at the anode this will mean that electrons will be given up, these electrons will travel through the metal to the cathode. When the atom at the anode has lost its electrons then it will take on a positive charge, as electrically it is now out of balance, the atom is then termed as a positively charged ion of the metal involved (i.e. a positively charged ion of zinc). As such it will no longer remain bound to the metal and will dissolve into the electrolyte, the reaction for iron will be as follows: Iron atom to Ferrous ion plus 2 electrons (see fig 16.2).

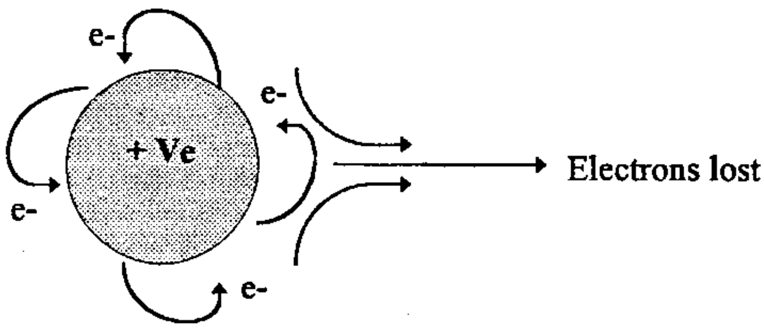


Figure 16.2 The Anodic Reaction

THE CATHODIC REACTION (NON CORRODING SURFACE)

The reaction occurring at the cathode will be as follows: An atom of a basically unstable material in the electrolyte will combine with electrons from the structure in order to make a more stable compound, this is called a **reduction reaction** (this will form either an oxide or a hydroxide in our case). When an atom which is neutrally charged takes up an extra electron then it will take on a negative charge and so become a negative ion of the material (see fig 16.3).

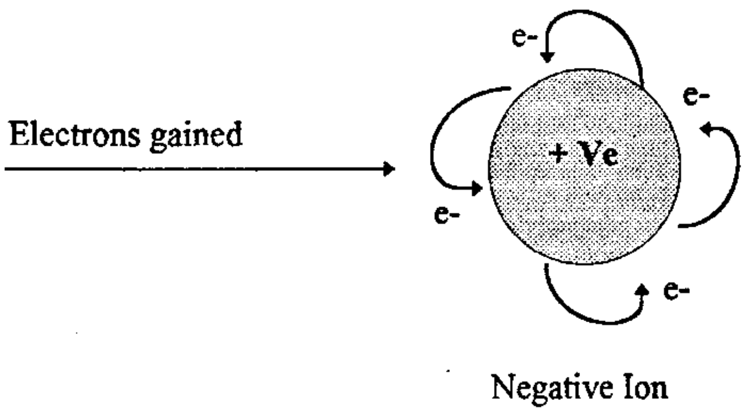


Figure 16.3 The Cathodic Reaction

This is called a reduction reaction. There are three reactions possible at the cathode they are as follows:

i) In an acidic solution:

2 positive hydrogen ions + 2 negative electrons = hydrogen gas

ii) In addition if there is oxygen present in the electrolyte:

oxygen + 4 positive hydrogen ions + 4 electrons = 2 H_2O

iii) If the solution is neutral or alkaline then:

oxygen + 2 H_2O + 4 electrons = 4 OH^-

So the reaction at the anode produces electrons which travel to the cathode where they are consumed by the reduction reactions in the electrolyte, thus removing the need for the material at the cathode to supply electrons from its own atoms, if this is done properly then corrosion of the cathode (our structure) will cease.

Corrosion of metals in water

If we put the two above reactions together then we can see that there is a circuit which if broken will slow down or stop the corrosion of a material.

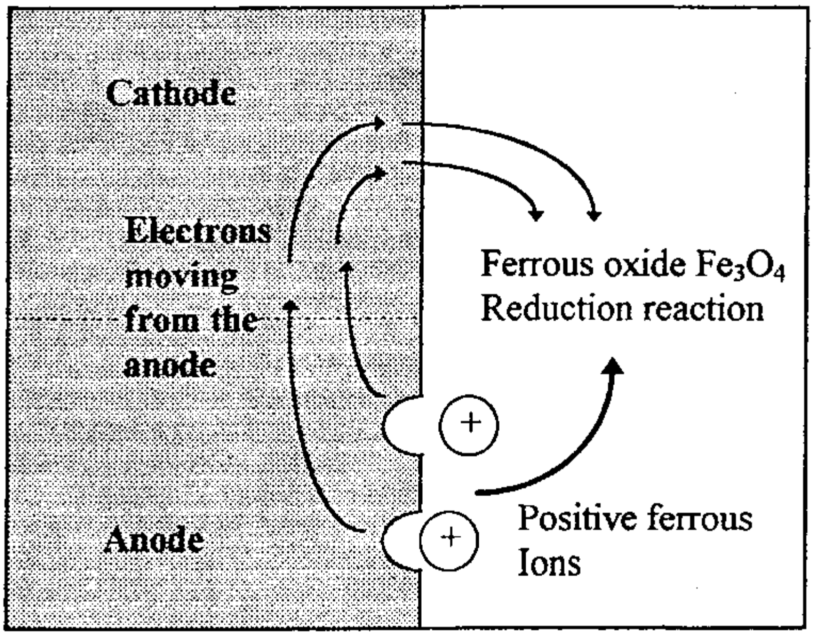


Figure 16.4 The Corrosion Circuit CEASES IF NO ELECTROLYTE CONTACT.

The reaction that occurs will depend heavily on the electrolyte and the ions dissolved in it, the above reaction is just an example.

CORROSION CELLS

All corrosion that takes place is bought about by the forming of a corrosion cell. The cell will need to have some sort of imbalance to produce an anode and a cathode, there are many different types, and indeed we can make use of some cells to protect our structures, the following is a list containing most of the different types of corrosion possible on a steel structure in seawater.

i) Galvanic corrosion 2 DISSIMILAR METALS.
ii) Concentration cell corrosion DIF IN AERATION OF
iii) Crevice corrosion
iv) Corrosion fatigue CYCLIC
v) Inter granular corrosion COR. INDIVIDUAL GRAIN.
vi) Grain boundary corrosion " GRAIN BOUNDARY.
vii) Stress corrosion CORRODE MORE UNDER STRESS
viii) Fretting corrosion " FRETTING.
ix) Erosion corrosion " EROSION
x) Biological corrosion CAUSED BY LIVING ORGANISMS.

GALVANIC OR DISSIMILAR METAL CORROSION

The imbalance here is the make up of the metals themselves. It was found that if two dissimilar metals were connected electrically with one another in an electrolyte then one would dissolve and the other would not. It was later discovered that if we put a volt meter across the two then there will be a measurable potential difference, in effect we have a battery.

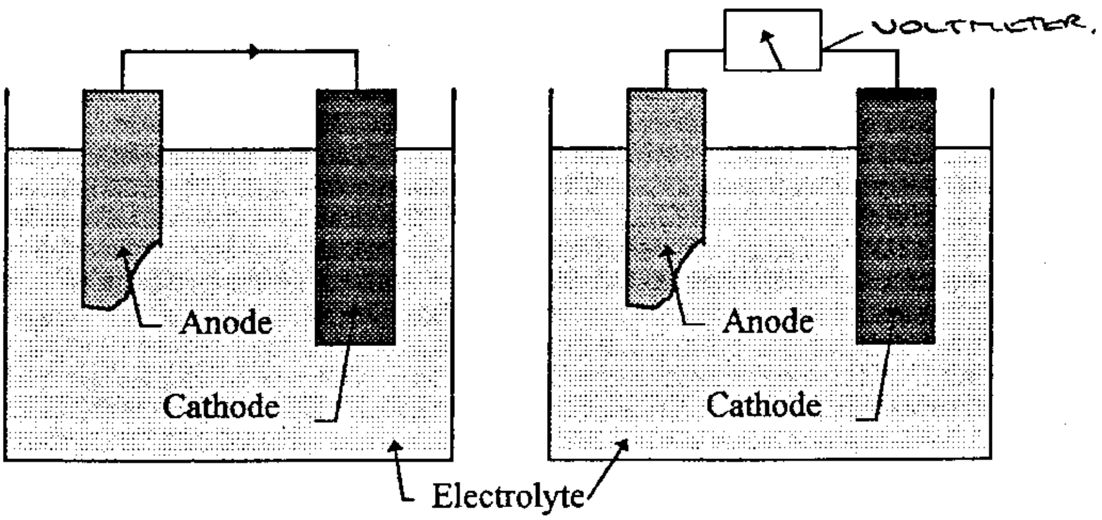


Figure 16.5 Dissimilar Metals in an Electrolyte

This was then carried out for a large number of different metals using a standard reference electrode, immersed in a standard electrolyte at a fixed temperature. The electrode used was a "hydrogen" electrode which consists of a bar of platinum immersed in a solution of hydrogen ions saturated with hydrogen gas. The electrolyte was dilute sulphuric acid and the temperature 25° C. The result was the ELECTRO CHEMICAL FORCE SERIES, this shows the relationship of one metal to another, the further apart they are in the table the more potential difference exist between them. The following is a brief excerpt from the electro-chemical force series:

Metal	Electrode potential in Volts
Platinum	+1.20 V
Hydrogen	0.00V
Iron	-0.44V
Zinc	-0.77V

This series does not have much relevance to our application as the situation does not reflect realistic conditions, so for our use the experiment was repeated using more realistic conditions i.e. the electrolyte is seawater and the temperature is 20°C, the reference electrode is still the "hydrogen" cell, this gives rise to the <u>**GALVANIC SERIES**</u> for metals in seawater.

