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

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

1) Design.
2) Manufacture of the raw material.
3) Fabrication of the structure.
4) Launch and installation.
5) Service life.
6) Decommissioning

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 note 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:

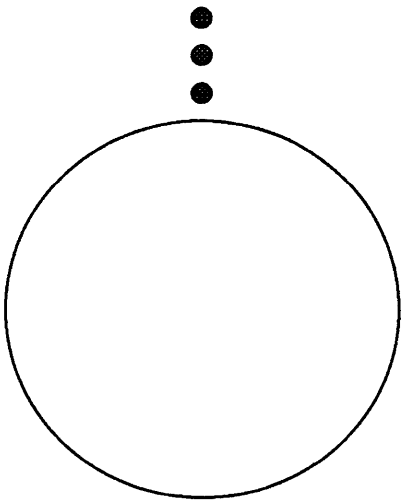


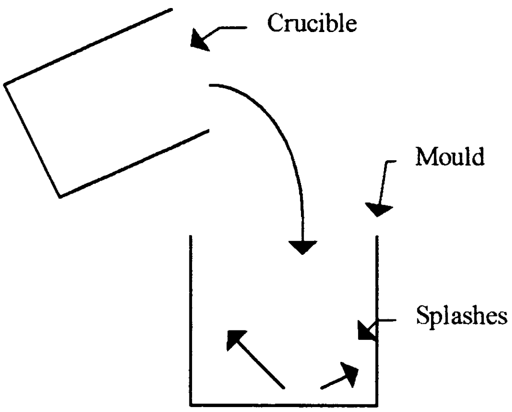
Fig 1.1 Datum points on a tubular brace

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:

i) Fish Tails

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.



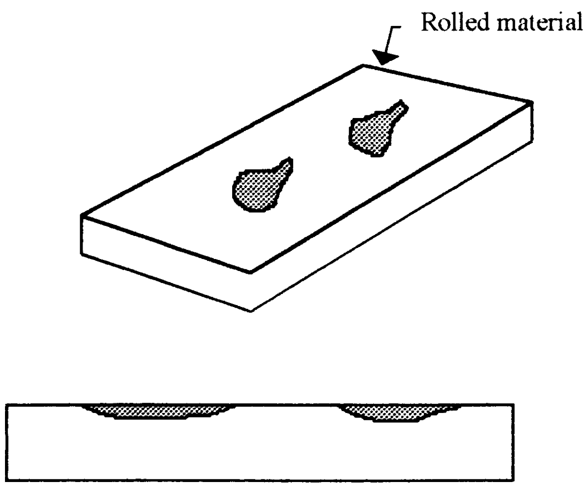
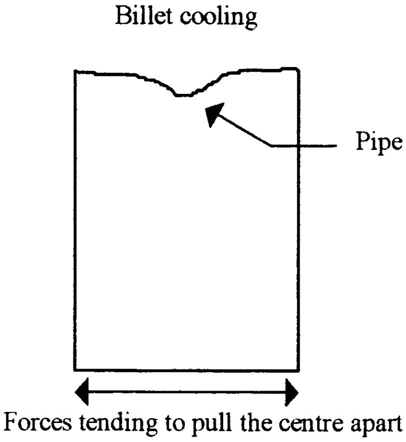
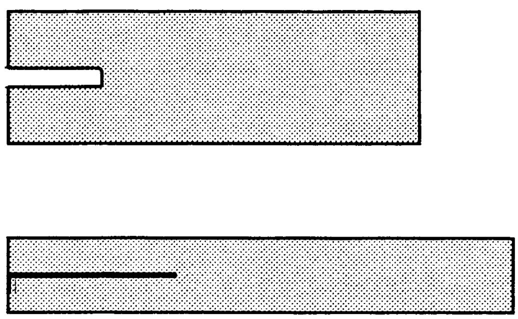


Figure 1.2 Fish Tails

ii) Laminations

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.





Progressive rolling of the material

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.

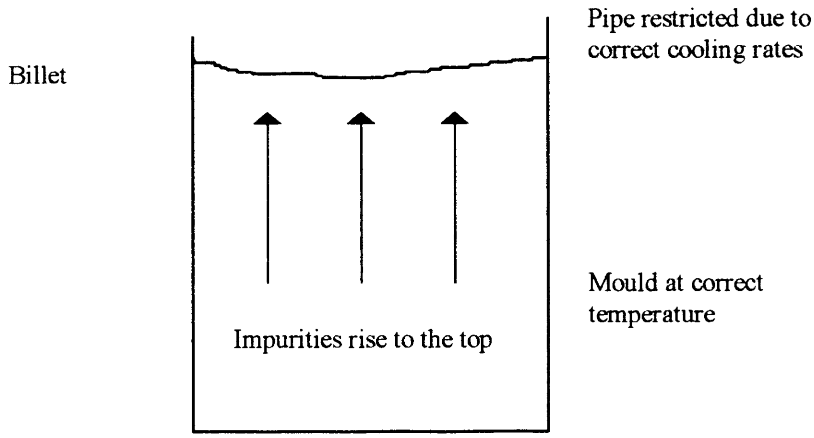


Figure 1.4 Inclusions and Porosity

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.

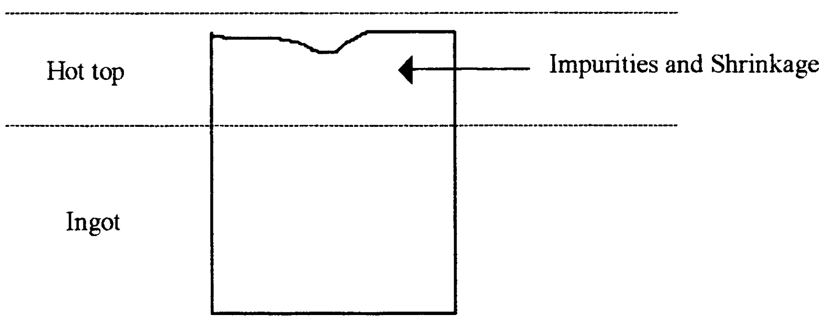


Figure 1.5 The Hot Top

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:

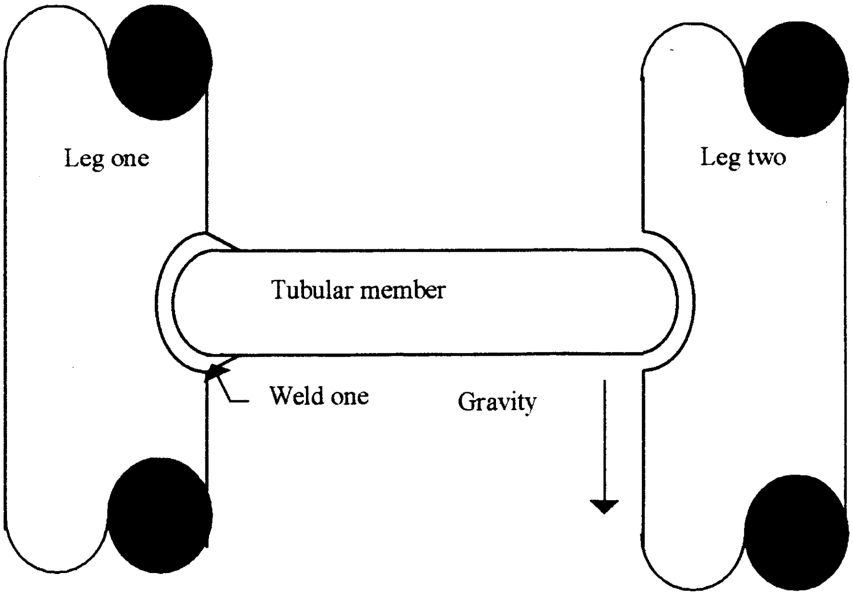


Figure 1.6 Tubular Member With only One End Welded

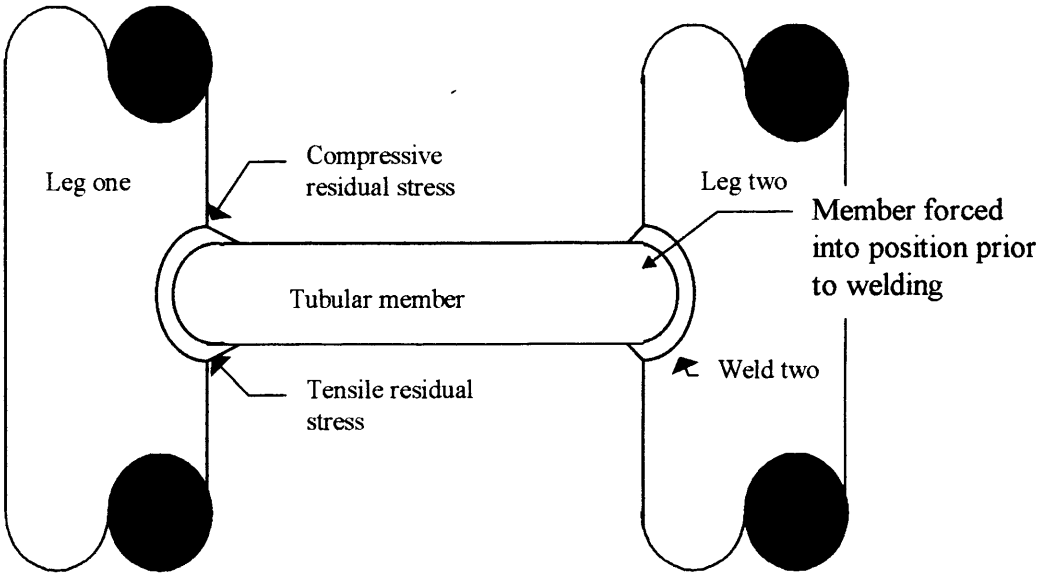


Figure 1.7 Residual Stress in a Tubular Member After Welding is Complete

iv) Machining Defects

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 the structures ability to perform the designed task safely. This has to be verified by an **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 is common during the installation are as follows:

i) Accidental Damage

Due to handling of heavy objects causing dents and deformation.

ii) Residual Stress

Caused through setting the structure on an unstable foundation or an uneven seabed, 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 or 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 in water 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.

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:

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

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 that will ultimately undermine the structure. This could cause failure especially in the case of Gravity Base structures (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 cannot be used.

6. DECOMMISSIONING

As fields become depleted, the structures which serve these fields will then become redundant. Removal of these structures will perhaps cause some concern environmentally, also some of the components may be re-usable. Inspection may be required to ensure that items being removed are removed in an orderly manner ensuring that damage to the environment does not occur. If items are to be re-used at another site, there will be a need to remove these items using care, this will involve procedures being followed. Finally, once the structure has been removed, seabed surveys will confirm that there is no debris left in place.

LEGISLATION RELATING TO INSPECTION OF OFFSHORE STRUCTURES

In 1992 the government brought into force **The Offshore Installations (Safety Case) regulations SI 2885 (1992)**. These regulations extend the **Health and Safety at Work Act (1974)** to offshore structures. These 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:

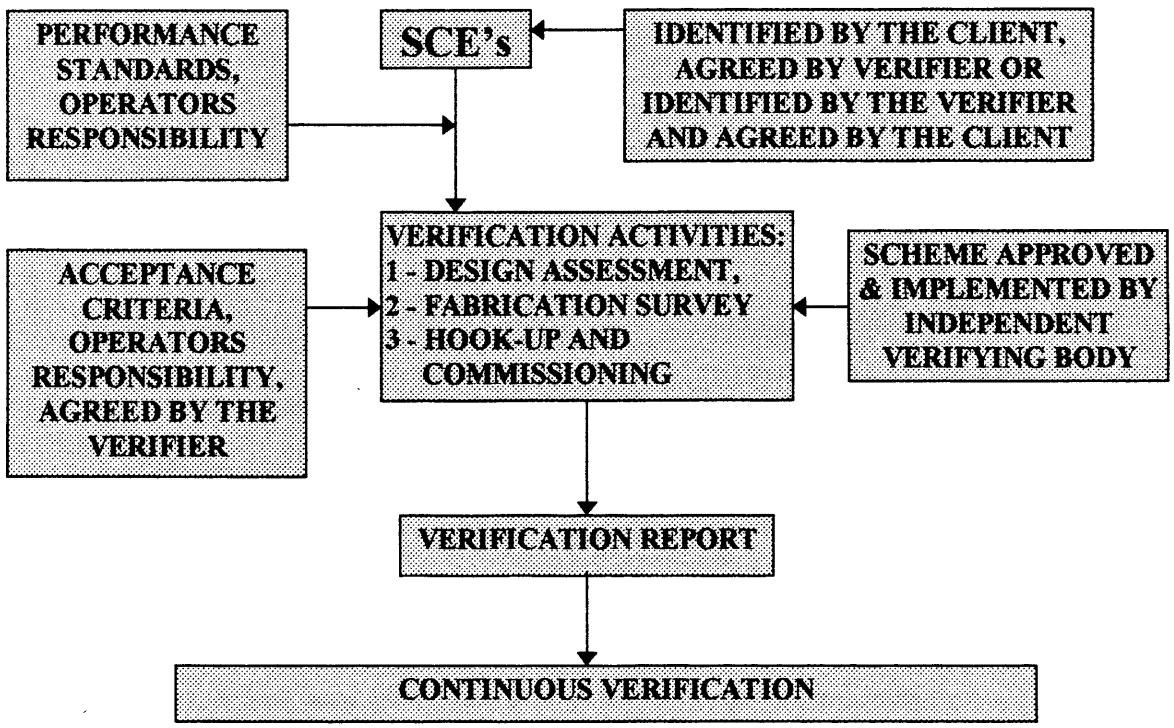
DCR SI 913 (1996)	Design and Construction Regulations
PSR SI 825 (1996)	Pipeline Safety Regulations
PFEER SI 743 (1995)	Prevention of Fire, Explosion and Emergency Response Regulations.
MAR SI 738 (1995)	Management and Administration Regulations
PUWER SI 2932 (1998)	Provision and Use of Work Equipment Regulations (Plant and Equipment)

The main aims of the above will be to reduce any risk to being **As Low As Reasonably Practical (ALARP)**

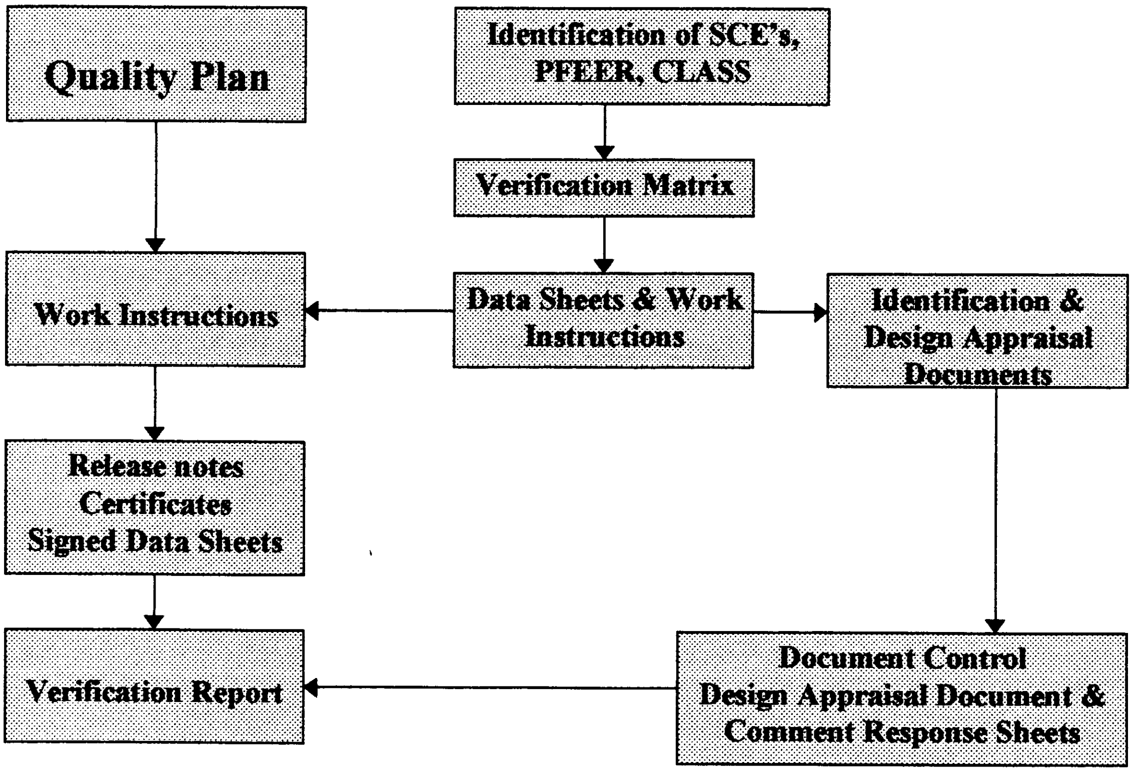
These regulations **SI 913 (1996) & SI 2885 (1992)** rely on **Verification** rather than certification; this means that all work carried out on offshore structures must be verified by an **Independent Verifying Body (IDVB).** This requirement is in schedule 2 of SI 913, however it will eventually move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

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:

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.