Any metal which lies above another in the table will become anodic to the lower one and so will corrode in order to protect the lower metal. For this we use the terms noble and less noble, the more noble a metal is the further down the table it will be placed, so more metals will be above it meaning that they will sacrifice themselves in order to protect it against corrosion. **THE FOLLOWING IS AN EXTRACT FROM THE GALVANIC SERIES FOR METALS IN SEAWATER**

Metal	
Magnesium	
Zinc	
Aluminium	Anodic to Steel
Cadmium	Less Noble
Mild Steel	
Stainless Steel	
Lead	Cathodic to Steel
Tin	More Noble
Naval Brass	
Nickel (Active)	
Copper	
Nickel (Passive)	
Monel (70% Nickel 30% Copper)	
Silver	
Gold	

This is of course by no means a complete table but as can be seen from the table if we connect zinc to mild steel the steel will become protected (Cathode) and the zinc will sacrifice itself (Anode). Also, it can be seen that if we connect mild steel to monel the steel will become the Anode and so will start to sacrifice itself in order to protect the monel.

CONCENTRATION CELL

Where the concentration cell is concerned the imbalance lies not with the metals but instead with the difference in aeration. This type of cell can be formed when a droplet of water lies on a metal surface forming the electrolyte. As can be seen from the figure 16.4 below the air around the droplet will allow the oxygen in the skin of the droplet to be replaced easily whereas the oxygen at the centre of the droplet will soon be used up in the reactions and cannot be replaced as easily.

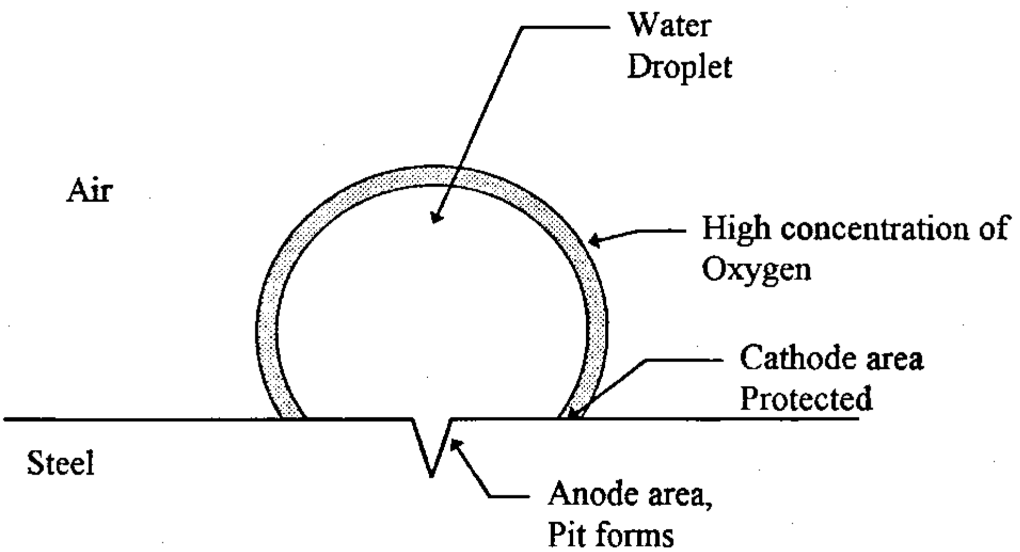


Figure 16.6 A Concentration Cell

As can be seen in figure 16.6 the ring around the edge of the droplet will become the Cathode and so will be protected and the Anode will be in the centre of the droplet so forming a pit under the droplet.

CREVICE CORROSION DIFFERENCE IN AERATION.

The origin of crevice corrosion is an ionic imbalance caused by the restriction of flow in a crevice:

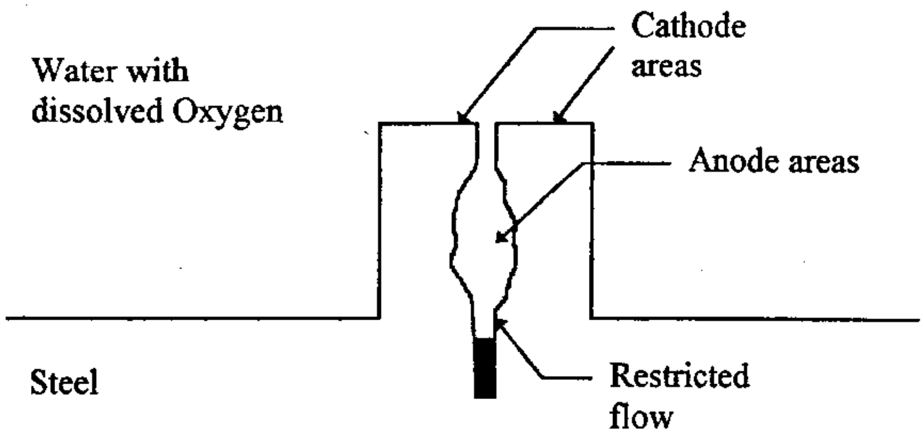


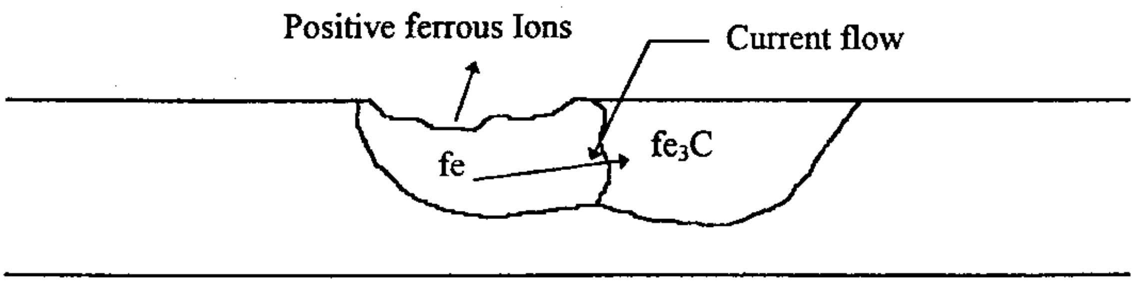
Figure 16.7 Crevice Corrosion on flange faces

CORROSION FATIGUE

Corrosion fatigue is caused by the component being subjected to cyclic stress while submerged in a corrosive media such as seawater, this will cause an increase of corrosion at the grain boundaries. This will effectively give the structure a finite fatigue life whereas it may have been infinite if fatigued in air using the same load characteristics.

INTER-GRANULAR CORROSION GENERAL THINNING NOT PITTING.

Inter granular corrosion is caused by the slight imbalances in the grains making up the metals themselves, for instance steel is a two phase metal made up of iron and carbon. In a perfect world the components would be mixed so that exactly the same amounts of each element are contained in each grain, this not being a perfect world one grain can easily receive a different amount of carbon to the grain adjacent so effectively the grains will have different nobility. The one with extra carbon will tend to be more noble and so will be protected by the other grain which will sacrifice itself.



fe = pure iron
fe_3C = iron carbide

Figure 16.8 Inter Granular Corrosion

GRAIN BOUNDARY CORROSION

Grain boundary corrosion comes about due to the energy imbalance between the grain and the boundary. A common example of this is preferential weld corrosion where the weld tends to corrode at a much higher rate than the surrounding parent plate due to the large amount of energy put into the fabrication of a weld.

STRESS CORROSION

Stress corrosion is actually enhanced grain boundary corrosion due to the component being under tensile stress. When this occurs the grain boundaries that are at 90° to the direction of pull will tend to corrode much faster. A member which is carrying a high tensile load will corrode at a higher rate than one which is at rest. An example of this is a bent piece of metal, the metal will corrode much faster at the bend than elsewhere because the bend has residual stress locked up in it, this stress will tend to be constantly pulling the grains apart.

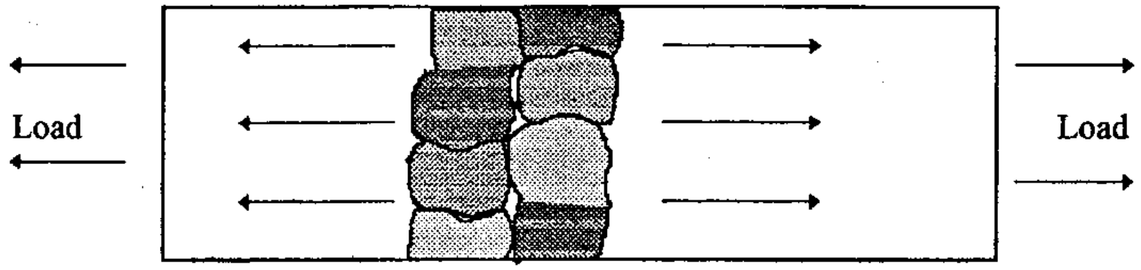


Figure 16.9 Stress Corrosion

FRETTING CORROSION

Fretting corrosion is the exposure of bright metal due to the rubbing together of two metal surfaces, this will then allow a good electrical continuity between the metal and the electrolyte. Often this will occur between risers and their clamps, conductors and conductor guides or maybe by a metal strop rubbing on a steel brace etc.

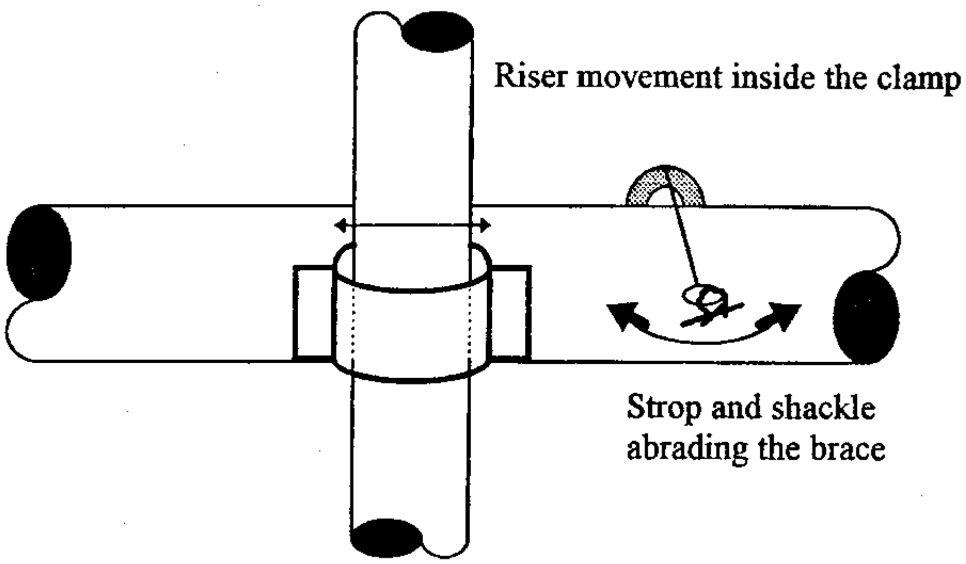


Figure 16.10 Fretting Corrosion

EROSION CORROSION

Erosion corrosion is essentially the same as the above but the abrasion is caused by particles carried in the fluid.

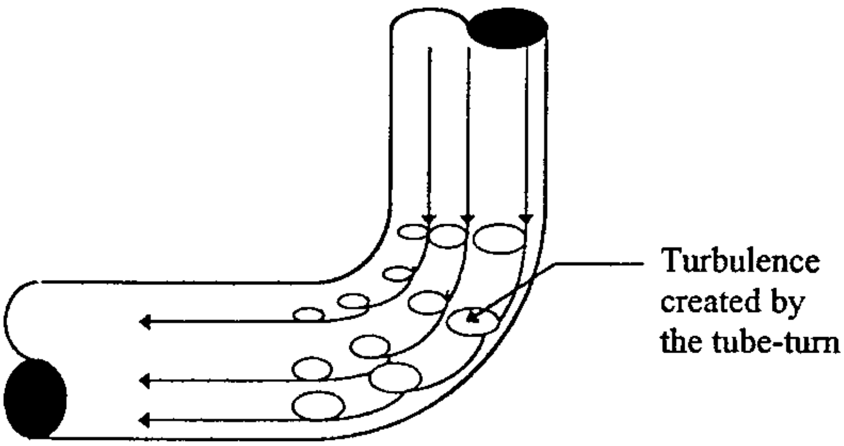


Figure 16.11 Erosion Corrosion

BIOLOGICAL CORROSION

Biological corrosion is slightly different from all of the above in that it is the marine growth itself which can cause the corrosion to result. There are four ways in which this can occur:

i) Production of Corrosive Substances

Marine growth can produce a number of substances which will attack the metal of the structure by way of chemical corrosion. The most significant chemicals produced are ammonia from the excreta of the organisms and hydrogen sulphide formed when the organisms die.

ii) Production of a Catalyst

A catalyst is a substance which will enable a reaction to take place between two chemicals which are normally stable when in contact. An example of a catalyst is the case of epoxy resin which will not harden until a few drops of catalyst are added.

iii) Anaerobic Corrosion (Corrosion Without Oxygen)

bacteria,
Certain sulphate reducing organisms (SRB's) such as Sporovibrio Desulfuricans are able to take the place of oxygen in the corrosion circuit. They occur anywhere where there is a reduction in the oxygen level such as under paint blisters or under clams and other hard marine growth, it is these bacteria which cause the mud in harbours to have such a strong smell and to turn black. When they are present there will be an increase in corrosion usually under marine growth or just below the mud line.

iv) By Causing a Concentration Cell to Form Under Hard Marine Growth

Because the growth will exclude the water from the structure it will not allow a renewable supply of oxygen, so the area beneath the animal will become the anode and the ring around the edge will become the cathode.

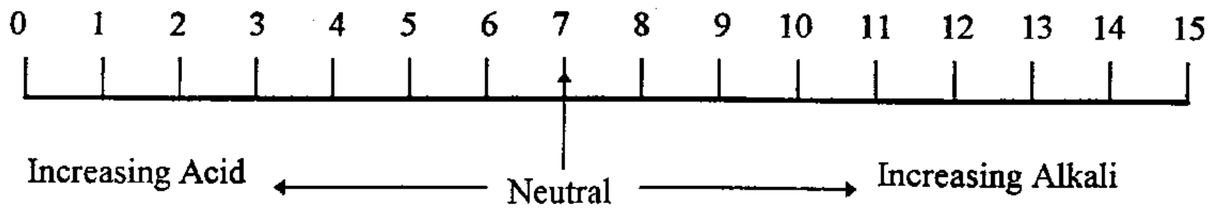
FACTORS AFFECTING CORROSION

The factors affecting corrosion are as follows:

i) pH level of the environment
ii) Temperature
iii) Flow rate of the water

i) The Level of Hydrogen Activity (pH)

In effect this is a measure of how acid or alkali the electrolyte is. Steel will corrode least at a value of between pH 10-12, distilled water will have a pH of 7, acids will be less than pH 7 and alkalis will have a pH of above 7 the further away they are from the neutral pH 7 the stronger the acid or alkali. Concrete protects the reinforcing bars by changing the pH of the electrolyte to approximately 11 which is called passivation.



The above shows the pH scale.

ii) Temperature

In general a increase in temperature will give rise to a higher corrosion rate, so areas around hot risers, exhausts, conductors and outfalls are particularly likely to suffer.

iii) Water Flow

As the flow of water increases then the rate of corrosion will also increase. Tests have shown that a straightforward increase in the flow will increase the corrosion rate but if there is aeration at the same point such as ships rudders and pump intakes etc. the rate will again be increased.

CORROSION PROTECTION

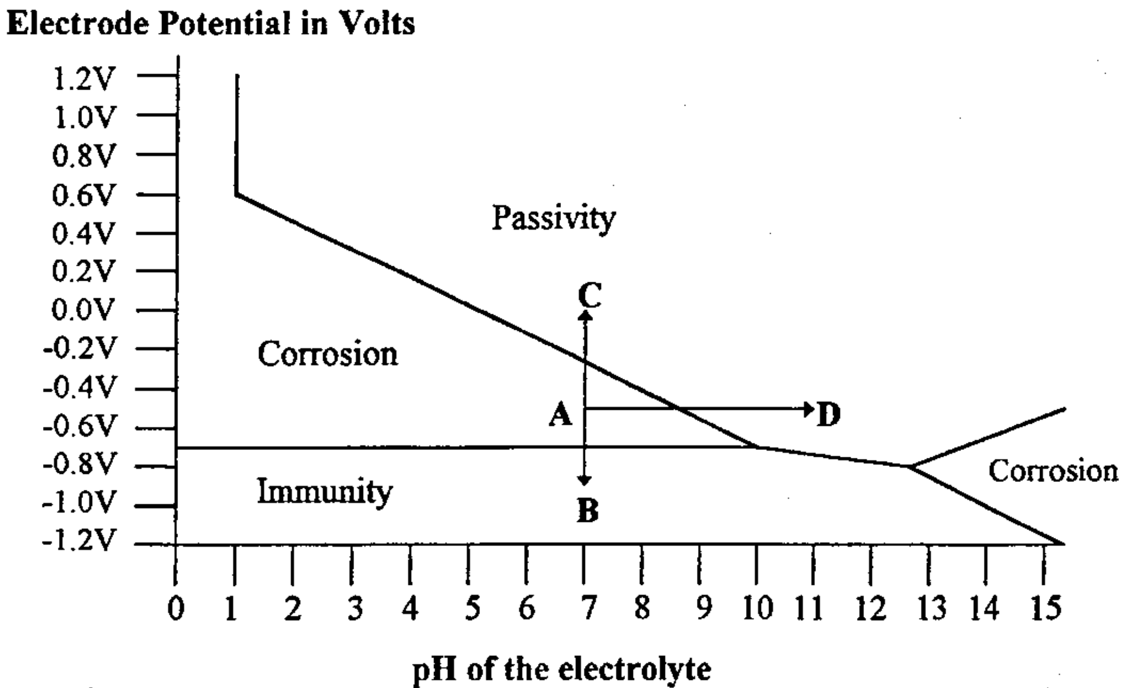
Having seen that the structures will be affected by the environment we will now look at the ways in which they can be protected from the effects. It can be said that there are three states of corrosion which depend on the electrode potential and the pH of the electrolyte, the three states are as follows:

i) Corrosion - If the electrode potentials are at a certain level then metal will be removed, (position A on the Pourbaix Diagram).

ii) Immunity - If the electrode potential is lowered i.e. the structure is made to be more negative by the application of free electrons then the structure will become immune to corrosion (position B on the Pourbaix Diagram).

iii) Passivity - There are two ways in which a structure can be brought in to the passive zone. The first is to give the electrode (the structure) a more positive potential, this will have the effect of producing an oxide coating on the structure, this may or may not protect the structure from the effects of corrosion, (position C on the Pourbaix Diagram). This is an unreliable method called anodic protection, it is not widely used offshore. The second way to bring a structure into the passive zone is to change the pH of the electrolyte to make it more alkali, steel will build up a coating which will protect it to an extent, the corrosion rate will at least be much reduced, steel will corrode least if the pH is kept between approximately 10 to 12, (position D on the Pourbaix Diagram) this is the method by which concrete protects its reinforcing bars buried inside.