This first major survey is sometimes called a <u>BASELINE SURVEY</u> 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 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 (20%).
4. Possible magnetic particle inspection or electromagnetic inspection of a representative portion of welds (20%).
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.

CHAPTER 2

Stress In The Offshore Environment.

Stress can be defined by the following:

$$\text{Stress} = \frac{\text{Load}}{\text{Area}}$$

The highest stress will always be evident in the skin a material. 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 its 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.

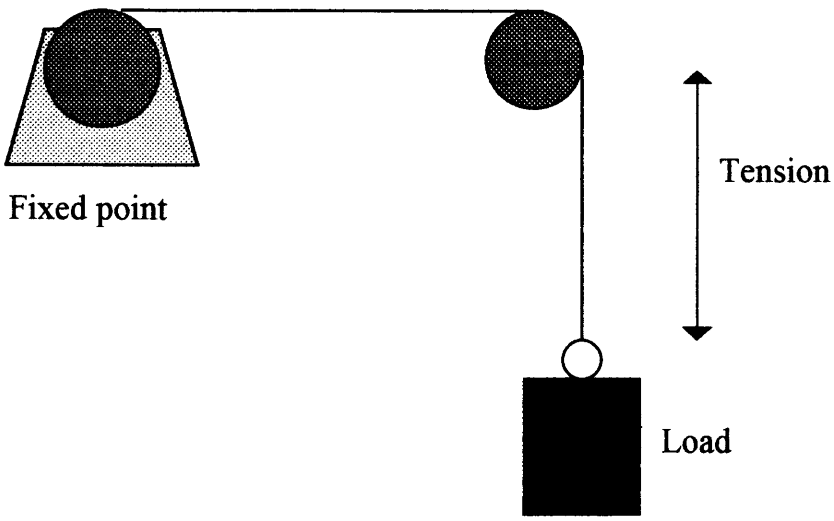


Figure 2.1 Tensile Stress

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.

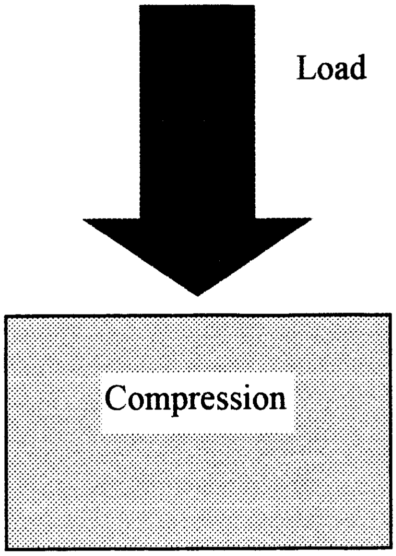


Figure 2.2 Compressive Stress

Shear Stress (τ)

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

Shear 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.

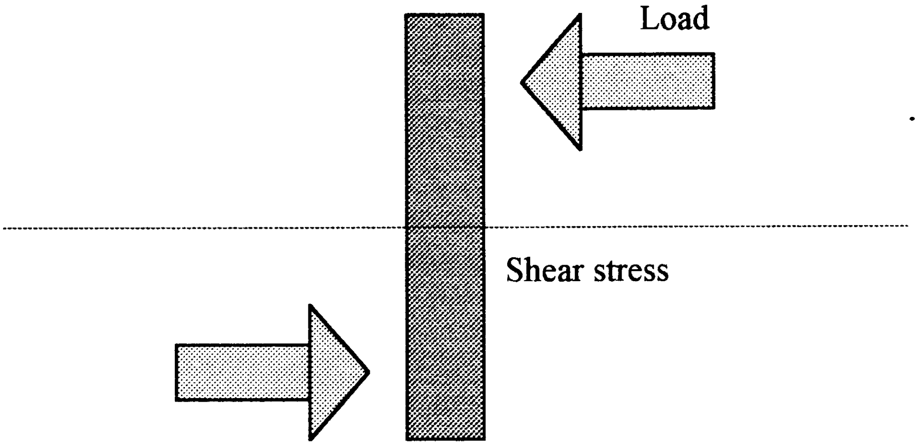


Figure 2.3 Shear Stress

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.

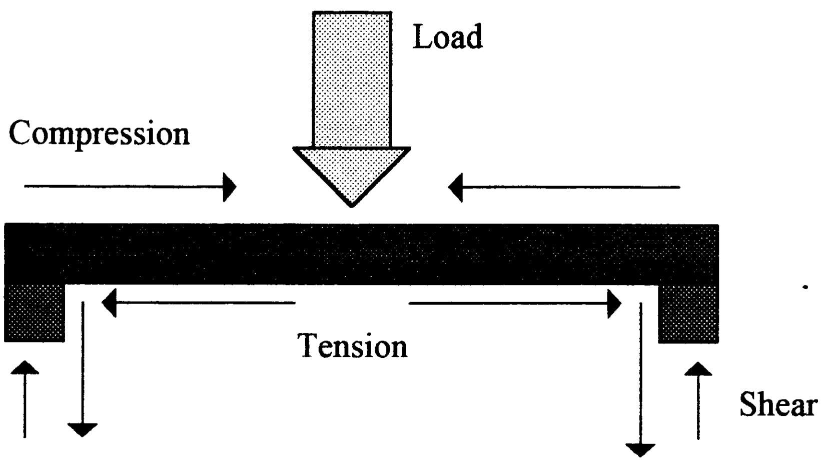


Figure 2.4 Stresses in a Beam Supported at Both Ends

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.

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**

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.

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 such as:

1. Drag Forces
2. Wind and Wave action
3. Drilling Vibration
4. Loading of the structures with modules and the like
5. Boats being tied up to them

There will of course also be 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.

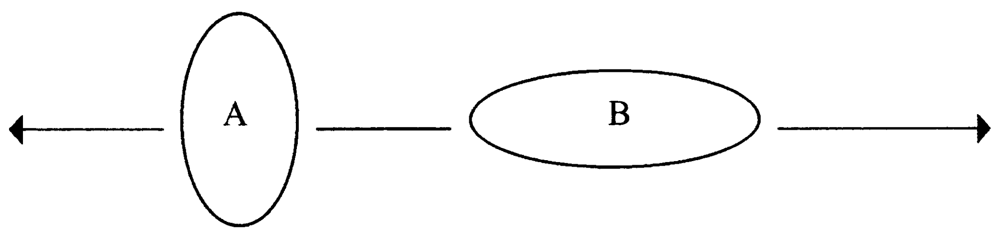
As can be seen the forces acting on the structure are very complex and so proper inspection of the structure is of paramount importance to ensure the continued safe operation of the structure in the offshore environment.

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, and 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 2.5 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 **Stopper holes or Crack Arrestor holes**.

STOPPER HOLES (Crack Arrestor 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.

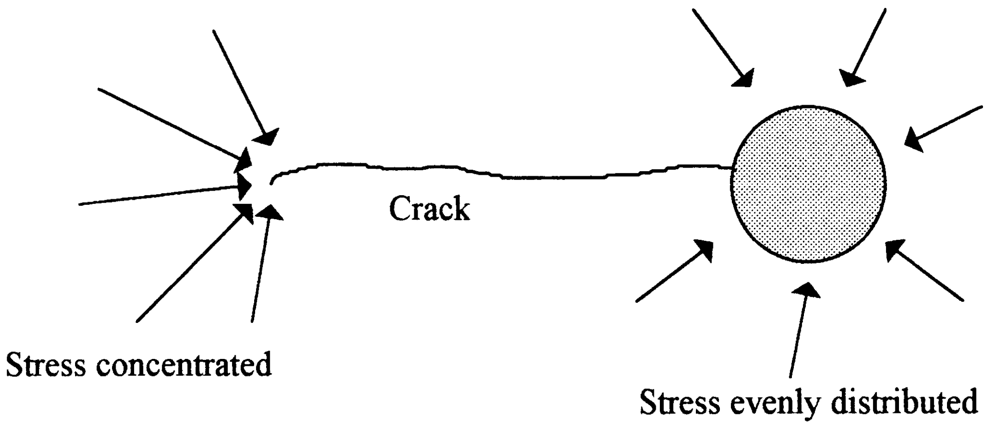


Figure 2.6 Stopper Hole (Crack Arrestor hole)

* Note: It should be noted that in order for stopper holes to be efficient, there would need to be a hole drilled at both ends of the crack.

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 seabed. 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.

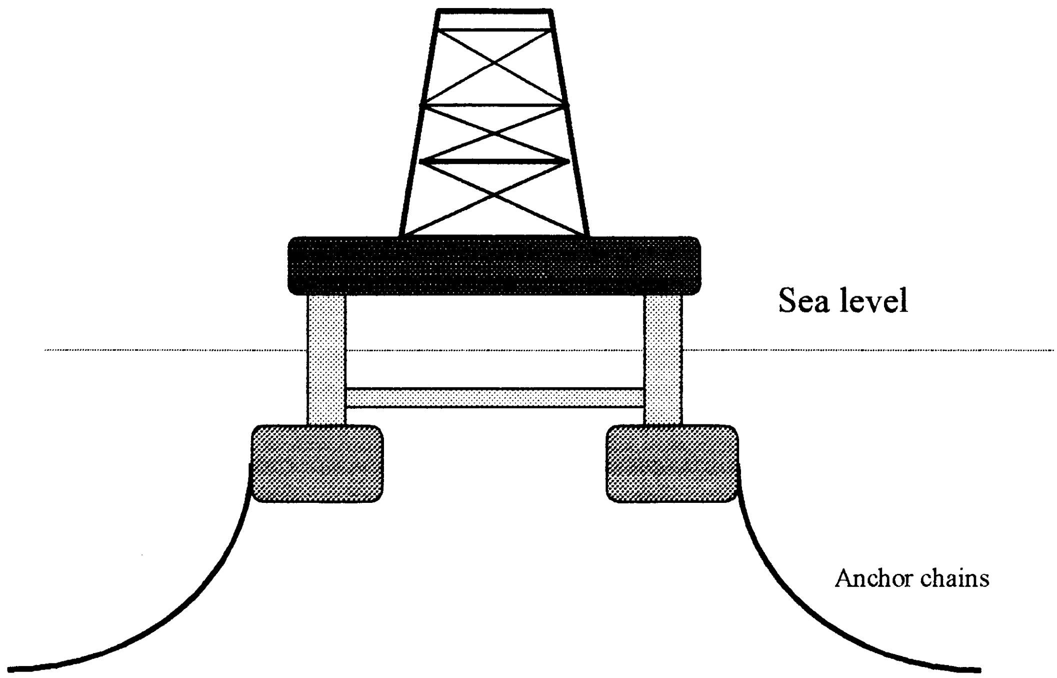


Figure 3.1 Semi-Submersible Drilling Rig

SEMI SUBMERSIBLE PRODUCTION PLATFORMS

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.

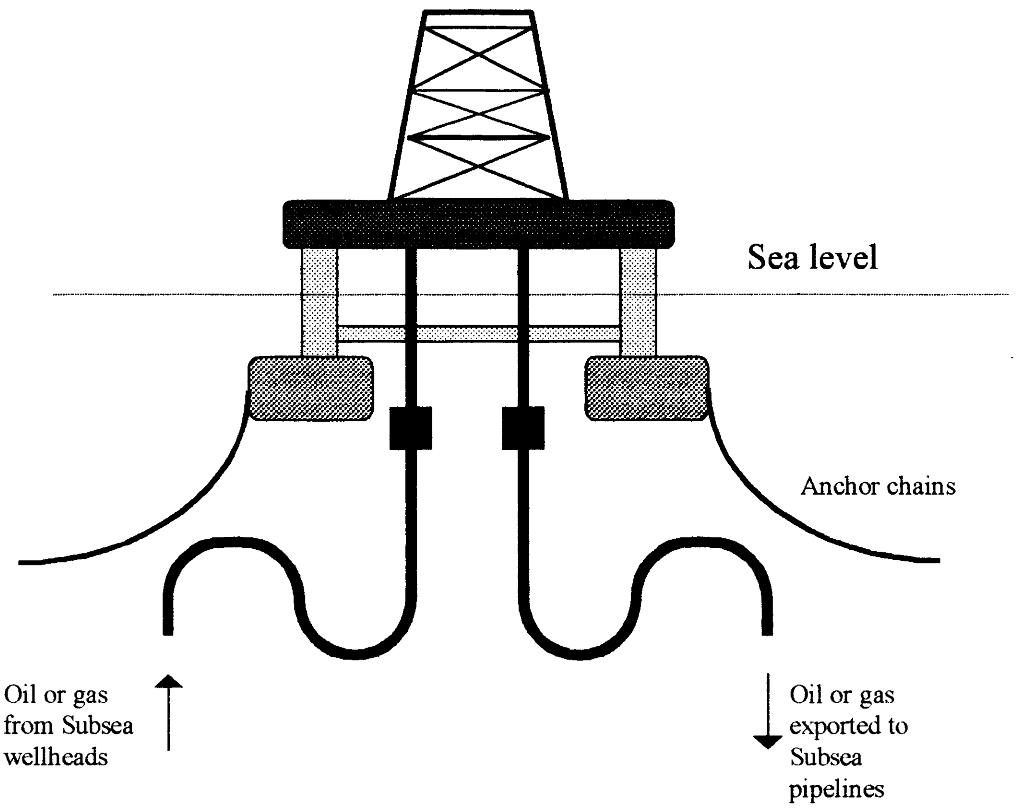


Figure 3.2 Semi-Submersible Production Platform

SELF-ELEVATING PLATFORMS (JACK UP DRILLING RIGS)

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.

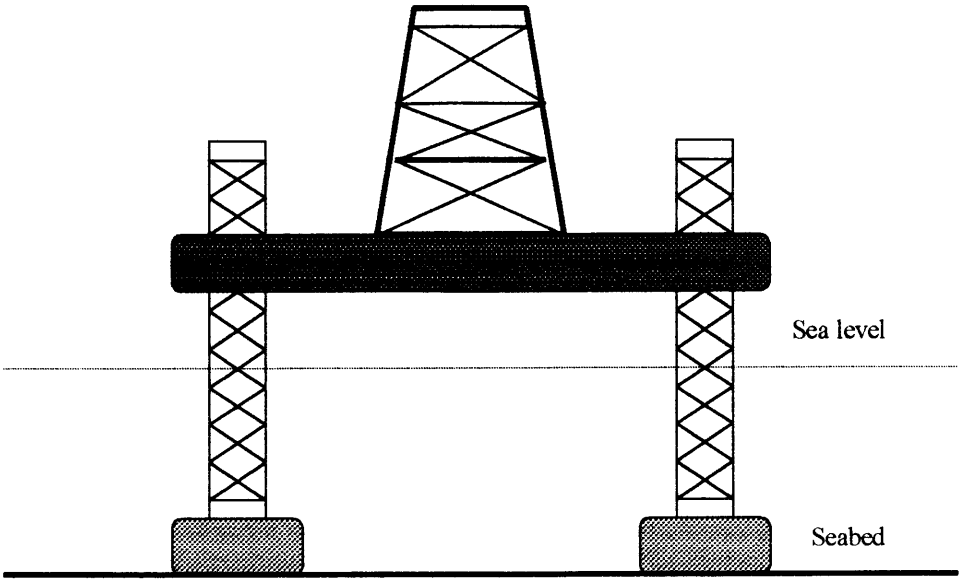


Figure 3.3 Self-Elevating Platform (Jack up rig)

TENSION LEG PLATFORMS (TLP)

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.