All of these can perhaps be best visualised by the use of the Pourbaix Diagram (figure 16.11), this is a result of laboratory testing using no flow and a constant temperature:



ANODIC PROTECTION NOT USED FOR STEEL.

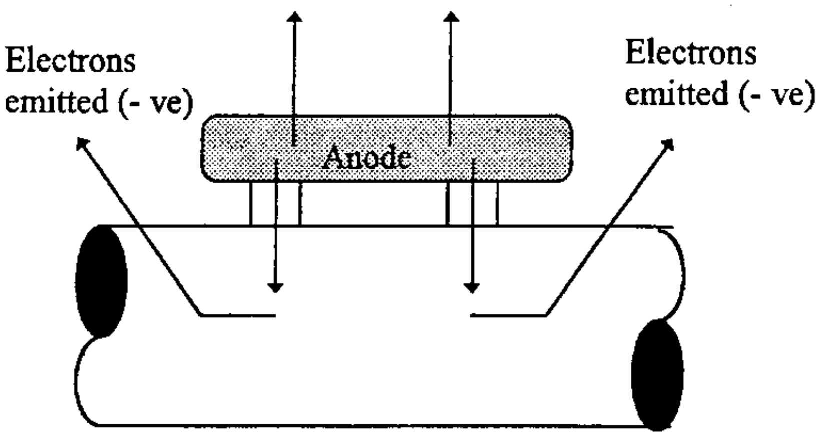
Figure 16.12 The Pourbaix Diagram for Iron in Water

The method most widely used offshore for the protection of the submerged part of the structure is **Cathodic Protection**. This aims to bring the electrode potential of the structure into the immune zone. The threshold for complete protection is said to be -0.8 volts (-800 millivolts). There are two ways that this can be accomplished they are as follows:

i) SACRIFICIAL ANODE PROTECTION SYSTEMS

When using this method we create a corrosion cell sympathetic to the metal in our structure i.e., if we attach a quantity of less noble metal such as Zinc, to the structure. The structure will then become the Cathode so being protected, the Zinc being a less noble metal will become the Anode so sacrificing itself. In our case where the structure is made of steel there **are three metals commonly used for anodes they are, aluminium, zinc and magnesium.** This system is widely used for the protection of structures and involves the placing of large numbers of Anodes at various locations throughout the structure. As soon as the structure is submerged the anodes will start to sacrifice themselves in order to supply the structure with the electrons it needs, so will protect the structure until the supply of anode material is exhausted. At this time the anodes will have to be replaced. There is an advantage in that this system starts to work as soon as the structure is installed and does not have to wait until a power supply can be hooked up. But the main disadvantage may be the additional weight that the structure has to carry. The figure 16.13 is a representation of the principles involved:

ADV. NO HYDROGEN EMBRITTLEMENT. — EXPENSIVE TO REPLACE.
NO OVERPROTECTION — HIGH MAINTENANCE
LOW VOLTAGE SAFE FOR DIVERS. — ADD. WEIGHT



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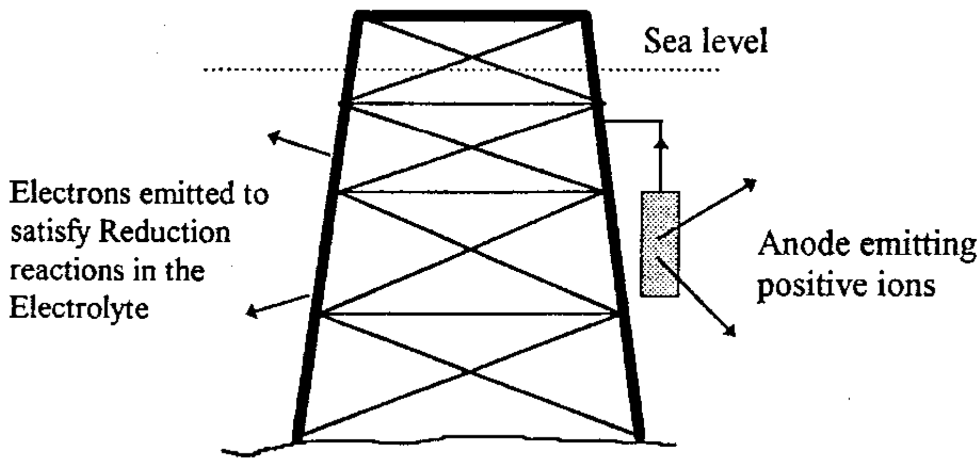

Figure 16.13 Sacrificial Anode Protection System

ii) IMPRESSED CURRENT SYSTEMS

The above method (Sacrificial system) relies on the less noble metal breaking down and giving the structure the electrons that it needs, Impressed Current systems will still supply the structure with the necessary electrons but instead of the electrons coming from a less noble metal attached to the structure they come from a direct current power supply, this will be in contact with the structure and the electrolyte. When connecting the power supply it is imperative that the polarity is correct i.e. **the structure must be connected to the negative terminal** and the auxiliary node which is in the electrolyte must be connected to the positive terminal. If the polarity is not correct then the structure will corrode more quickly which is obviously not the object of the exercise. The auxiliary node is also a very important part of the system. Whereas with the sacrificial system the Anodes were being constantly eaten away, in the case of an Impressed Current system the surface area of the auxiliary node is important, and so the auxiliary node must not corrode. This means that we must use a very noble metal for the auxiliary node there are several substances which can be used, such as **Niobium, Graphite, Tantalum and Lead Silver alloys**, perhaps the ~~most commonly~~ used substance is **Platinum sheathed Titanium**. LEAD SILVER ALLOYS MOST COMMON

The current needed in the North Sea is about 150 milliamps for every square metre of exposed steel, this will mean that very high current values will be needed.

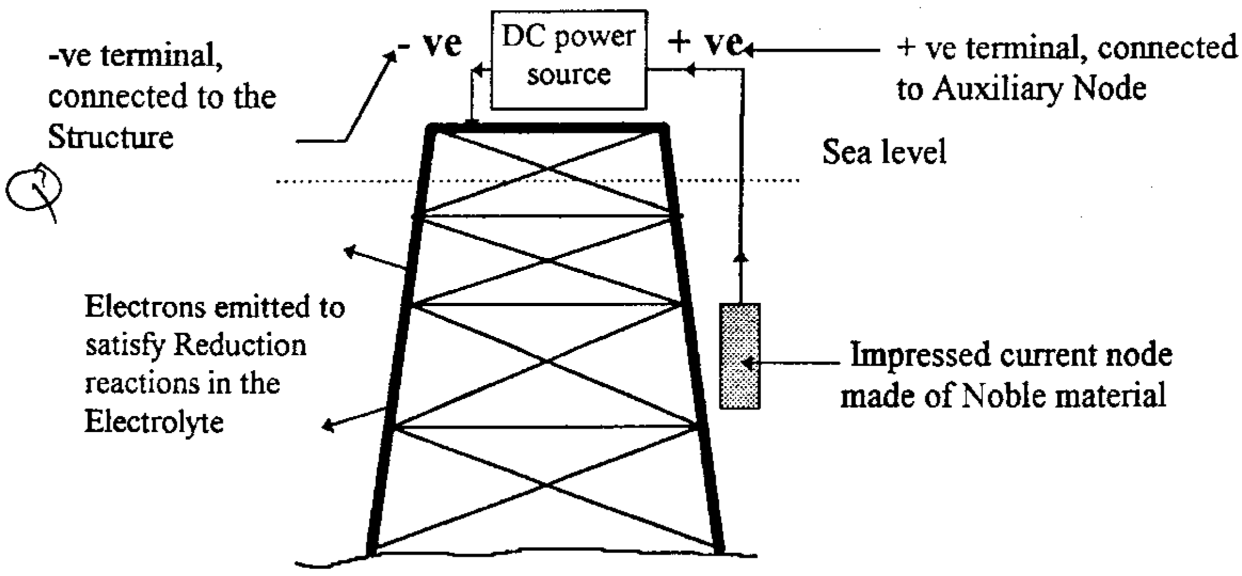

Figure 16.14 Impressed Current Protection system

There are two ways in which an impressed current system can be installed on a structure:

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i) **Platform Based**

The nodes are attached to the structure at intervals around it rather similar to the sacrificial Anode installation. The problems with this method are that there can be some "shadows" in so far as the structures protection is concerned. There can also be a drawback as far as diver safety is concerned, as the system can employ up to 1000 amps at 80 volts there is a chance of electrocution. For this reason the system should be switched off during diving operations or at least the current should be reduced.

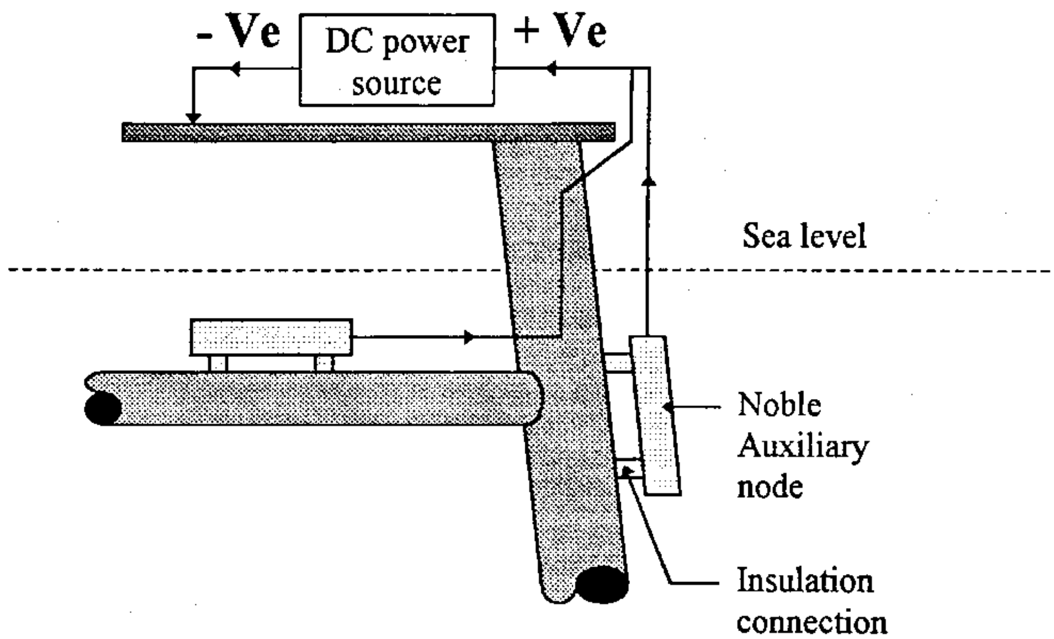

Figure 16.15 Platform Based Impressed Current System

ii) Remote From The Structure

A number of nodes (maybe six or eight) are placed on the seabed some distance from the structure, this method gives perhaps the best coverage over the whole of the structure with fewer "shadows". The safety problem still exists, it is said that the diver is safe if the node is more than about 40 feet away (12 metres), so unless he is checking the electrical cables the system can remain operational while the diver is in the water (providing there is no break in the insulation of the cables).

Q

ADV. DON'T NEED TO REPLACE AS OFTEN.
LESS WEIGHT
HIGH INITIAL COST LOW MAINTENANCE.
VARY PROTECTION LEVEL.

DIS. CAN OVERPROTECT
HYDROGEN EMBRITTLEMENT
PRODUCE H.E.
UNSAFE FOR DIVERS.
NEED POWER SOURCE
TAKES TIME TO BUILD UP LEVEL OF PROTECTION

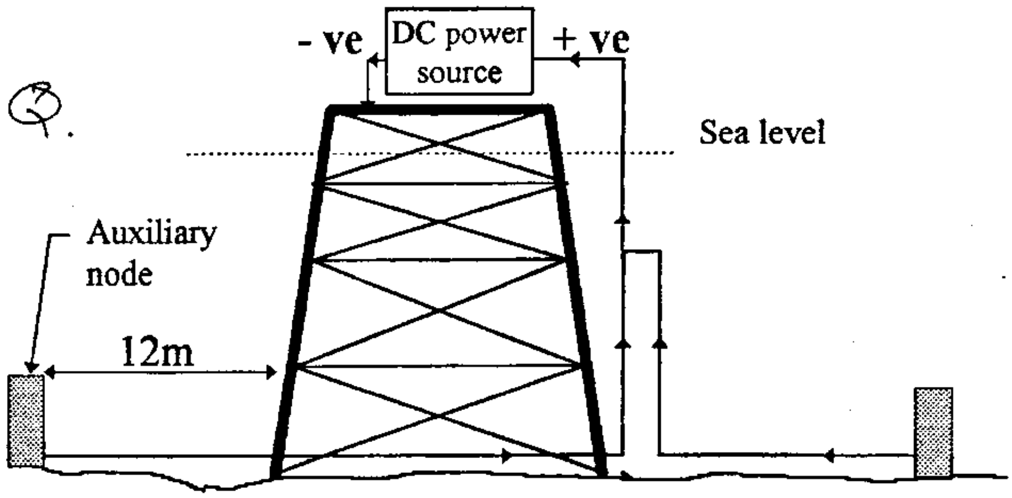

Figure 16.16 Remote Impressed Current Protection System

Both Sacrificial and Impressed Current Protection systems are used extensively, they can often be employed simultaneously on the same structure. If this is the case then the Sacrificial Anodes will not corrode or become wasted unless the Impressed Current nodes are insufficient to cope with the corrosion taking place. This may give rise to a method of monitoring the Impressed Current protection by using Monitored Anodes which will be discussed later.

CORROSION PROTECTION MONITORING

The problem with corrosion protection is that it is very difficult to predict exactly how much current will be needed, or even if it is predicted accurately then the distribution of the current may be a problem due to the structures geometry. The amount of protection needed will vary according to the factors shown below:

i) Metal to metal - Different metals and alloys need differing rates of protection.
ii) Environmental differences - temperature, pH and oxygenation.
iii) Geometric differences in the structure.
iv) Other factors affecting the resistance of the corrosion circuit - paint coating removal and marine growth etc.

Because of these variables we will have to monitor the corrosion protection at various locations on the structure in order to be assured that the structure remains adequately protected. We can use the following methods to achieve this:

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INSPECTION REQUIREMENTS

*

1) Visually assess the anode condition, noting the presence of any deposits, their type and extent.

   IMP. CUR DOESN'T DEPLETE.

2) Note anode wastage, this may be an estimate but should really be measured.

   CHECK CONTINUITY. CP both ends of cable = ± 2mv.

3) Anode to structure integrity, or if impressed current then cable to anode connections.

4) Visual assessment of the surface condition of the structure, looking for corrosion products and pitting.

5) Marine growth, as marine growth can be increased by Impressed Current protection.

6) Local Cathodic Potential readings and ANODE photographs taken at intervals around the structure.

Cathodic potential readings can be taken by two main methods as follows:

i) **Silver/Silver chloride (Ag/AgCl)** half cell - Either in a self contained diver held meter such as the Bathycorrometer which the diver will have to read, or a proximity cell which will give continuous readings and be read on the surface.

   ZRE = ZINC REFERENCE ELECTRODE.

ii) **High purity Zinc (Zn)** electrodes - These tend to be left in-situ for constant monitoring of impressed current systems.

Silver/Silver Chloride (Ag/AgCl)

The most widely used method is the **Silver/Silver Chloride** (Ag/AgCl) half cell as is found in the Roxby Bathycorrometer (and also the Morgan Berkeley Rustreader). This method measures the potential of the structure at the point of contact of the meters tip and relates it to the known potential given by the reference half cell. It will then display the difference in volts either on the back of the machine, or as in the case of an ROV application it can be displayed on either the video monitor or on a meter located on the surface.

The above method requires good electrical continuity between the meter and the structure, in the case of the diver held contact meter as shown in figure 16.17, the contact will have to be made below the water line by the diver, this is because in this case all of the apparatus will be in the water with the diver who will make the contact and read the result on the back of the meter, he will use one of the meters described above, or possibly we could use a proximity probe as shown in figure 16.18 where the diver or ROV only take the Silver/Silver Chloride half cell in the water and do not have to make a contact below the water line as this contact is made on the surface. The proximity cell will be brought in close to the structure less than 100mm away and then the reading will be taken on the surface. This system relies on contact being made on the surface and so will not normally be available for use on pipelines.

With both of the above methods the meter will possibly not show a minus sign, it should be noted however that all of the readings taken will be negative values and should be reported as such.