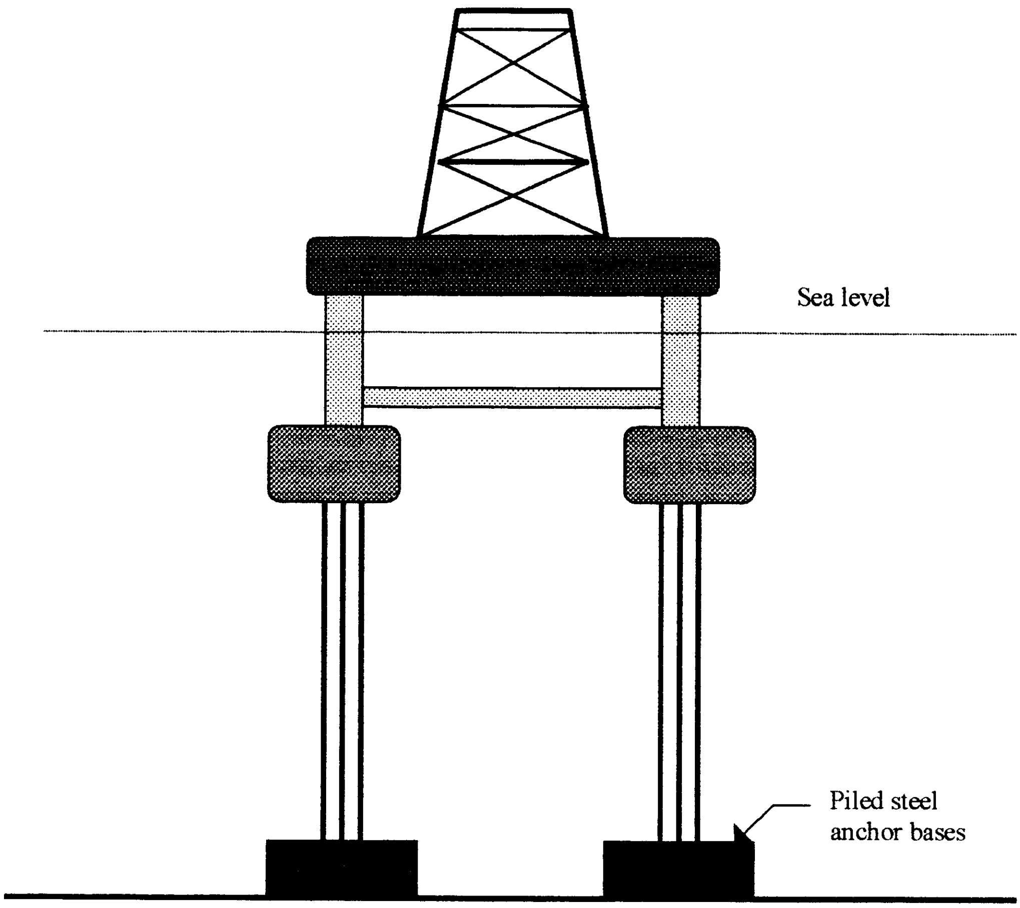


Figure 3.4 Tension Leg Platform (TLP)

PILED STEEL JACKETS

Most fixed production platforms in the North Sea are of the piled steel type. These platforms sit on the seabed 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.

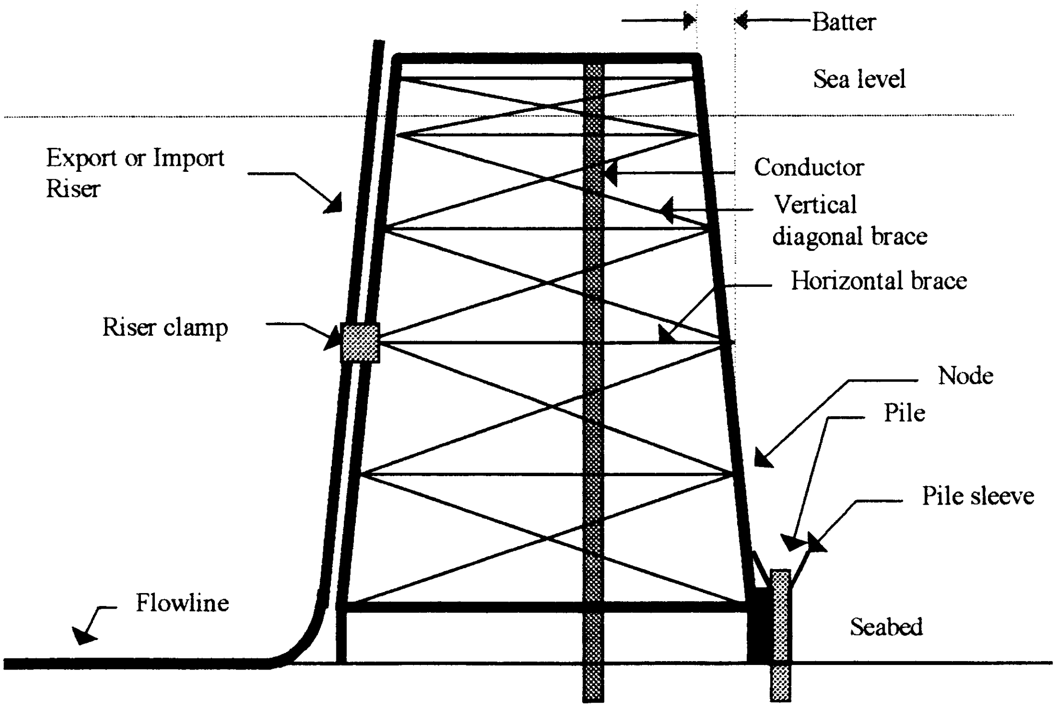


Figure 3.5 Steel Jacket

CONCRETE "GRAVITY BASE" 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.

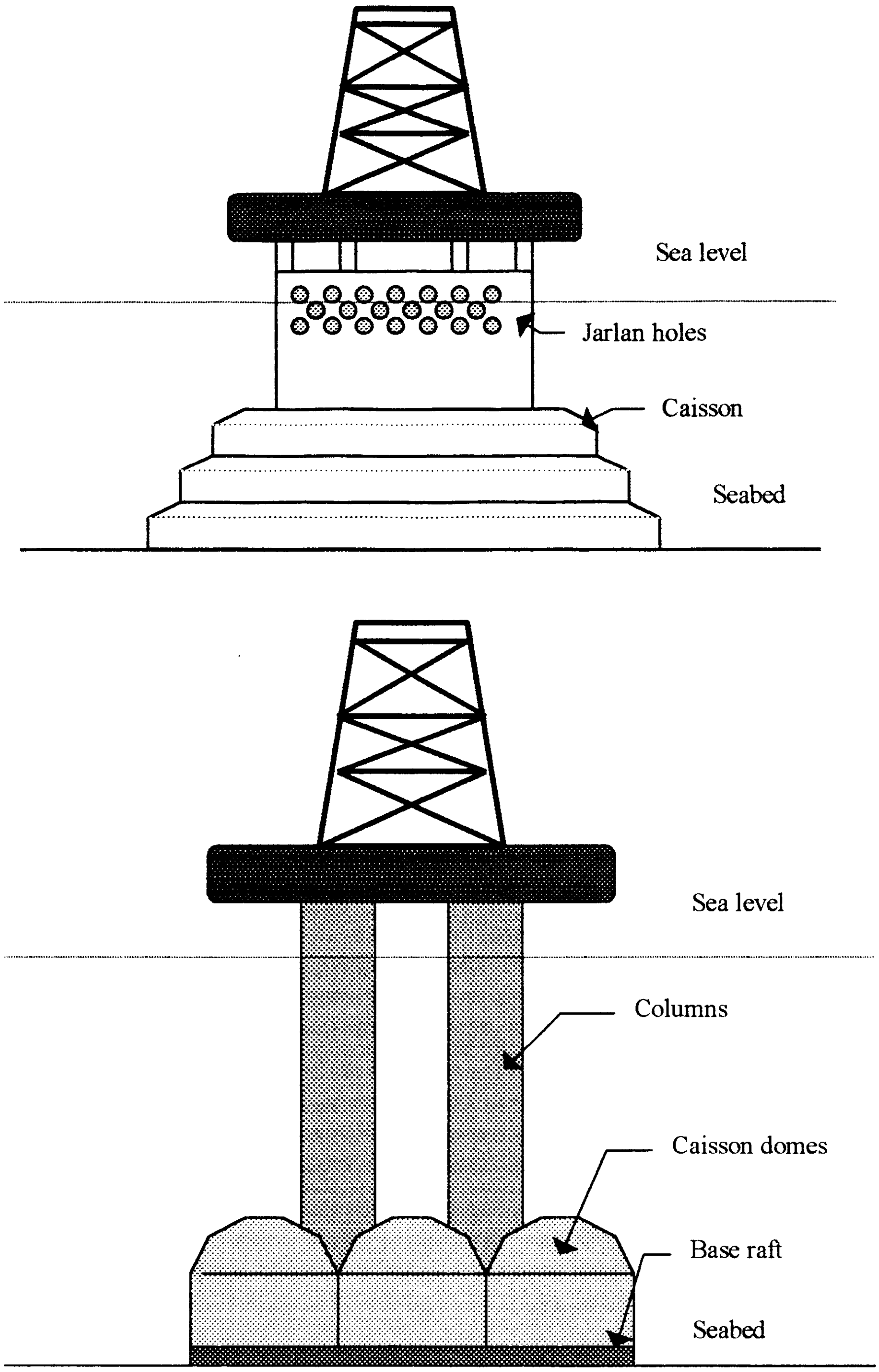


Figure 3.6 Concrete "Gravity Base" Structures

JARLAN WALLS

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.

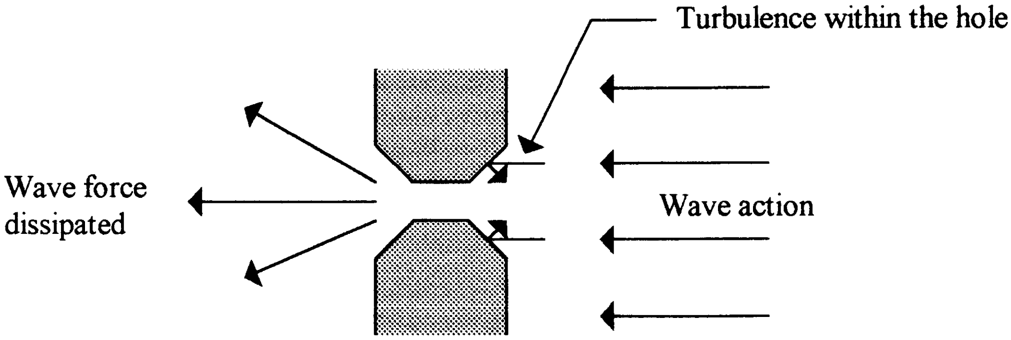


Figure 3.7 Jarlan Hole

FLOATING PRODUCTION STORAGE & OFFLOADING units (FPSOs)

FPSOs are converted tankers which are moored above small fields, and hooked up to the producing wells, these wells produce oil which is taken up to the FPSO through flexible Subsea risers. The produced oil is stored in the FPSO and from time to time a transfer tanker will come alongside to offload the oil and to transfer it a shore base.

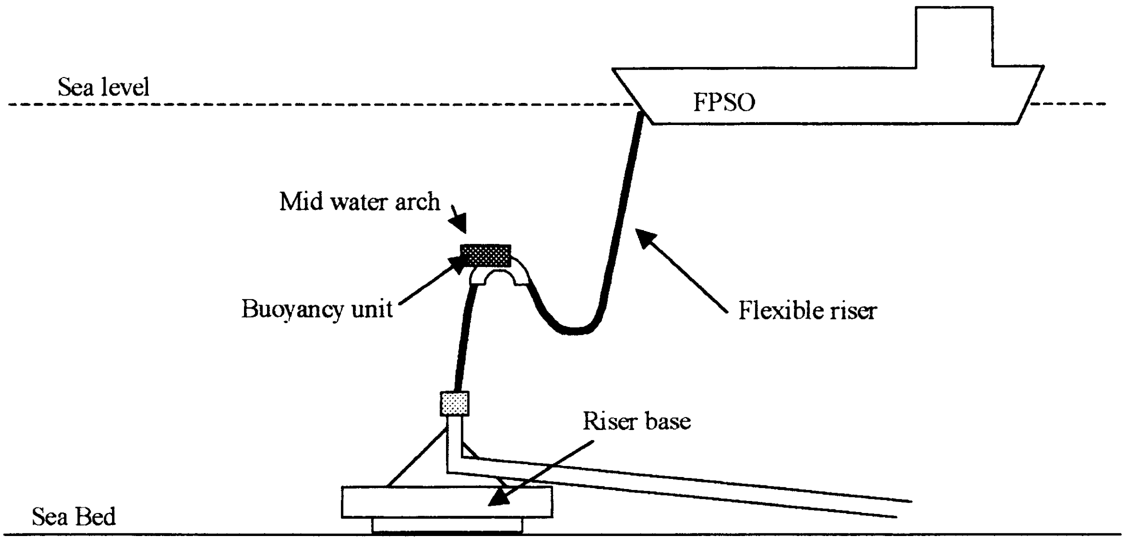


Figure 3.8 Floating Production Storage and Offloading unit (FPSO)

MID WATER ARCH

A mid water arch is a buoyancy device used to keep the lower part of a flexible riser in tension, it will prevent the riser from being laid onto the seabed during rise and fall of tide or wave action acting on the floating vessel.

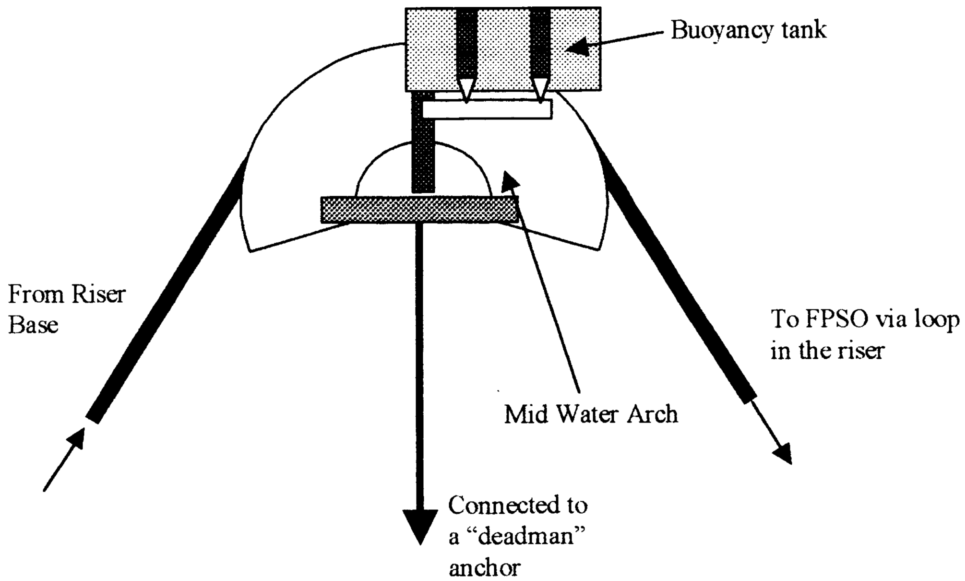


Figure 3.9 Mid water arch.

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.

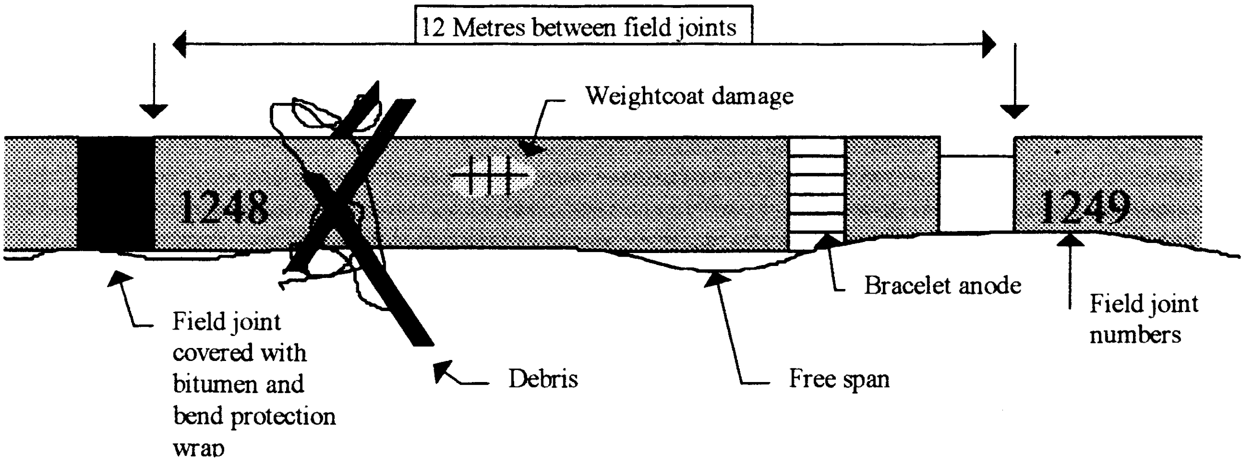


Figure 3.10 Pipeline

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.

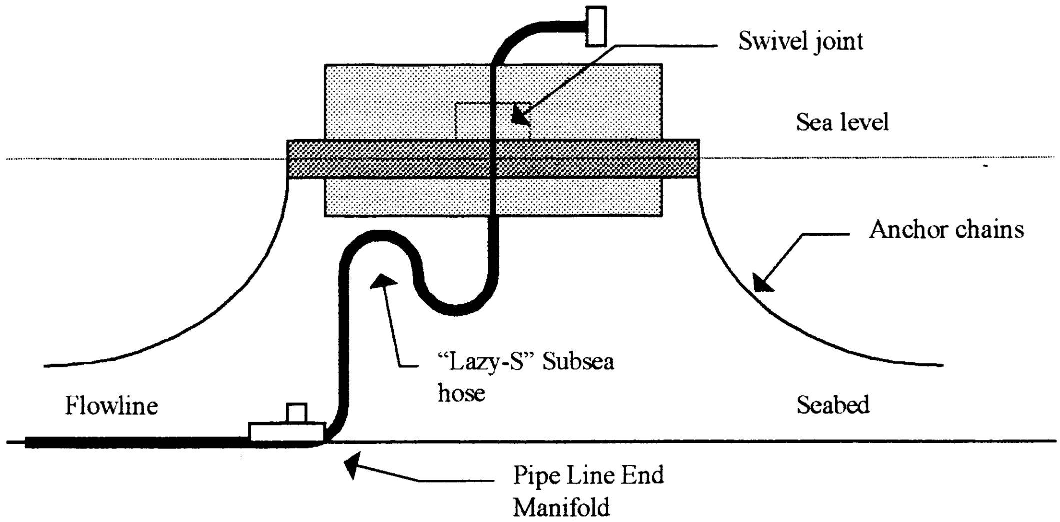


Figure 3.11 Single Buoy Mooring (SBM)

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.

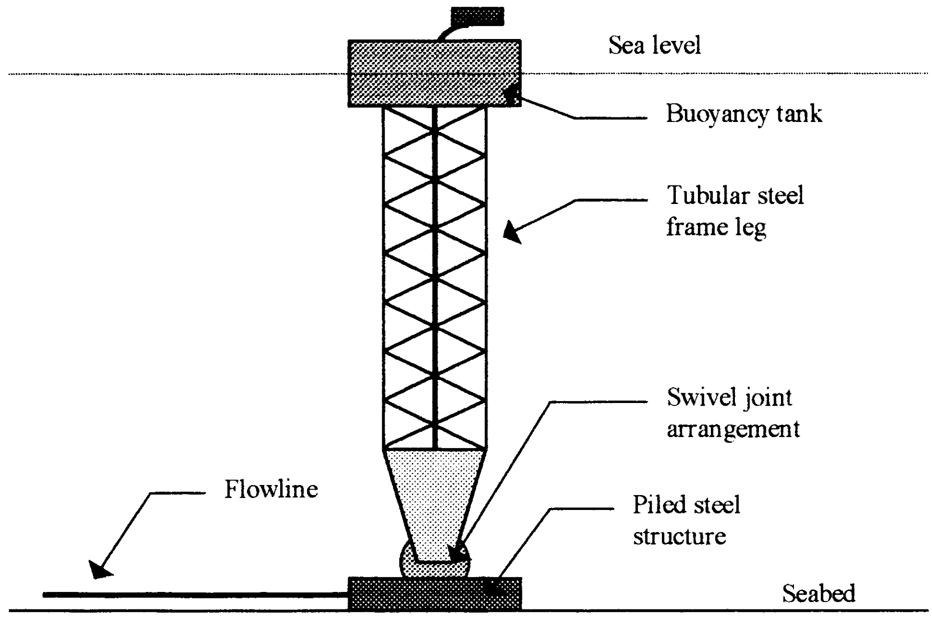


Figure 3.12 Single Anchor Leg Mooring (SALM)

SUBSEA COMPLETION AND EXPORT MANIFOLDS

Subsea completions 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 completions will be connected to the main platform via flowlines.

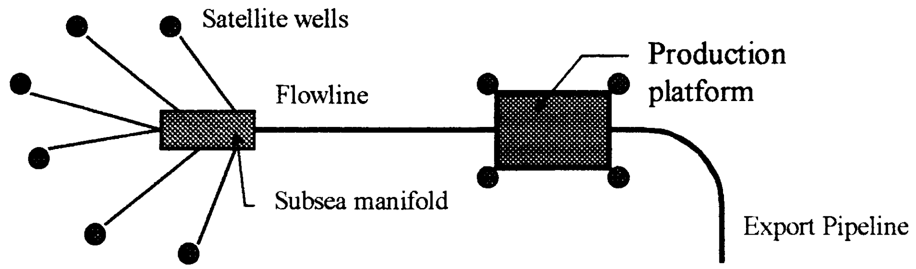


Figure 3.13 Subsea Completion

SUBSEA WELLHEAD (Christmas tree)

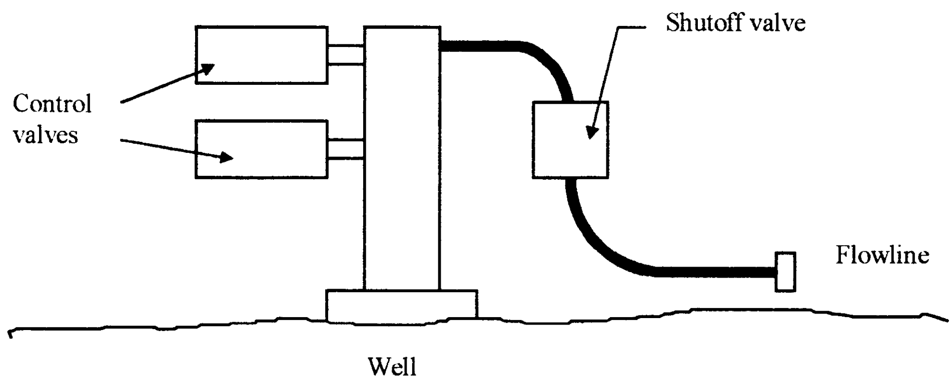


Figure 3.14 Subsea Wellhead

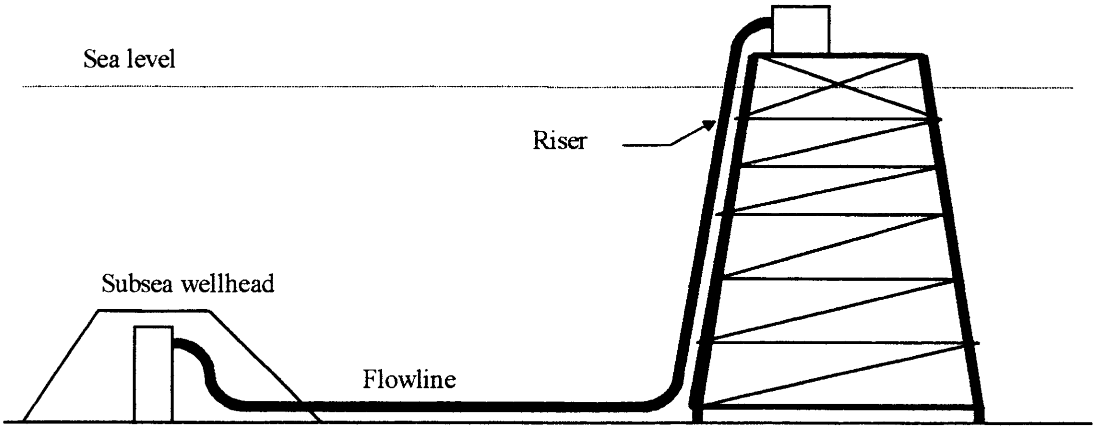


Figure 3.15 Subsea Completion Showing Flowline and Structure

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.

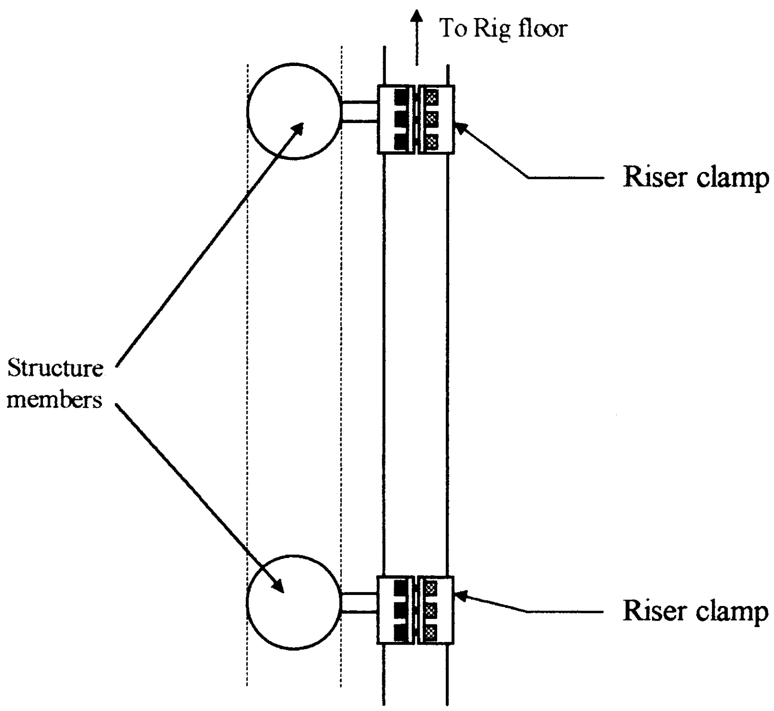


Figure 3.16 Risers

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.

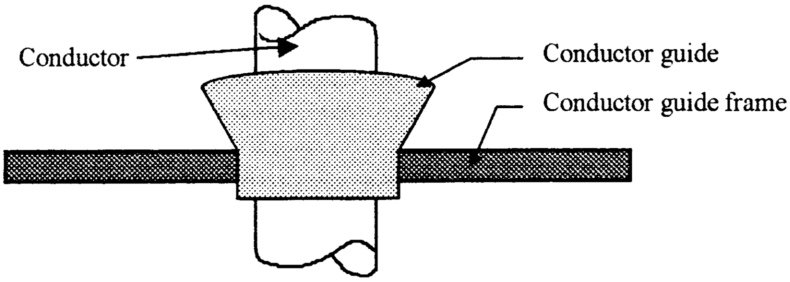


Figure 3.17 Conductor Guide Frame

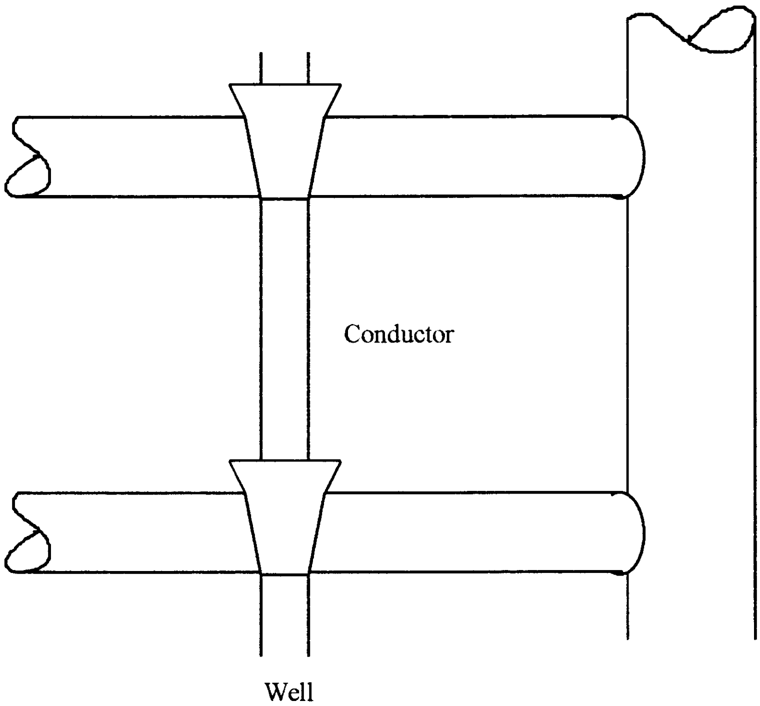


Figure 3.18 Conductor

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.

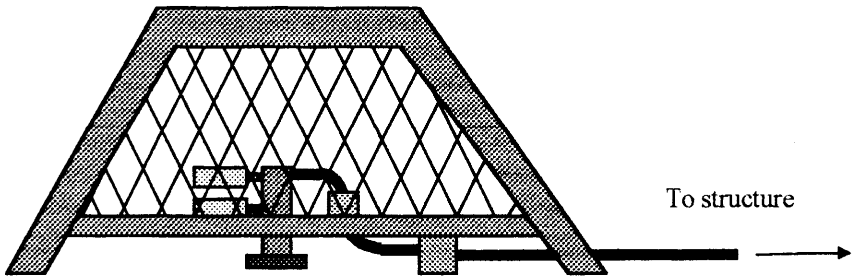


Figure 3.19 Subsea Wellhead Protection

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:

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.

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 seabed, which is the anchor point of the leg, thus the bending moment on the structure will increase.

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 <u>without prior cleaning</u>, 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, although this is limited and will decrease with depth.

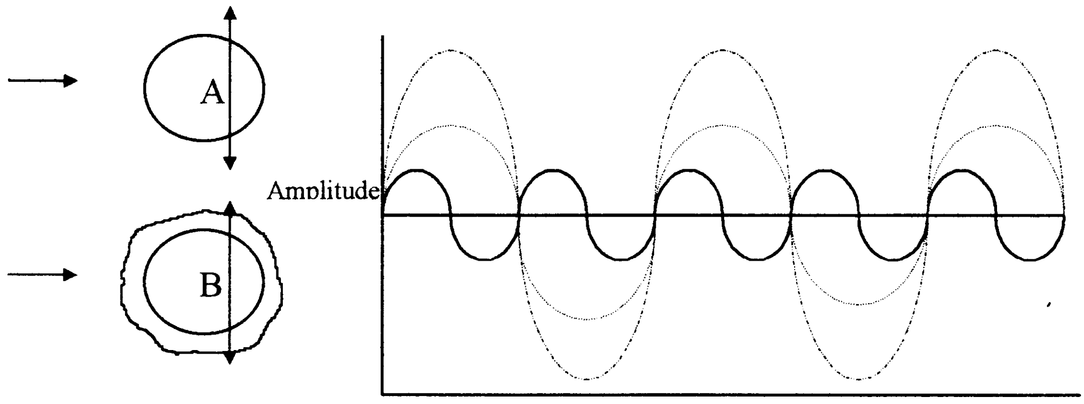
8 Increase the effects of wave slam in the splash zone

9 Increase the dead weight on the structure due to wave action.

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 seabed and so the bending moment will be increased.**

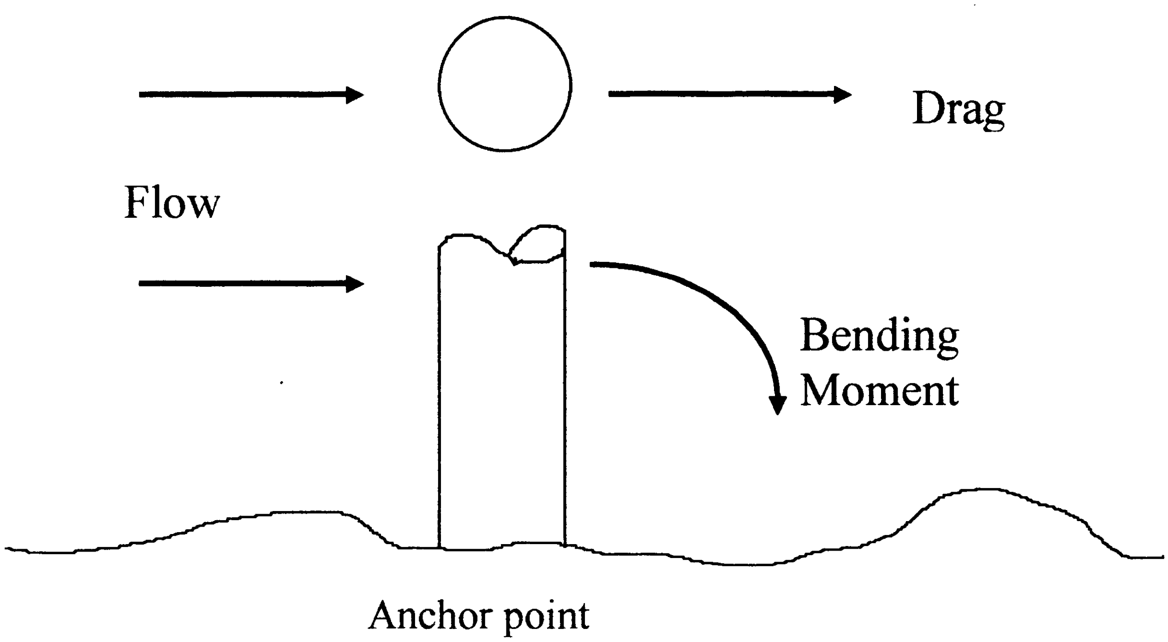


Figure 4.2 Drag and Bending Moments

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 "Morrisson" 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.