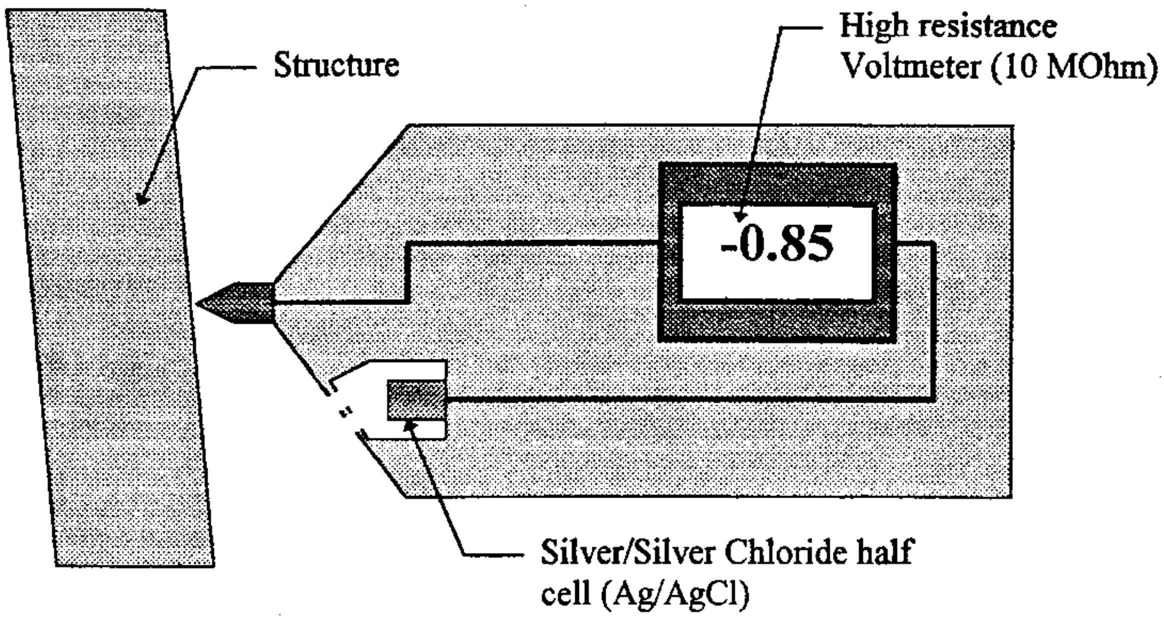

Figure 16.17 Self Contained Diver held Silver/Silver Chloride (Ag/AgCl) half cell

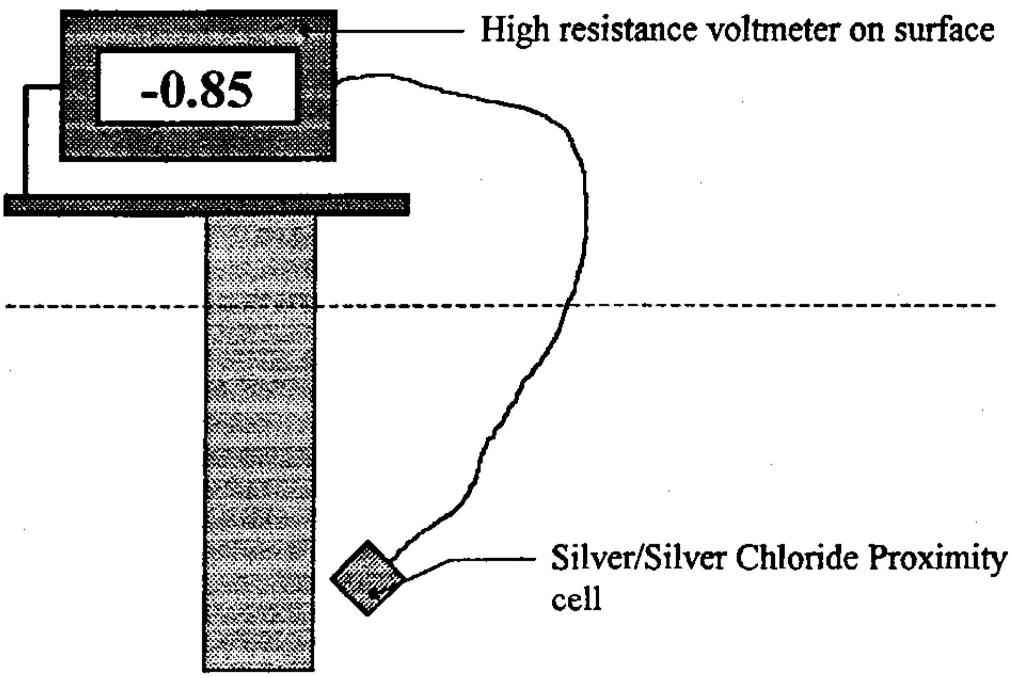

Figure 16.18 Proximity Probe using Silver/Silver Chloride half cell

Q.

PROCEDURE FOR THE USE OF DIVER HELD CATHODIC POTENTIAL METERS (CP)

In order for any meter or inspection technique to be used properly, there must always be a clear and concise procedure to follow. If this is done then the readings obtained should accurately reflect the true status of the component.

1. Ensure the meter is charged properly prior to use; normally 14 - 16 hours from completely discharged.

2. Ensure the tip of the meter is sharp; a blunt tip will not allow a good contact to be made with the structure.

3. Soak the meter in a plastic bucket in fresh sea water which has not come from a fire main for a minimum of **THIRTY MINUTES**. This will enable the Chloride ion concentrations in the reference cell to be established at the right level.

4. Check the calibration of the cell using at the least a Zinc block, possibly a corroding mild steel block will also be used and a Calomel Electrode.

   (Note: see calibration using calomel electrodes at the end of this chapter). **The readings must be recorded on the log sheet**. (all of the expected readings can be found at the end of the procedure).

5. When the meter is at the survey site the calibration should be checked once again, to prove the meter at depth, and recorded.

6. Clean a small area of the structure to bare metal and ensure a good contact with the tip of the meter.

7. Carry out the survey and record the results.

8. At the end of the survey the calibration should again be checked to ensure the meter is still functioning properly. During dives where a lot of readings are being taken it is prudent to check the calibration often, then if the meter fails not all of the previous readings will be lost.

9. Recover the meter, wash in fresh water and dry thoroughly.

10. Charge the meter to the manufacturers instructions

    Note: Roxby Meters can be left soaking in a solution of silver chloride, on trickle charge in order for them to be ready for use at all times.

Q.

EXPECTED READINGS WITH A SILVER/SILVER CHLORIDE HALF CELL

1. Over protected structure will give a reading of - 1.1 volts (-1100 mv *).
2. Zinc will give - 1.0 to - 1.05 volts (-1000 to -1050 mv).
3. Protected steel will give a reading more negative than - 0.8 volts (-800 mv).
4. Unprotected steel will give between - 0.45 and - 0.64 volts (-450 to -640 mv).
5. Calomel reference cell will give a reading between 0 to -10 millivolts (-0.01 volts). Calomel cells are used to test the reference cells as they give a very exact known potential which should be close to the potential of the Silver/Silver Chloride half cell, therefore there should be virtually no potential difference between them.
   MONEL = ± -2000mv.

If using a Silver/Silver Chloride half cell to take a reading on a steel structure, the reading obtained is between - 0.64 Volts and - 0.8 volts (- 640 to - 800 millivolts) the structure can be said to be under protected, so **- 0.8 of a volt (- 800 millivolts) would be considered to be the threshold of adequate protection**.

* Note: mv means millivolts. 1 volt = 1000 millivolts.

As discussed earlier another way that the Silver/Silver Chloride half cell can be deployed is as a proximity cell. This means that there is no contact necessary below the water line, all the diver or ROV has is a small probe and a wire which goes to the surface where it is connected to the positive terminal of a volt meter. The negative terminal of the voltmeter is connected to the steel structure. Care must be taken that the connection is to a bright clean area of the structure and also to a part of the structure which is in electrically continuity with the area of the structure being surveyed below the water line. Using this method the diver or ROV just swims around the structure and holds the cell close to but not in contact with the structure gently moving it to and fro within approximately 100mm of the structure. The reading is then taken on the surface. The cleaning is not so critical with this method as there is no contact necessary below the water line.

CALIBRATION PROCEDURES USING CALOMEL ELECTRODES

SHOULD BE DONE AT LEAST 1/MONTH.

Equipment needed:

3 Calomel Electrodes
High Impedance Voltmeter (10 Mega ohm) DIGITAL VOLT METER.
Zinc Block with Clamp and Lead (Zinc should be 99.99% pure)

First we must check that the calomel electrodes are in good condition, this is done by following the following technique:

a) Visually inspect the electrodes, ensure they are filled with Potassium Chloride (KCL) solution. Free crystals may be visible if the cell is made of glass and there should be no air bubbles evident (note: These days most cells provided offshore will be plastic and will not be see through).

b) Label the electrodes 1, 2 and 3. Soak the electrodes for 24 hours.

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 from the DIGITAL Voltmeter. READING SHOULD BE 0 ± 2.

e) Rinse the electrodes in fresh water.

f) Repeat the test with each of the possible permutations of electrodes. RECORD READING IN LOG.

g) The following procedure will dictate which electrode should be used for the calibration of the meters.

Acceptable readings between a pair of electrodes is - 2 mv to + 2mv, if all the readings are within this range then any electrode may be used, if one reading is out of this range then the electrode not in that pair is the one to use. If one reading is in range then either of the electrodes in that pair can be used.

If all of the readings are out then the pair giving the least reading may be used assuming clients acceptance.