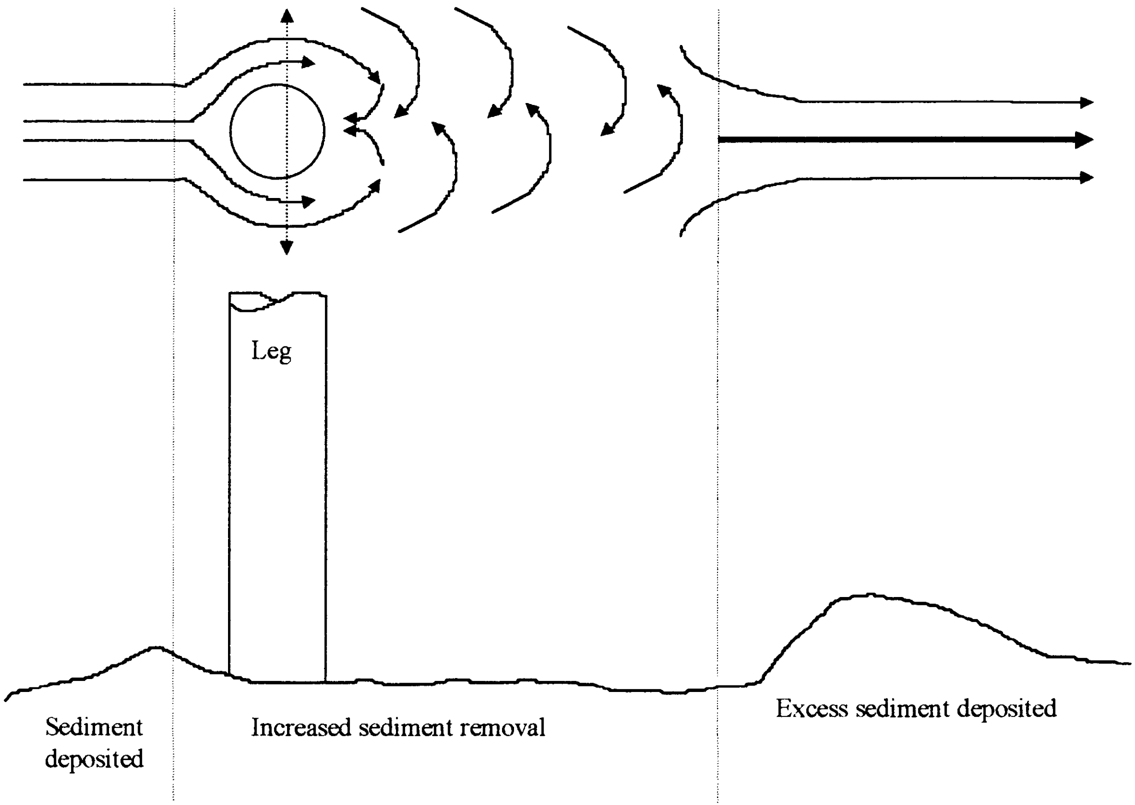


Figure 4.3 Drag and Scour

8 Increase the effects of wave slam in the splash zone

The result of increasing the size of the member in the splash zone 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 splash zone

The marine growth, which attaches in the splash zone, 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.

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 (Photic Zone)
iii) FOOD SUPPLY
iv) FLUID FLOW RATE
v) CATHODIC PROTECTION LEVEL
vi) SALINITY

TEMPERATURE

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. The depth to which light can penetrate seawater is known as the **Photic Zone.** As the depth increases so the amount of light available will decrease, this means that the flora (Plants) will not be able to photosynthesise food as effectively. This will limit the plant life, and this in turn will perhaps 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.

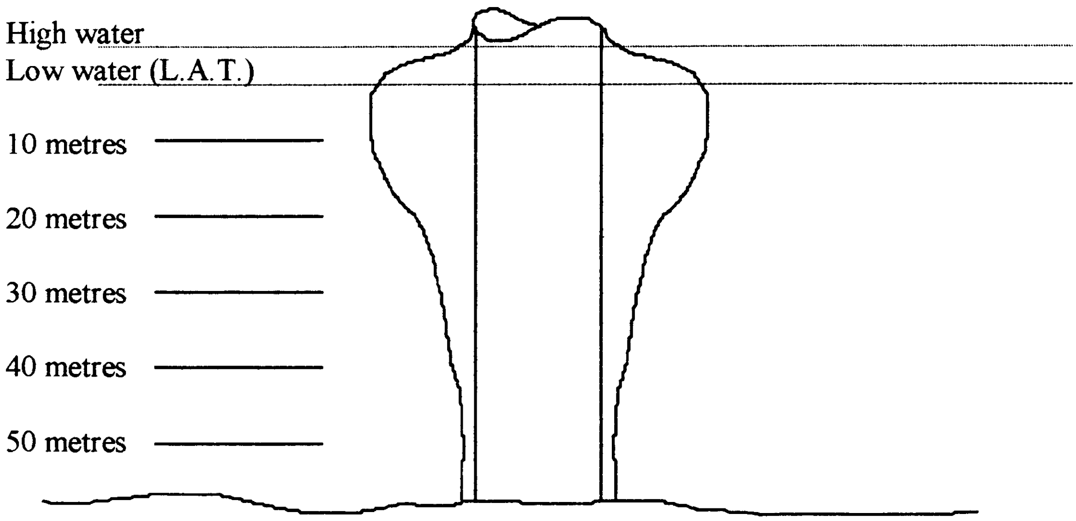


Figure 4.4 Accumulation of Marine Growth on an Offshore Structure

FOOD SUPPLY

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 this is not proven.

SALINITY

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.

- Tube worms (Pomatoceros)
- Mussels (Mytilus edulis)
- Barnacles (Balanus hameri)
- Hard corals (Caryophyllia)
- Bryzoa

Tube worms (Pomatoceros) - Maximum depth -100 metres

Description: Worms living in hard, white, calcareous tubes. Normally these will be 3 - 5 cm long it should be reported as "Tubeworms", either "isolated or extensive"

Hard corals (Caryophyllia) - Maximum depth -40 metres

Description: Single or branching calcareous growths, hard and stony, firmly attached to the surface. Reported as "Hard Coral", and describe abundance as "Isolated or Extensive"

Barnacles (Balanus hameri) - Maximum depth -120 metres

Description: Hard, white and sharp-edged growths tapering from the base and firmly attached to the surface. A pair of plates, which cover feathery structures, which beat the water, protects the top of the barnacle. Reported as "Barnacle", describe the abundance as "Isolated or Extensive"

Mussels (Mytilus edulis) - Maximum depth -20 metres

Description: Blue-Black glossy shells up to 10cm long and attached to the surface of the structure by means of "Bysall threads". Reported as "Mussels". It is essential to note if mussel layer is one individual thick or more than one layer thick.

Bryzoa - Maximum depth -1000 metres

Description: Colonial organisms that occur as thin, flat encrusting forms, or as erect leaf-like colonies, or as calcareous coral-like structures. Reported as "Bryzoans", describe abundance as "Isolated or Extensive".

2 SOFT GROWTH

This is made up of a large number of animals as well as the plant life which may be expected, the following are just a few examples:

- Alagae — Soft slime
- Seaweed's — Kelp, Thongweed & Bladder Wrack
- Deadmans fingers — Soft white fleshy growths
- Soft Corals — Soft covering to the structure
- Sponges — Filter feeding animals
- Hydroids — Plant like animals
- Anemones — "Flowering" animals
- Sea Squirts — Filter feeding animals

Algae - Maximum depth -20 metres

Description: Soft slime covering to the structure, may colonise within half an hour of cleaning the structure. Reported as "Algal Slime".

Seaweeds:

Kelp (Laminaria) - Maximum depth -30 metres

Description: Large, greenish-brown Seaweeds, firmly attached by a strong "Stalk" and complicated root-like holdfast. Reported as "Kelp", and give information on numbers and approximate length of individuals.

Thongweed - Maximum depth -30 metres

Description: Large, Olive-brown seaweed, like a bunch of narrow, divided straps which grow up to about 1m in length, each plant growing from a small "Button or Mushroom" 2.5 or 3cm in diameter. Report as "Thongweed", and give some indication of numbers and density.

Bladder Wrack (Ascophyllum) - Maximum depth -30 metres

Description: Tough, leathery, brown seaweed of various shapes, normally in bunches with "Bladders". Length will be 30 to 60cm. Reported as "Wrack", and give some indication size, numbers and density.

Deadmans fingers (Alcyonium) - Maximum depth -150 metres

Description: Soft coral, fleshy lobed growth, white, up to 20 cm long with polyps extending from the main part. Reported as "Soft Coral", describe abundance as "Isolated or Extensive".

Soft Corals (Alcyonium) - Maximum depth -6000 metres

Description: Soft coral, fleshy, white, Pink or Orange growths extending across the structure with polyps extending from the main part. Reported as "Soft Coral", describe abundance as "Isolated or Extensive".

Sponges - Maximum depth -1000 metres

Description: Patches of soft, coloured tissue spreading over and adhering to the surface, variable colour and size, usually irregular in shape and penetrated by many holes. Reported as "Sponges", describe abundance as "Isolated or Extensive".

Hydroids (Tubularia) - Maximum depth -1000 metres

Description: Small plant-like colonial animals, forming feathery or flower-like growths usually no more that 5cm high. Easily recognised as a mass of thin, pale stalks, which in summer bear obvious pink flower-like heads. Reported as "Hydroid", describe abundance as "Isolated or Extensive".

Sea Anemones (Metridium, Tealia) - Maximum depth -1000m

Description: Soft columnar growths, each with a circle of tentacles, which withdraw when, touched. Reported as "Anemone", describe abundance as "Isolated or Extensive".

Sea-Squirts (Polyps) - Maximum depth -80 metres

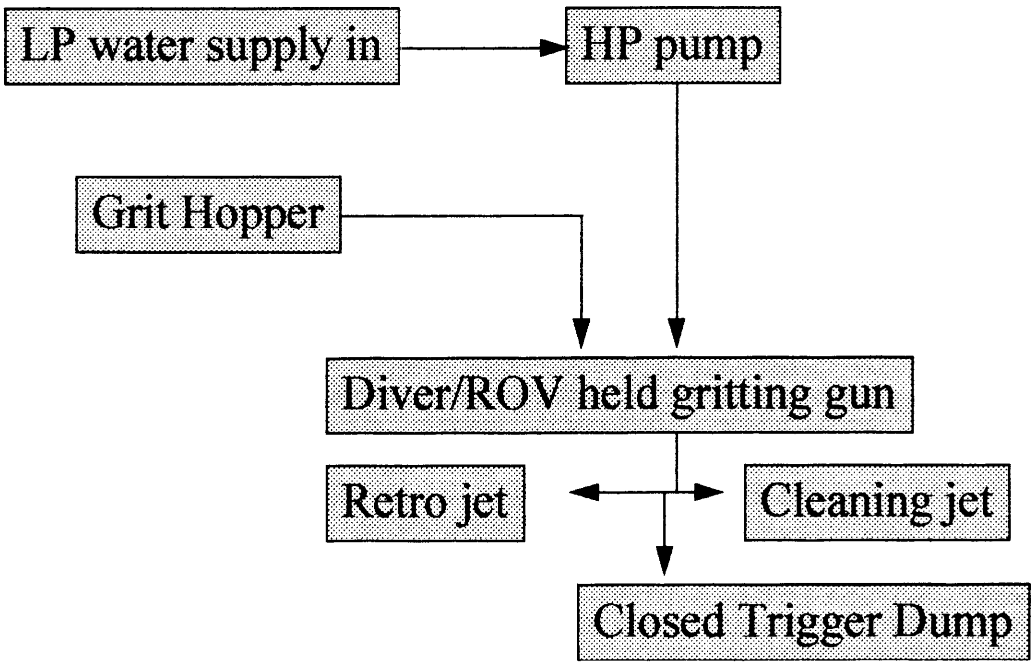
Description: Solitary or colonial animals, Fine almost transparent tubes standing about 100mm high, with 2 circular openings, they are filter feeding animals. Reported as "Sea-Squirts", describe abundance as "Isolated or Extensive".

METHODS OF MARINE GROWTH REMOVAL

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	Depth limitation, difficult to control, exhaust air causes problems and there is a high maintenance requirement, 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	Hazardous, polished finish, reflects light in CCTV/Photography
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
Marine growth inhibitors (Antifouling & Henderson Rings)	No diver intervention after installation	may only work 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.

Layout of HP Jetting system + Grit



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 Km/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

STANDARDS OF SURFACE FINISH

The system, which has generally been adopted in the North Sea, is an adaptation of a Swedish standard originally used for the assessment of blast cleaning of steel prior to painting. **ISO 8501-1** defines this standard.

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

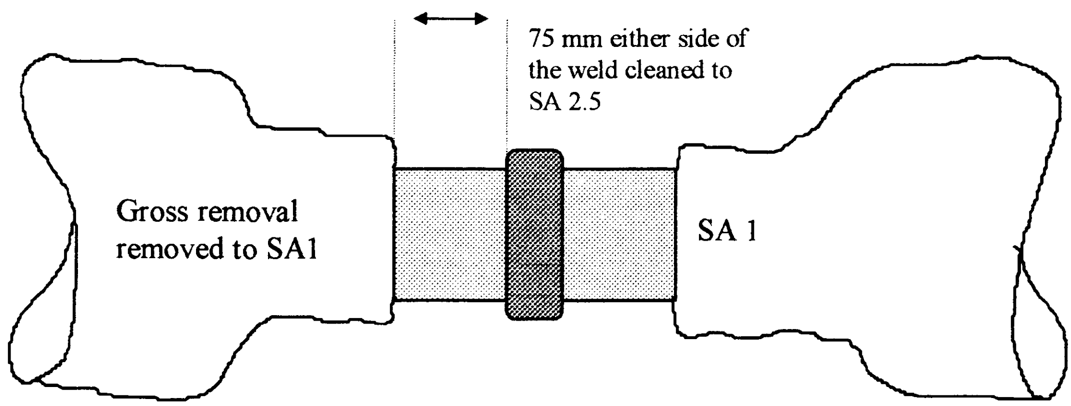
SA 2 - Cleaning to paint coat including removal of loose paint and corrosion products.

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. This finish is sometimes termed **Stippled**.

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.



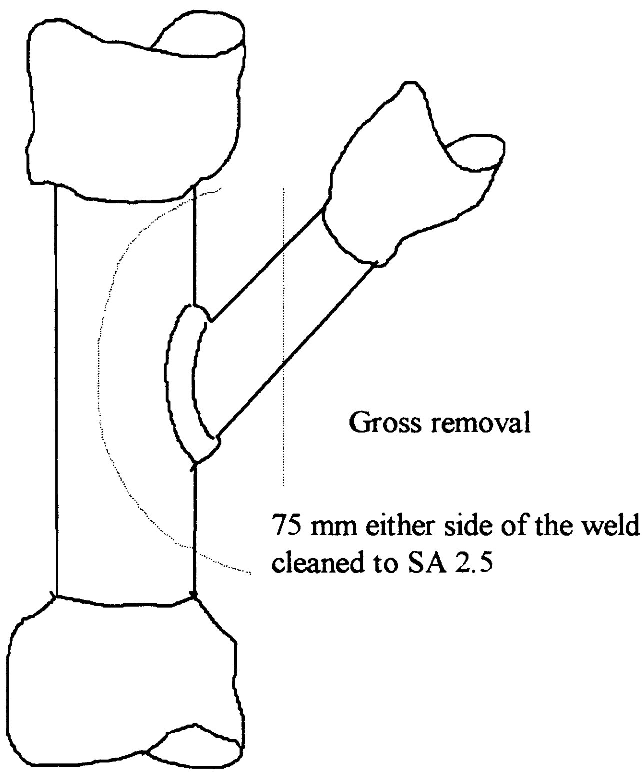


Figure 4.5 Cleaning of a Nodal Structure

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.
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
g) 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 consist 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.

Vortex Shedding Around a Flowline

If there is a current flow across a flowline or pipeline, this will cause vortices to be shed behind the pipe as shown below (fig 5.1). The effect of this will be to cause the downstream side of the pipe to be undermined as seabed material is removed, this could lead to "Free spans" which must be located and logged.

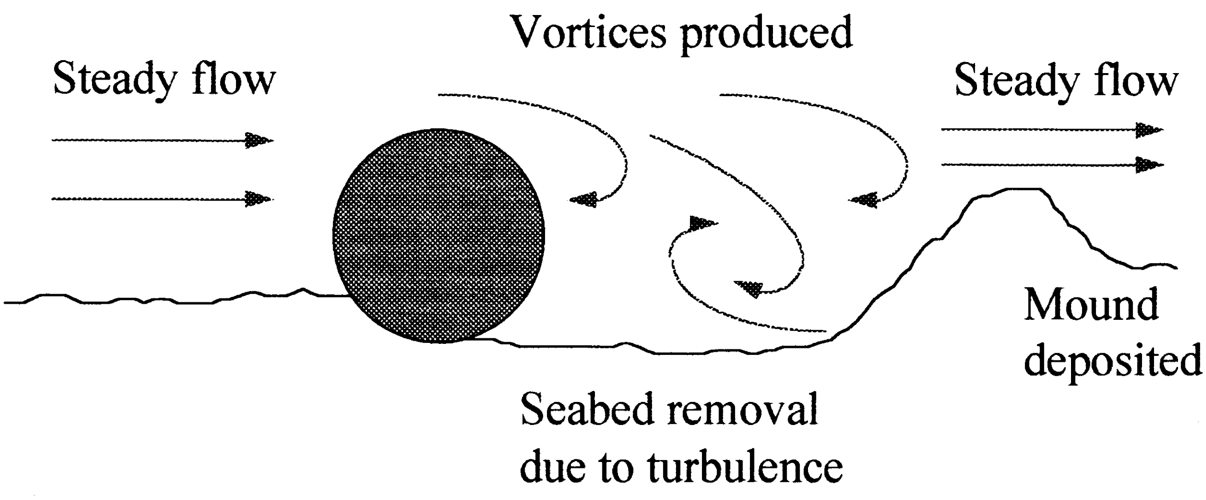


Fig 5.1 Vortex shedding past a horizontal pipe.

6. METAL AND INTERNAL WELD DEFECTS (BS 499 {BS EN ISO 6520-1})

British Standard 499 (BS EN ISO 6520-1) groups internal metal and weld defects into the following six categories:

1. **Cracks** - Fracturing of the material.

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

6. **Miscellaneous** - Such as arc strikes 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 un-repaired. 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 kinds 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).

CHAPTER 6

Inspection Of Concrete Structures

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 cannot 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.

NB **Cement is a mixture of chalk, limestone, shale or clay 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.

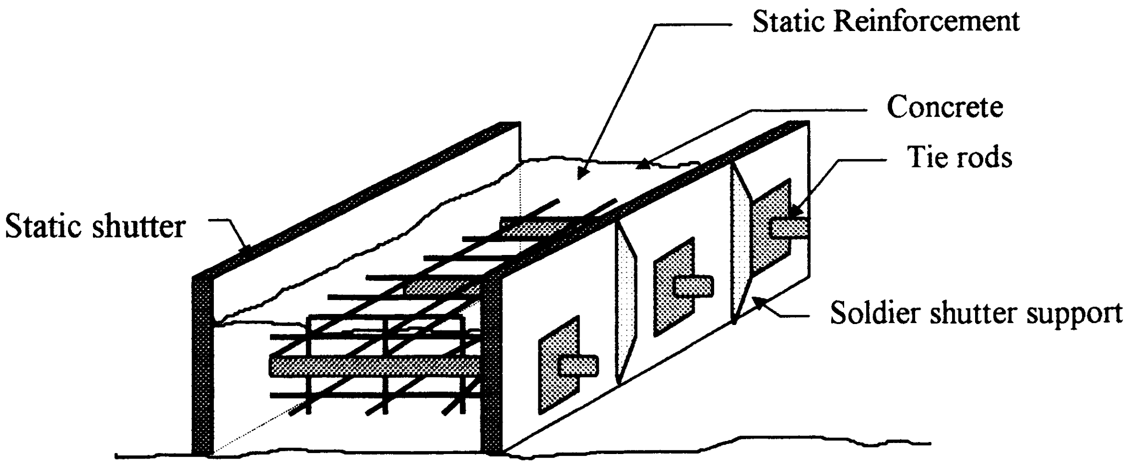


Figure 6.1 Concrete Formwork (Static Shuttering)

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).

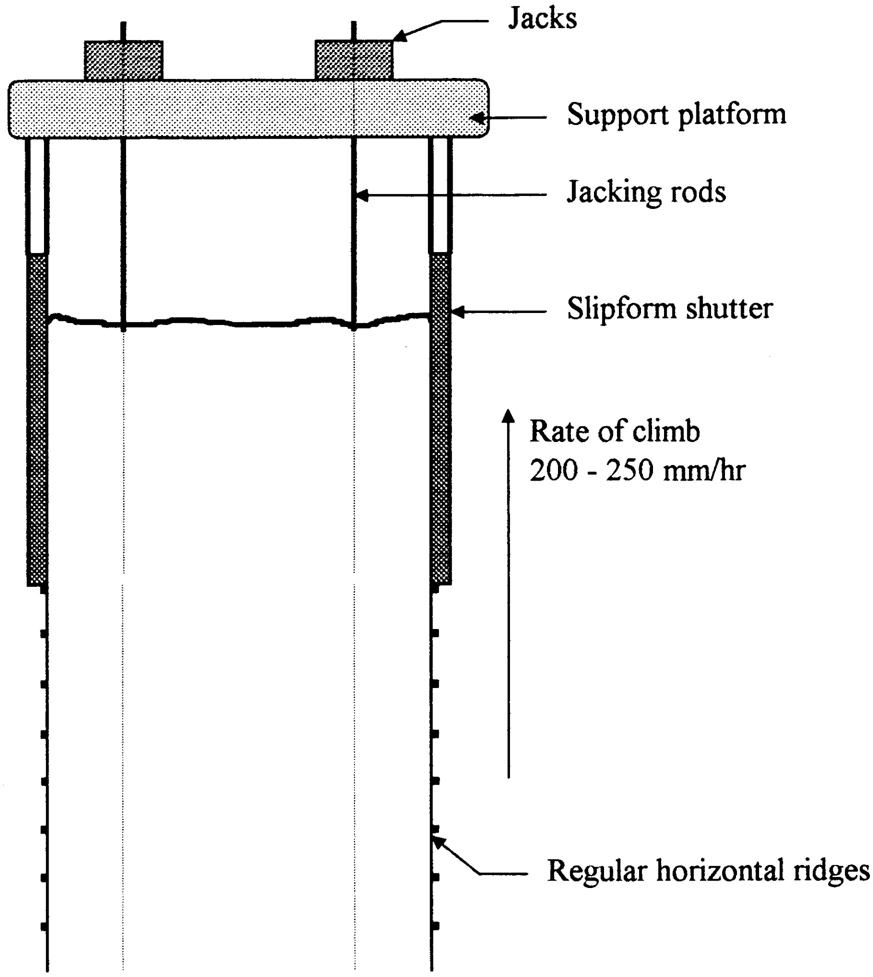


Figure 6.2 "Slipform" Shuttering

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

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.

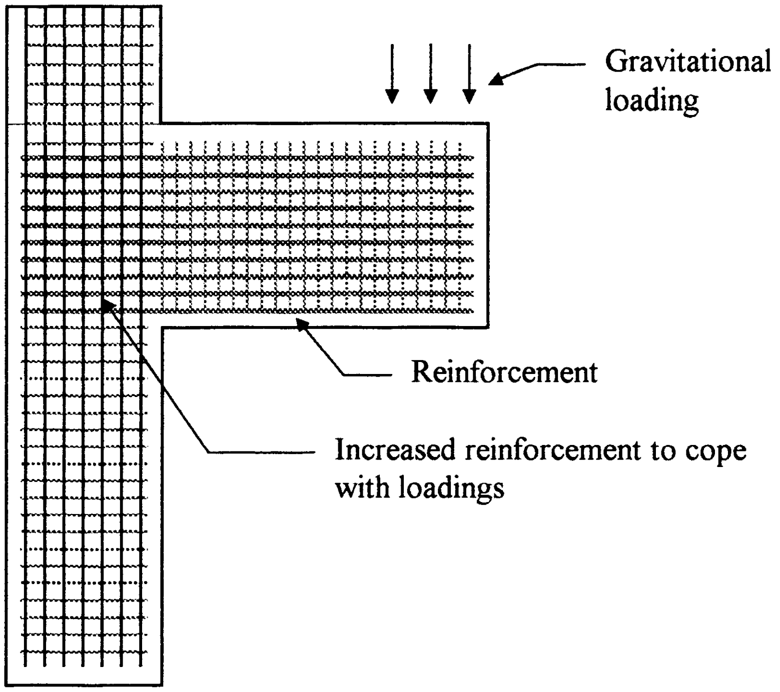


Figure 6.3 Static Reinforcement (Re-bar)

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, and 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.

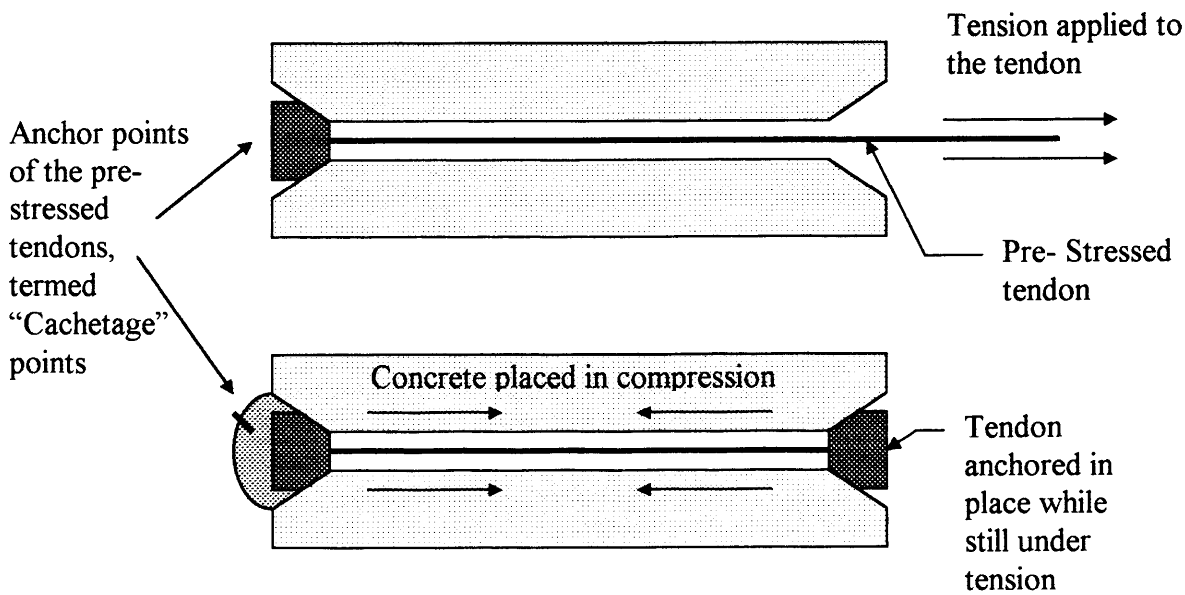


Figure 6.4 Pre-Stressed Concrete Reinforcement

The Protection of the Reinforcing Cage

Concrete is a porous substance and as such it will allow a certain ingress of seawater 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.

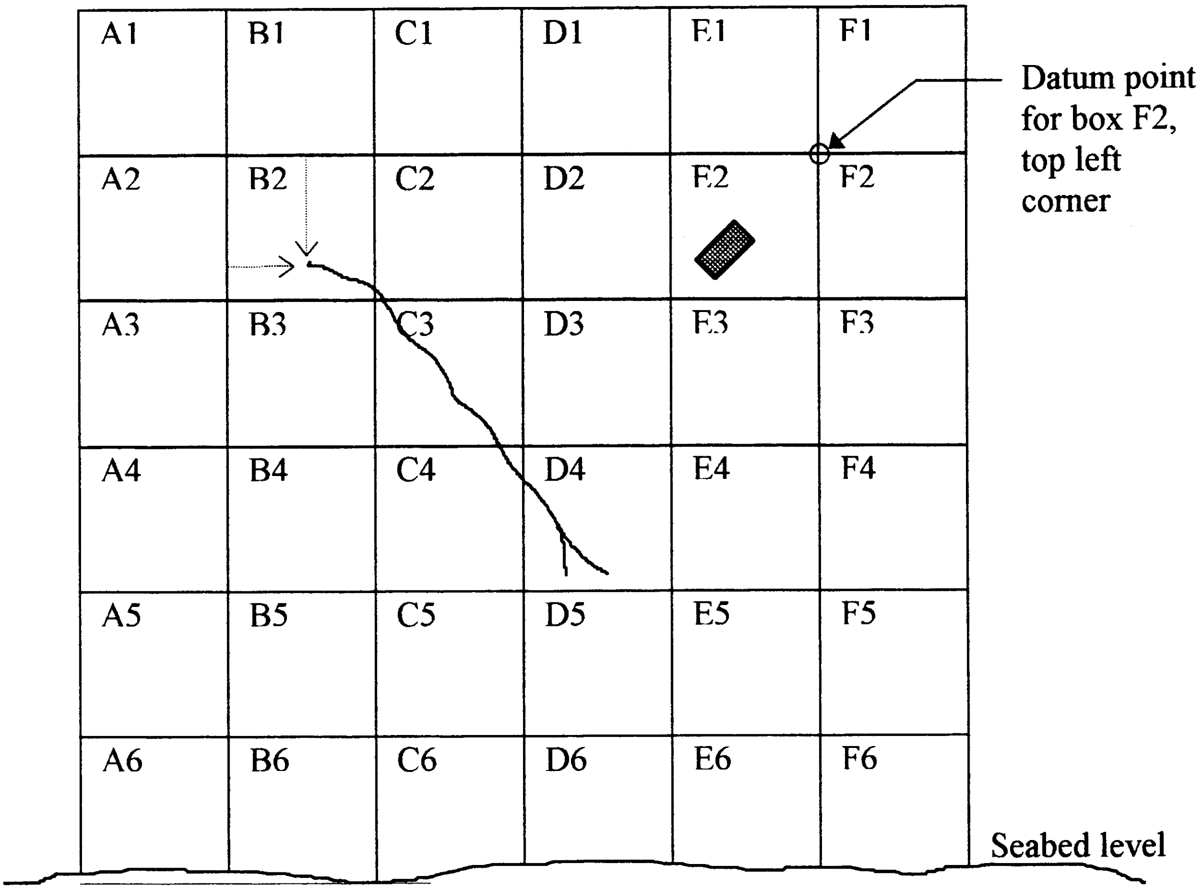


Figure 6.5 The Grid System

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.