CALIBRATION OF Ag/AgCL DIVER HELD CONTACT METER

a) Fully charge the Bathycorrometer, and soak for at least 30 minutes in fresh sea water (not from a fire main).

b) Remove the stainless steel tip from the meter. AND NYLON CONE.

c) Screw the Calomel reference electrode onto the Bathycorrometer in place of the tip.

d) Replace the meter complete with the Calomel electrode in the sea water and allow the electrode to reach a stable potential (10 - 15 minutes).

e) The Voltage difference between the Saturated Calomel and the Ag/AgCl electrode can be read directly off the Bathycorrometer Voltmeter, should be - 4mv ± 5mv.

f.) CALIBRATE AGAINST ZINC.

The above complies with the D.N.V. specification "Guidelines for Potential Measurement"

Note: In the Bathycorrometer, the internal Ag/AgCl reference electrode is connected to the positive terminal of the internal Voltmeter.

CALIBRATION OF THE DIRECT CONTACT METER ROV DEPLOYED

a) Ensure Calomel electrodes have been properly calibrated (As described above).

b) Soak contact CP meter in clean, fresh seawater in plastic bucket for 30 minutes prior to calibration.

c) Connect the Calomel electrode to the negative terminal of a high resistance 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 same bucket of seawater as the Calomel electrode is in, ensuring only the Zinc is submerged and not the clamp or the cable.

e) Take the reading from the Voltmeter and record, should be -1.00 Volts to - 1.05 Volts.
RECORD READING.

f) Disconnect the clamp from the Zinc block.

g) Take the Zinc block to the contact meter on the vehicle and while the meter is still immersed make contact with the Zinc block, record the reading. - 1000mv - 1050mv
SUBTRACT READINGS.

h) When both the readings are compared there should be little or no difference, i.e. 0 to -10mv. DEPENDING ON WAY VOLTMETER CONNECTED.

CALIBRATION OF Ag/AgCL PROXIMITY CELL

a) Ensure the Calomel electrodes have been properly calibrated (as above).

b) Soak the Ag/AgCl half cell in clean seawater in a plastic bucket for 30 minutes.

c) Connect the negative terminal of the Voltmeter to the Ag/AgCl measuring electrode.

d) Connect the positive terminal of a high resistance Voltmeter to the Calomel electrode and immerse the electrode tip in the seawater.

e) Take and record the reading from the Voltmeter, should be 0 to -10 mv.

f) Repeat this procedure if the readings are outside this range.

g) Using the procedure above measure the potential of the Zinc block with the Proximity cell. The reading should be in the region of -1.00 V to -1.05 V

High Purity Zinc Reference Electrode (ZRE 99.9% Pure) Only for imp. cur

Another method is **high purity Zinc** electrodes, these are pieces of Zinc which are placed at specific locations around the jacket. These locations may be areas where the stress is high or where the protection is thought to be marginal, they are generally used with impressed current systems as they can be left in-situ on the jacket and will give a constant readout of the structures potential at that location. The readout will normally be displayed in the control room on the surface. The disadvantage of them is that they cannot move about and so whereas their location may well be fully protected, an area just a short distance away may be under protected.

Looking for less than 0.2v

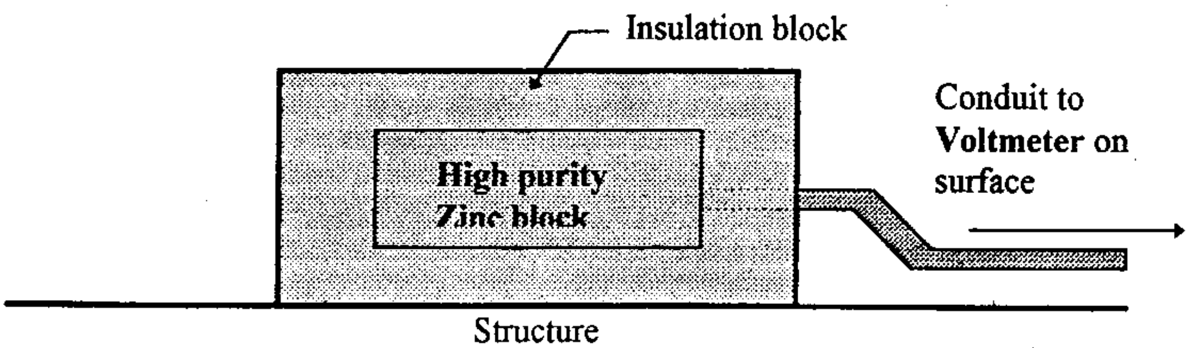

Figure 16.19 High Purity Zinc (Zn) Electrode

Monitored Anode Only for imp. curr.

One other way in which an Impressed Current corrosion protection system can be observed is by the use of a monitored anode, this is simply a sacrificial anode which is only in electrical contact with the structure via an Ammeter. If the impressed current fails for any reason, leaving the structure unprotected, then the Monitored Anode will exhibit a current flow shown on the surface readout thus raising the alarm.

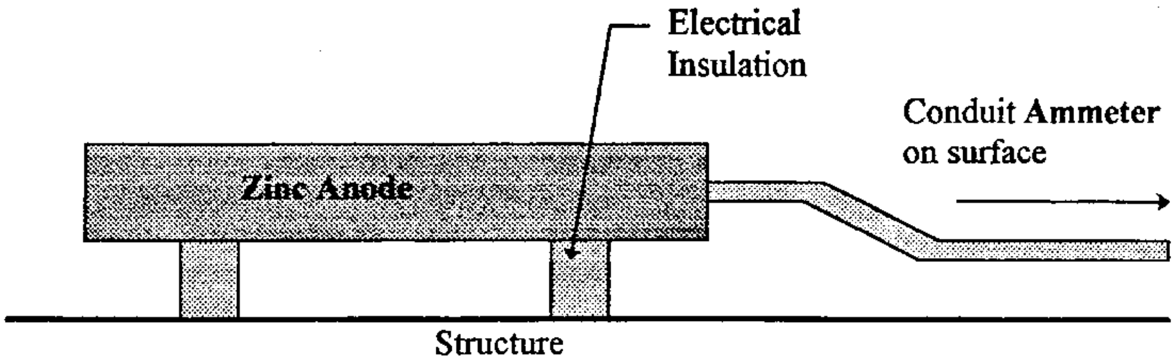

Figure 16.20 Monitored Anode System

The following is a sketch to show a summary of the various methods of protection monitoring mentioned above:

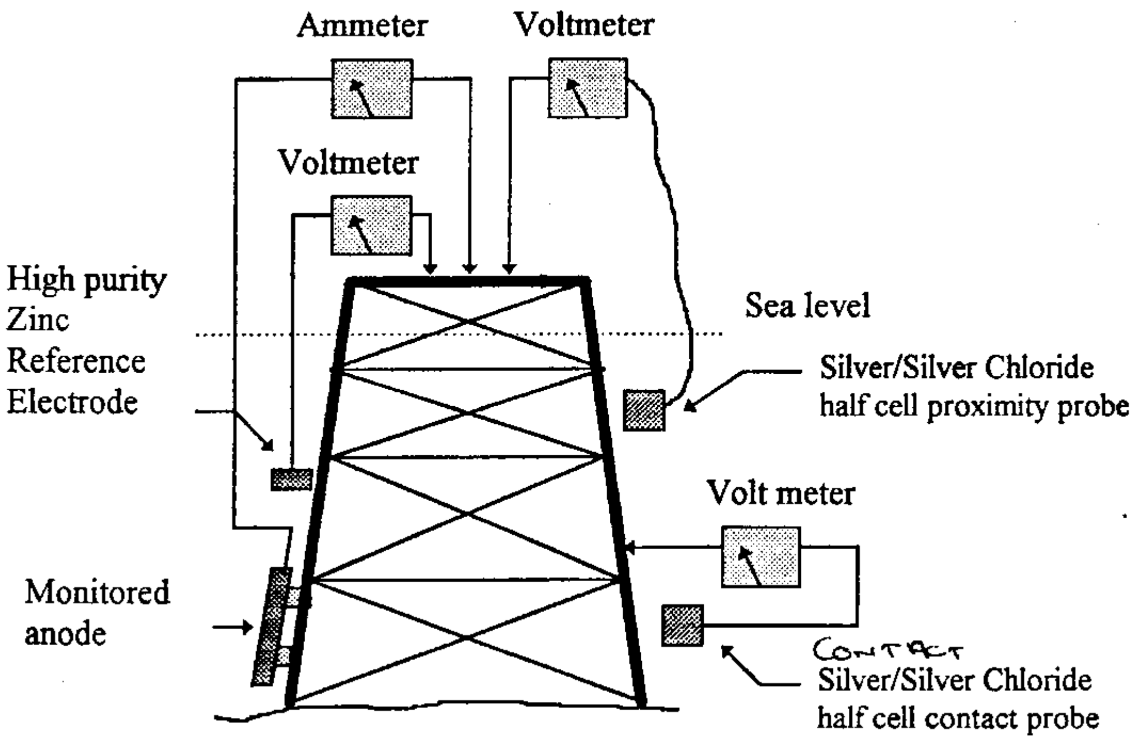

Figure 16.21 Summary of protection monitoring methods

CURRENT DENSITY

In order for the cathodic potential of the structure to be sufficient for protection the current density must be 150 milliamps/M^2. This can be measured using a specialist probe either by a diver or by a Remote Operated Vehicle.