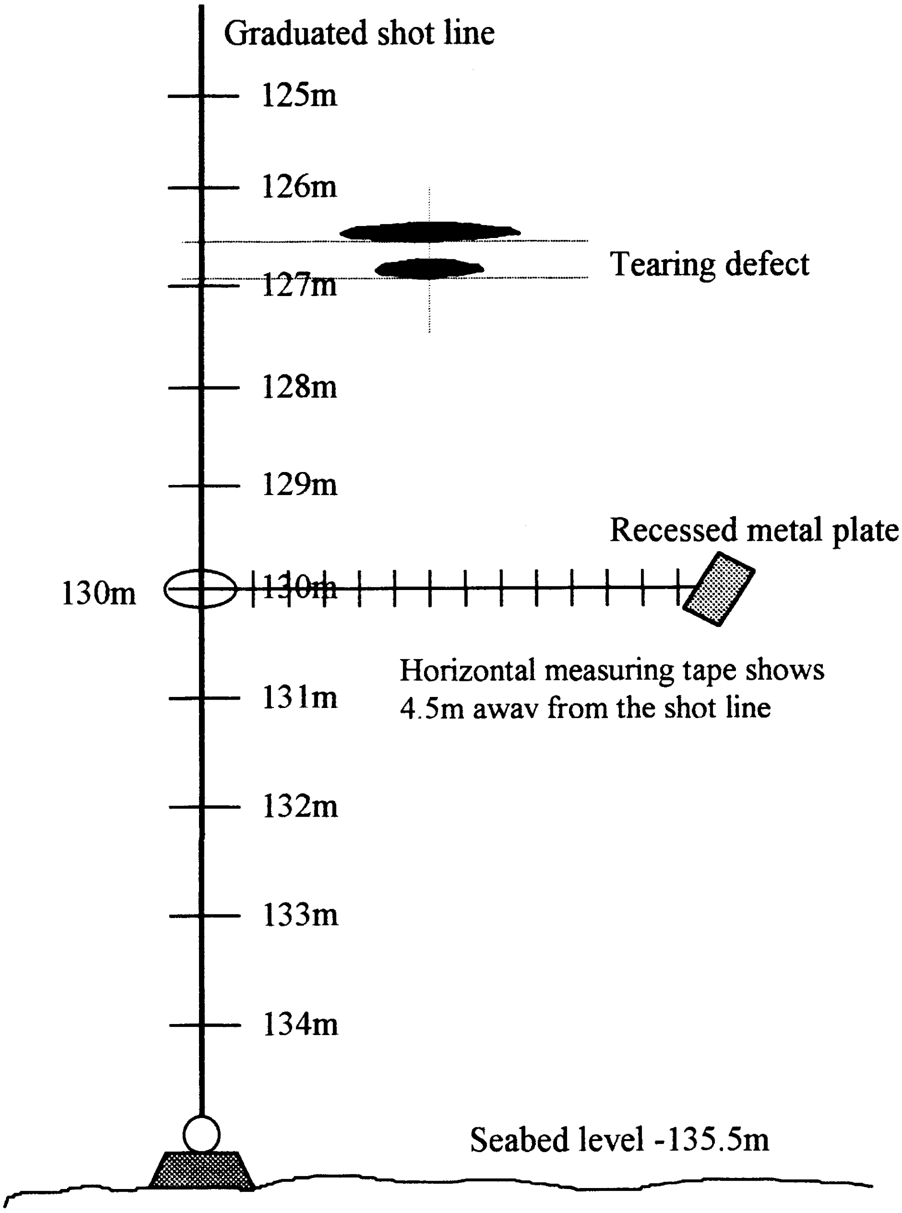


Figure 6.6 Shot Line and Tape System

3. Hydro-Acoustic Position Referencing Systems (HPR)

Hydro-Acoustic Position Referencing Systems (HPR) involve the use of transponders placed at intervals around the structure, the ROV or diver will be fitted with a positioning transponder, these transponders can then be used to accurately position the vehicle or diver on the face of the structure. The transponders use ultrasound to communicate with each other and this can be a very accurate method which is easily employed and as such is the most likely method to be used.

TERMINOLOGY

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

CATEGORY A (DEFECTS):

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

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):

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

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

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 its 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.

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 seawater 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, which has occurred during the construction phase and has been repaired badly.

8. VARIABLE COVER

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 too high, or by the use of a jet which is too small.

Water jet damage will occur in-service.

5. ABRASION

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 will be caused by movement of hard objects against the concrete wearing away (abraiding) the surface of the concrete. This is normally an in-service problem.

6. HONEYCOMBING

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 seawater 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 below the shutters.

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.

Therefore 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.

General Terms Applied to Concrete.

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

Grout is a 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

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

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, The Following Is A List Of Required Information:

1 - All Defects, Areas of Concern and Blemishes Must Be Reported Using Correct Terminology.
2 - Length Of Defect Must Be Reported Accurately.
3 - Width Of Defect Must Be Reported Accurately.
4 - Depth Defect Extends Into The Concrete Must Be Reported Accurately.
5 - Position of The feature According To The Marking Procedure In Use.
6 - Staining Evident On The Surface Of The Concrete.

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 seabed 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 too 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 effects of the environment on concrete and could be said to be the equivalent of 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
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

Description	Title
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	Surface seal to construction joint
Smooth coloured band around a Built-in item	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

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) Gas shielded arc-welding techniques
3) Friction welding

1) FLUX SHIELDED ARC TECHNIQUES

These can be split into a further three groups:

a) Manual Metal Arc (MMA).
b) Automatic Metal Arc.
c) Submerged Arc.

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.

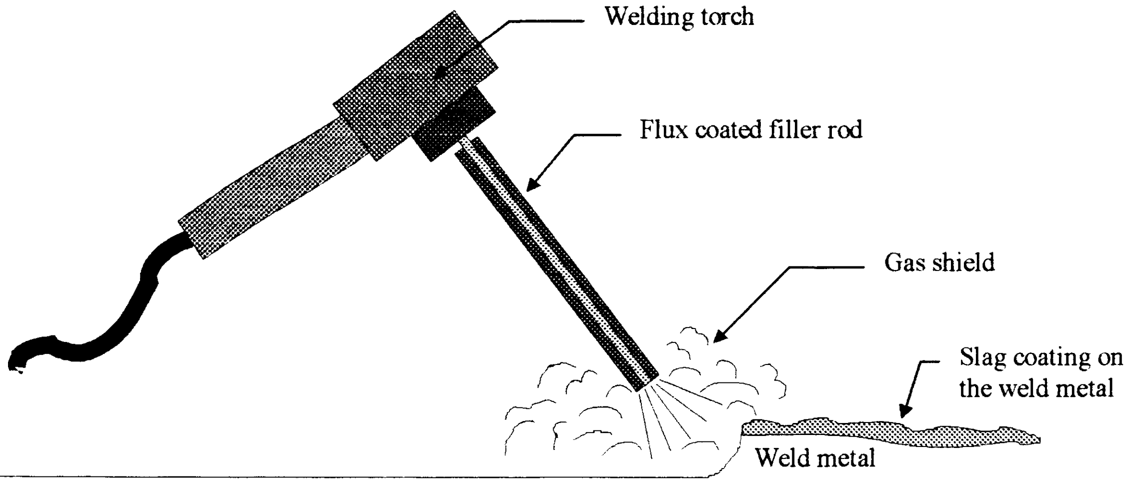


Figure 7.1 Manual Metal Arc Welding

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.

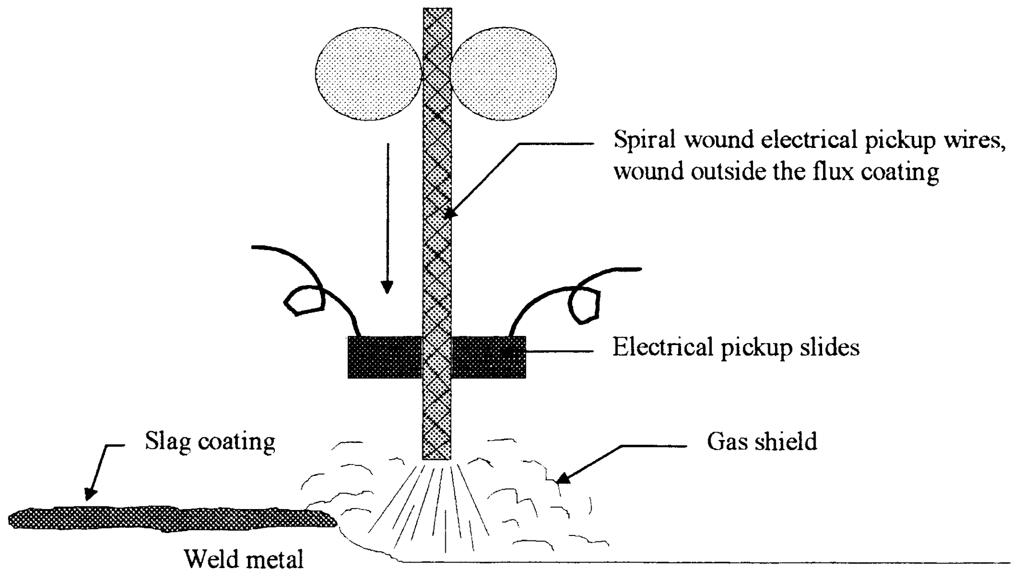


Figure 7.2 Automatic Metal Arc Welding

c) Submerged Arc

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.

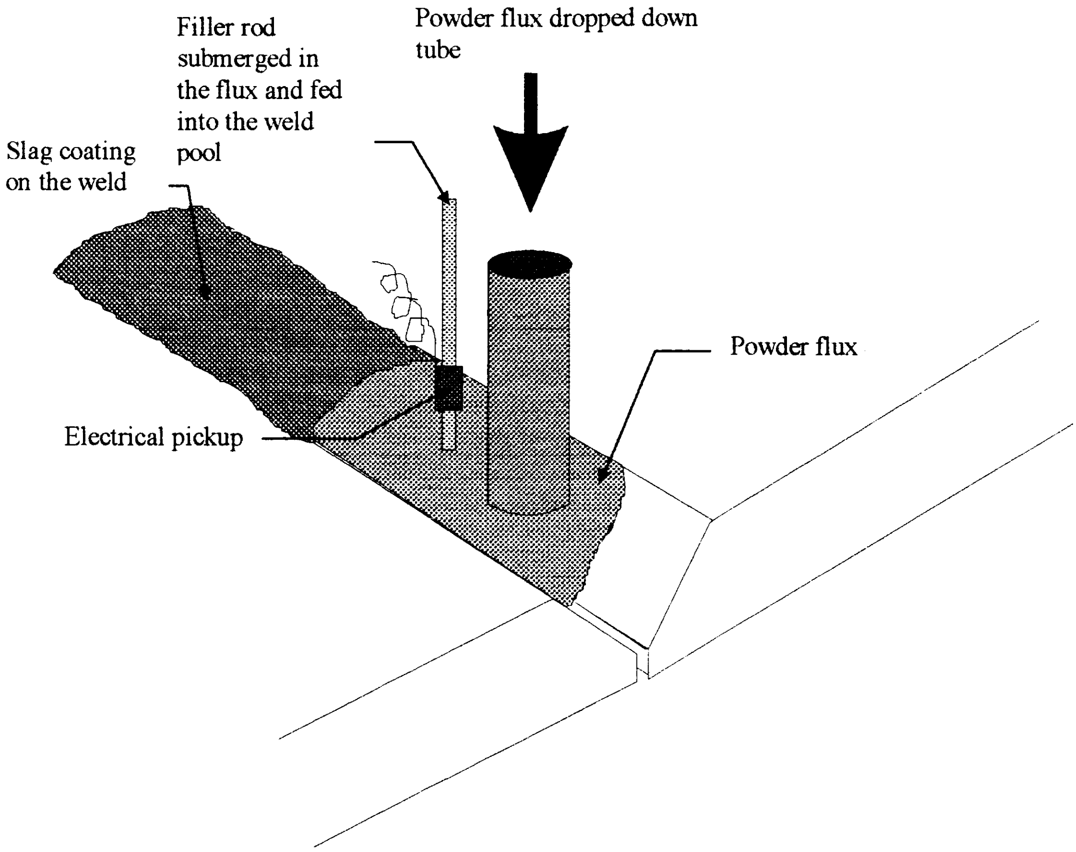


Figure 7.3 Submerged Arc Welding

2. GAS SHIELDED ARC WELDING 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

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.

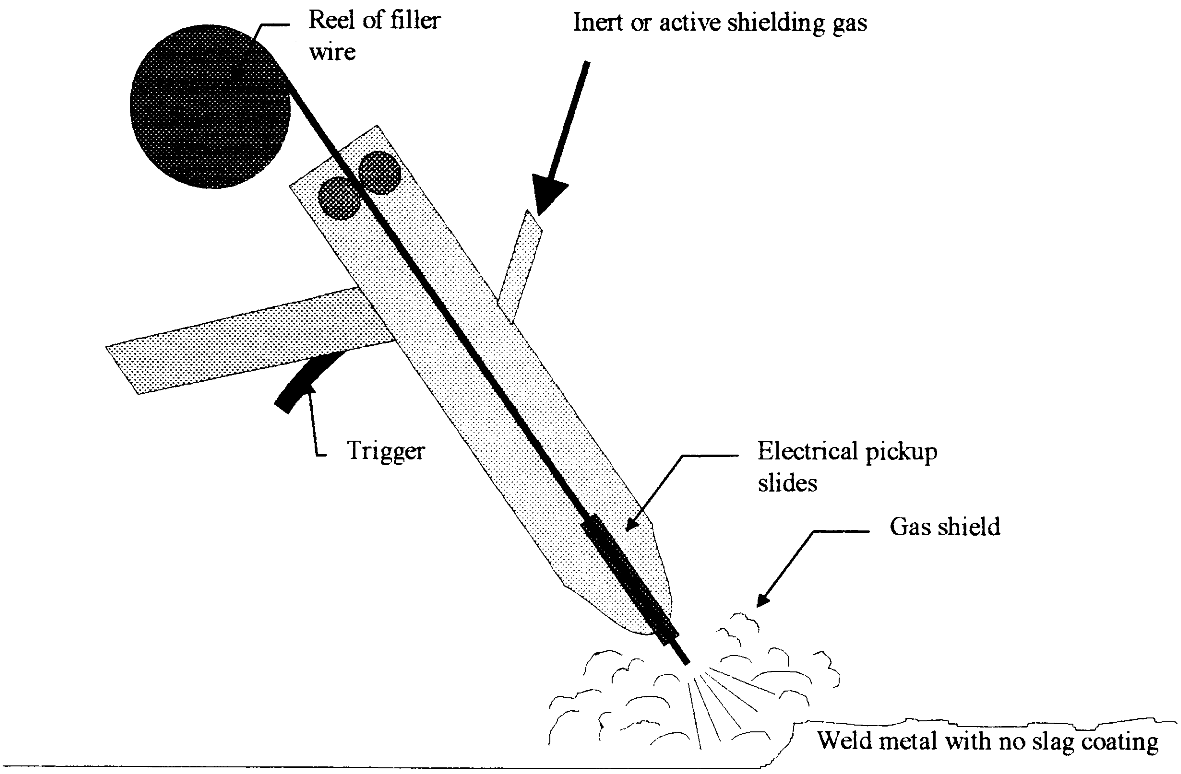


Figure 7.4 Metal Inert Gas (MIG) Welding

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.

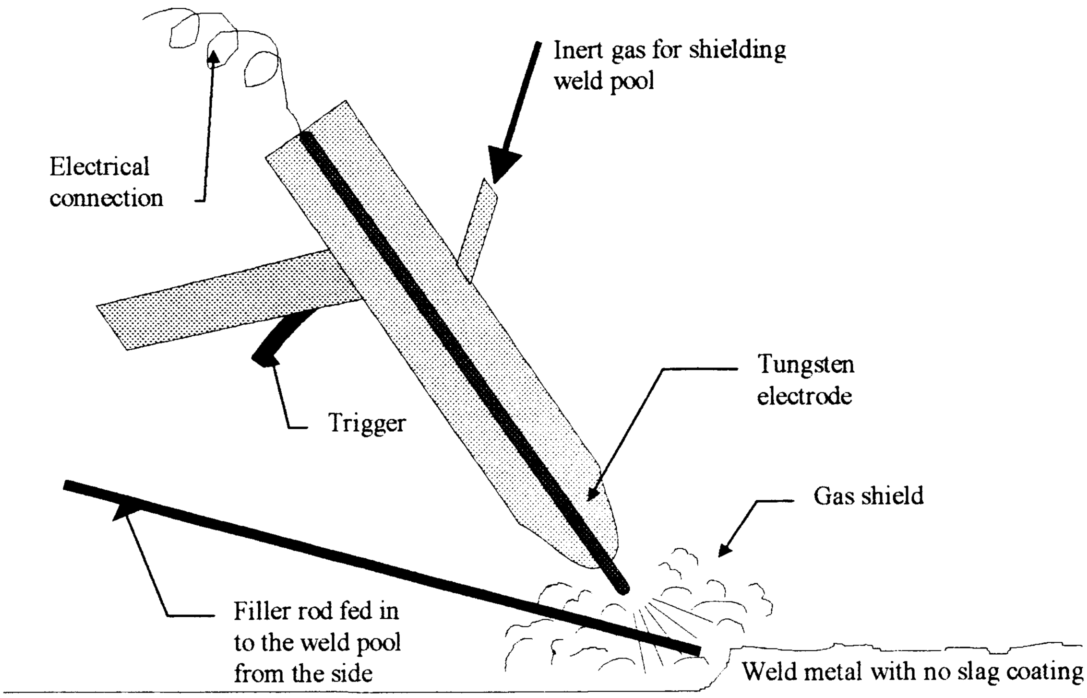


Figure 7.5 Tungsten Inert Gas (TIG) Welding

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.