ANODIC PROTECTION USED ON ALL ZINC NOT STEEL.

This method of protection relies on the build up of a protective coating on the surface of the material. One metal which can be protected in this way is Aluminium, but where steel is concerned the coating formed is not reliable in protecting the steel underneath and so this method is not used to protect steel structures offshore. The way that it may be bought about on an appropriate metal is by making the metal more positive, which will effectively accelerate the corrosion, and in certain cases build up the protective coating but as has been said, in the case of steel it is unreliable.

All of the above are fine where the structure is constantly submerged but where the structure is not always under water then they will not work and so we need another method, the method used is coatings.

COATINGS AND THE INSPECTION OF THEM

Protection of a steel structure in the area of the splash zone will not be effectively accomplished by means of either Impressed Current or Sacrificial Anode systems as both of these rely on the continuity of the electrolyte.

Therefore there will have to be another means employed; usually protection is accomplished using some form of a coating.

Coatings can be split into the following groups:

1. ORGANIC COATINGS

Such as paint, plastics, bitumen, lacquers, rubber, grease and oil. All of these coatings rely on their having good adhesion to the surface being protected and no breaks in the surface In short they work by excluding the electrolyte from contact with the metal so increasing the resistance of the corrosion circuit.

2. INORGANIC COATINGS

This is made up of some substance such as ceramic, they are very good on hot surfaces and so are used in boilers and the like. They work in much the same way as the organic coatings.

3. METALLIC COATINGS

Metallic coatings can be split into two groups:

i) More noble coatings such as Monel cladding, used extensively in some locations. They rely on the coating being relatively unaffected by the environment and so protecting the metal. Problems can arise if the coating is breached, such as can happen if a boat punctures it. If this were to happen then the steel underneath would become anodic to the cladding, the steel would then sacrifice itself to protect the cladding, this is precisely the opposite to the desired effect. The cladding will usually be attached to the structure by means of a weld at the top and another at the bottom of the cladding. In order to protect the area where the cladding finishes below the water line usually there will be a heavy coating of bitumen or some such protection. In addition there will probably be a larger than normal concentration of anodes to counter any drain of electrons from the structure to the cladding. This will be an area of particular interest to the client.

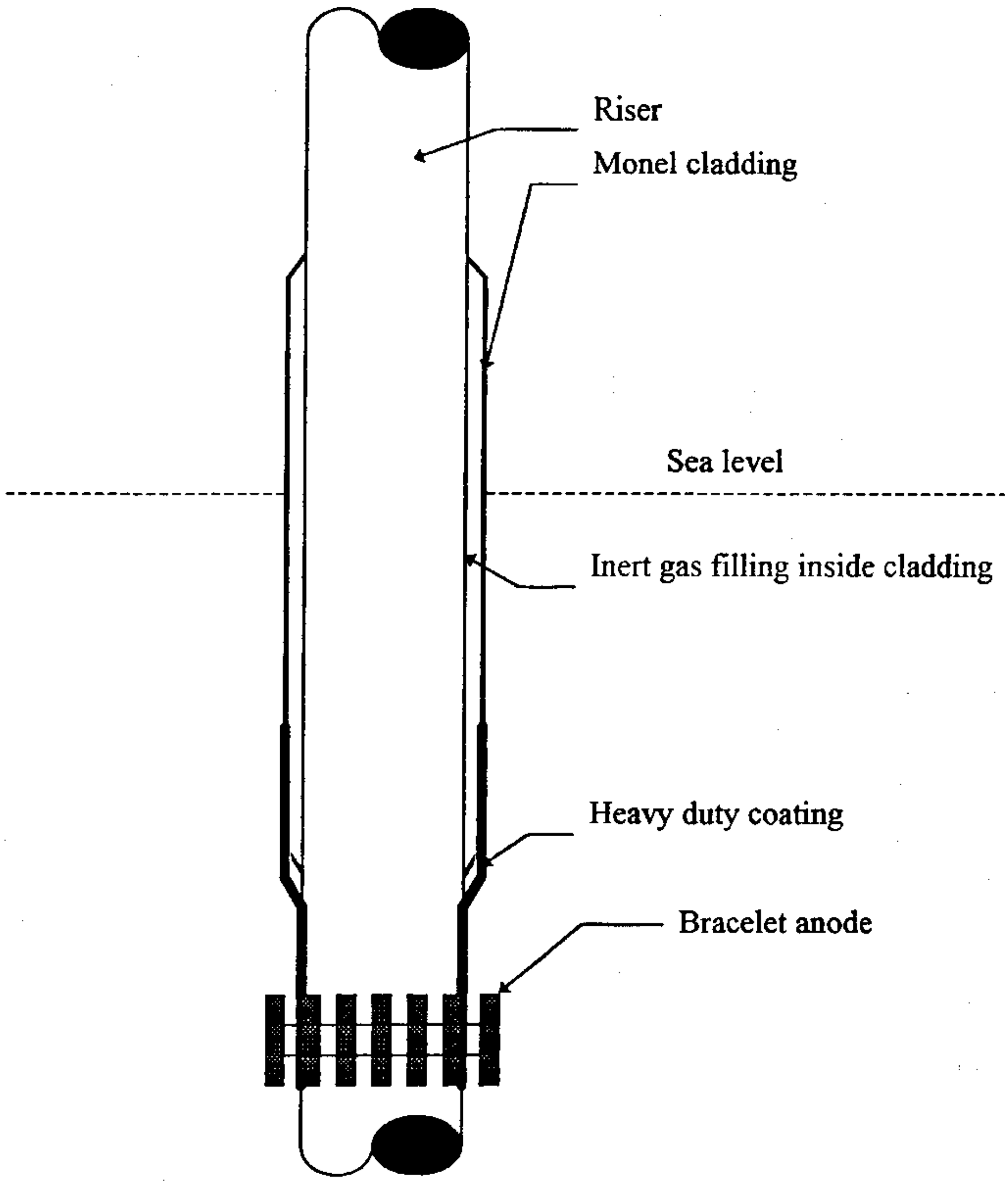

Figure 16.22 Monel Cladding

EFFECTIVE METHOD. FOR SMALLER ITEMS.

ii) Less noble coatings such as zinc. We call this method galvanising, most people are familiar with this method, it involves spreading a thin coating of zinc all over the surface of the structure, this coating will not corrode much, indeed it will just tarnish and thus will tend to protect the structure anyway. If it is breached then the zinc will sacrifice itself in order to protect the exposed metal. This will be effective for longer than bolting the same weight of zinc onto the structure as the coating will only start to sacrifice itself once there is bare metal for it to protect. This is an effective method for smaller items as can be seen from the length of time some household items can withstand corrosion while they use this method. The problem is that it is not feasible to coat large structures in the same way.

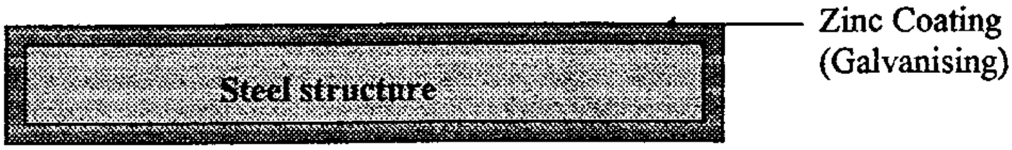

Figure 16.23 Galvanising

4. CONCRETE

Concrete can be used to coat pipelines and of course concrete reinforcement bars, the coating will "passify" the electrolyte and so chemically protect the structure from corrosion, as well as providing stability and protection from impact and collision to a pipeline.

INSPECTION OF COATINGS

When inspecting coatings it is normal to talk of percentage cover or percentage missing. This form of assessment is notoriously inaccurate and so it is important to make as much effort to be precise as possible. When inspecting you should take an area of say one metre square and assess the coating in that area this will make your findings more accurate. Normally the topcoat is of a different colour to the primer so it should be relatively easy to assess how much top coat, primer and bare metal is visible, but only if you know which colour relates to which coating layer. It is advisable to take photographs and perhaps a video as a permanent record of the inspection.

You will be asked to note the following:-

1. Percentage of topcoat visible.
2. Percentage of primer visible.
3. Percentage of bare metal.

4. Blistering - If there are blisters evident then the diver should burst a sample to assess the surface condition of the steel underneath.

5. Cracking - If there is cracking of the paint coat then the extent should be noted.

6. Poor surface adhesion - The coating may not be adhered well and may start to blister or flake if it is left.

7. Sagging - This occurs with heavy coatings such as bituminous coatings. The extent of the sagging should be noted as in extreme cases the coating can separate at the top of the area and so expose the metal underneath.

8. Wrinkling - Usually allied to the sagging above and may be the first visible sign of trouble.

9. Flaking - If the coating starts to become detached then it may well come off in large strips and flakes.

When inspecting monel cladding then the client will need to know of any break or deformation in the coating which could allow the ingress of water to the cavity between the monel cladding and the steel of the structure or riser. Note should be taken of the method of cleaning for Monel as suggested by the client, this is because the coating is very easily damaged by use of the wrong method.

NOTES