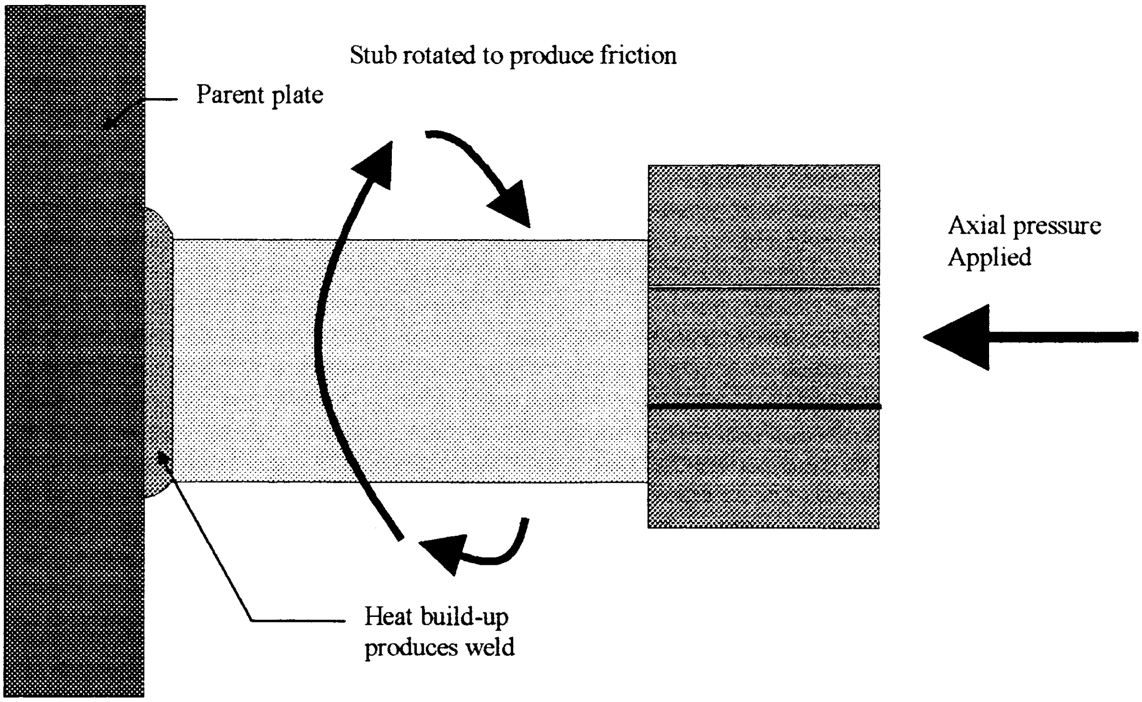


Figure 7.6 Friction Welding

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 type of joint can be used offshore for circumferential girth welds, plate-to-plate welds and seam welds.

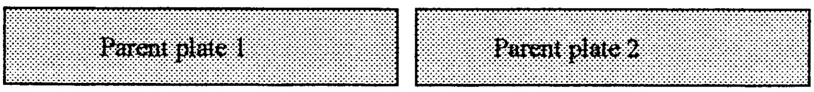


Figure 7.7 The Butt Joint

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 would be found in a nodal joint.

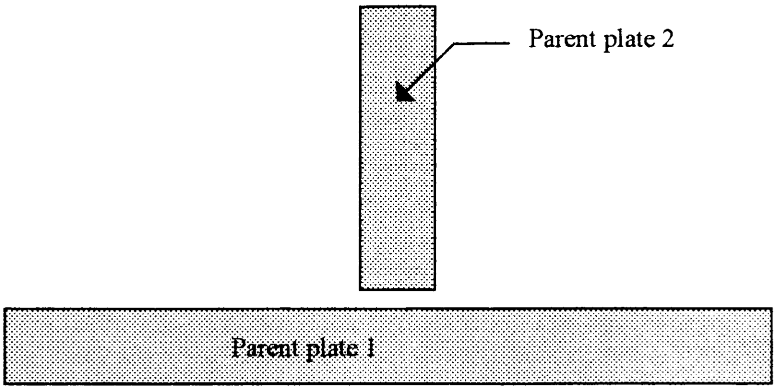


Figure 7.8 The "T" Joint

3. Lap Joint

The two parent plates are fitted one on top of the other the angle will be 0° to 5°, this is the joint used for doubler plates.

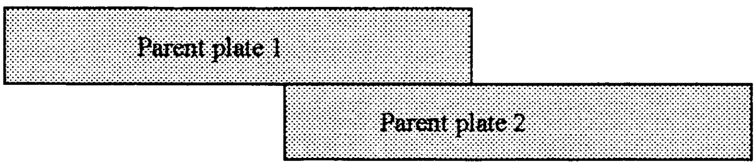


Figure 7.9 The Lap Joint

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°.

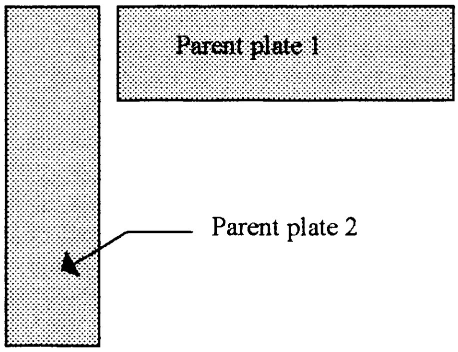


Figure 7.10 The Corner Joint

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, this joint will be found in conductor guide frames or anywhere where a lattice of members is needed.

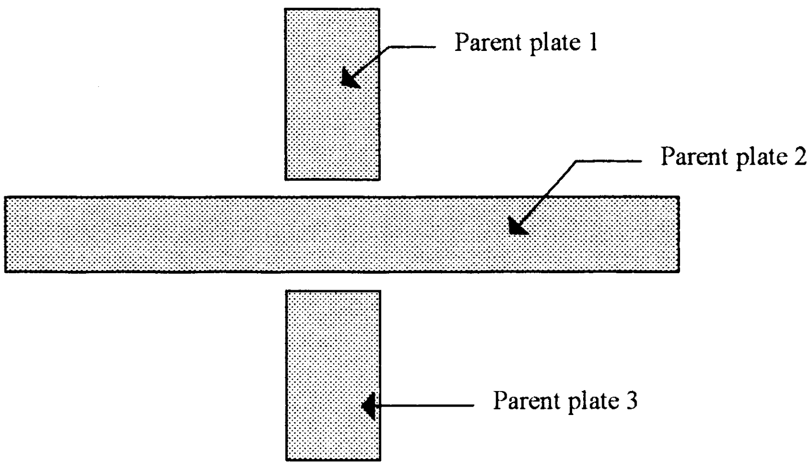


Figure 7.11 The Cruciform Joint

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, i.e. 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:

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

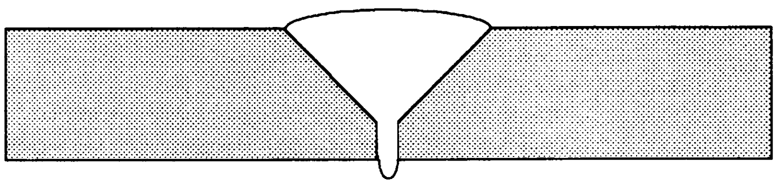


Figure 7.12 Butt-welded Butt joint (Single "V")

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".

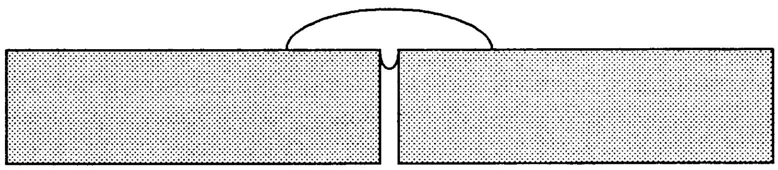


Figure 7.13 Fillet welded Butt joint

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

WELD DEFINITIONS FROM BRITISH STANDARD (BS499 {BS EN ISO 6520-1})

The British standard 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 movement.

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 welder 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) Toe Blend -The transition between the weld material and the parent plate.

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

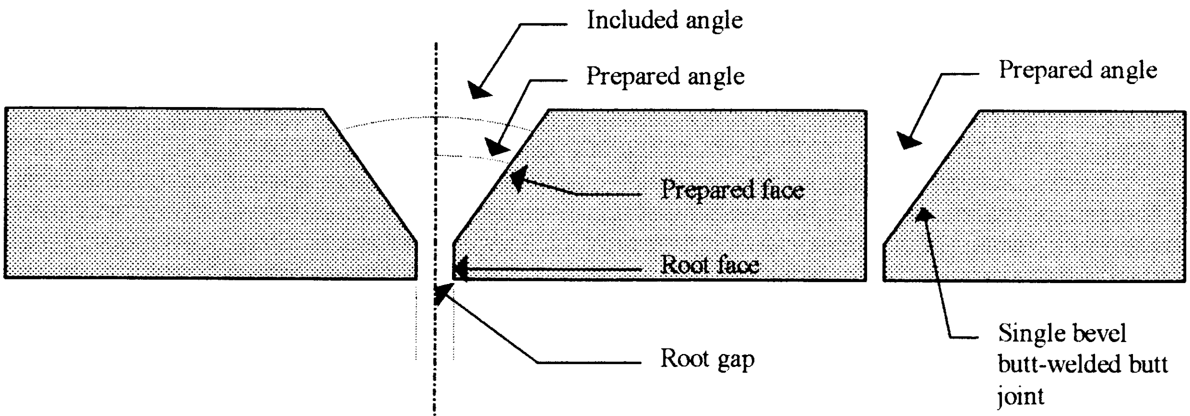


Figure 7.14 Plate Edge Preparation (Single "V" & Single bevel welded from one side only)

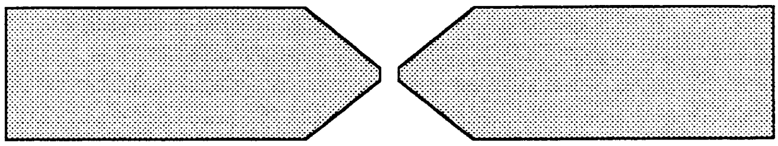


Figure 7.15 Double "V" Butt weld (Welded from both sides)

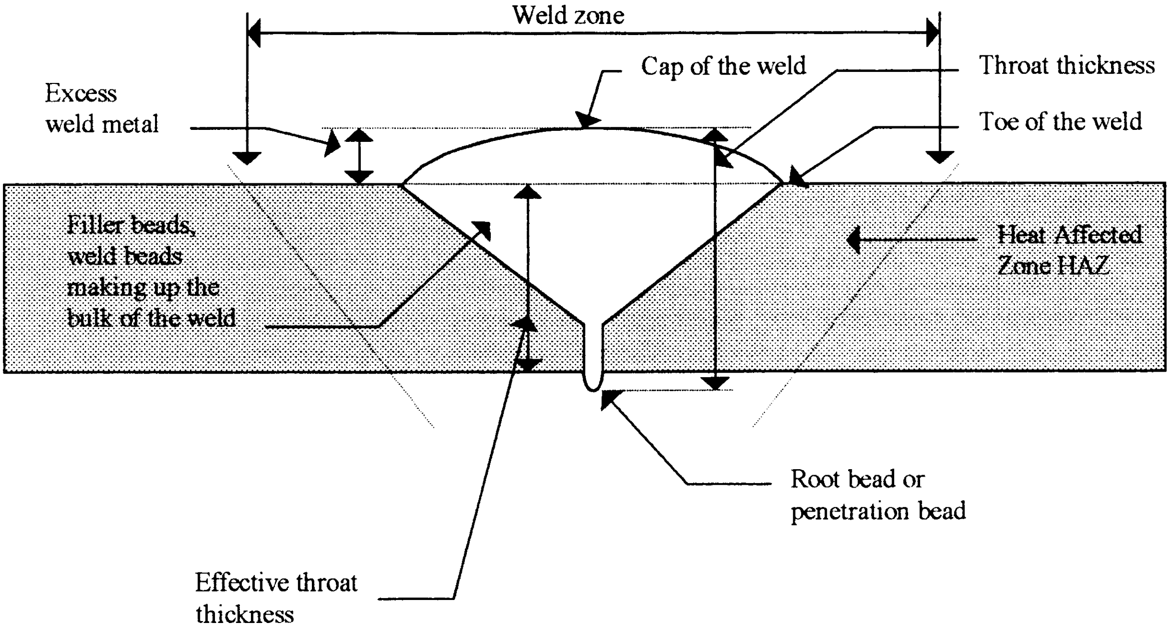


Figure 7.16 Butt Weld Terminology

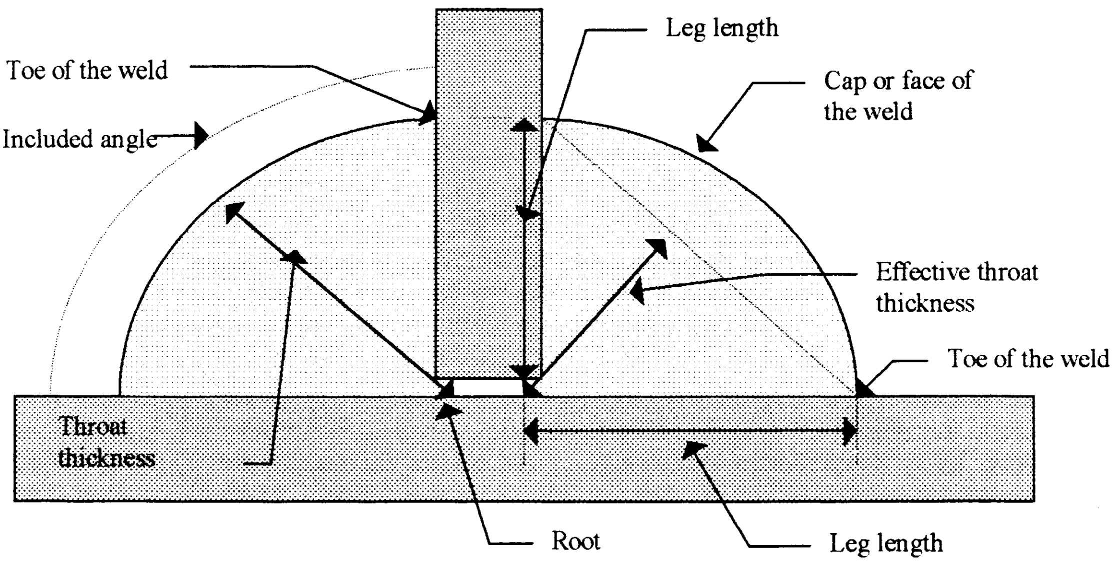


Figure 7.17 Fillet Weld Terminology

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**.

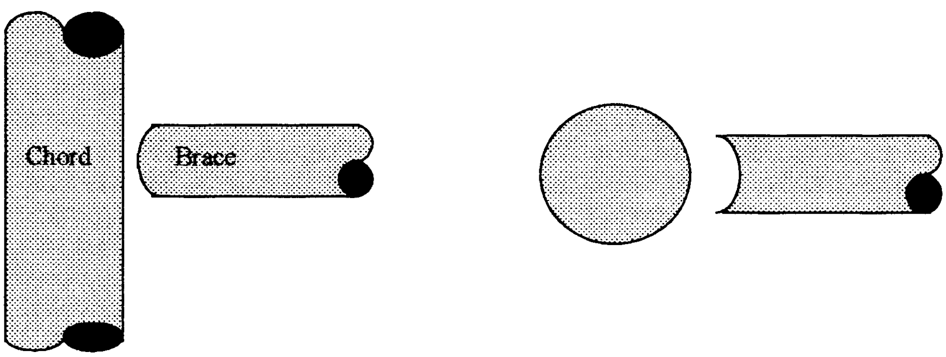


Figure 7.18 Node

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.

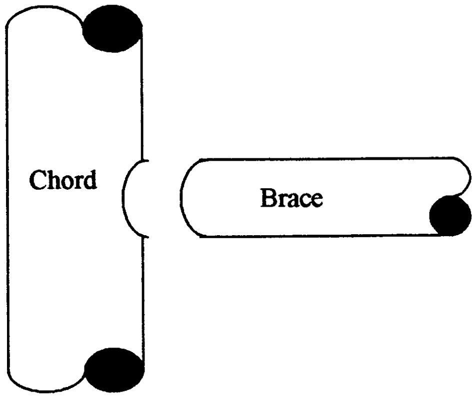


Figure 7.19 Nozzle

DEFECTS IN WELDS (BS 499 {BS EN ISO 6520-1})

IDENTIFICATION

There are **6** categories of defects according to **BS 499 or more correctly to BS EN ISO 6520-1** 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 more than 1.5 mm in diameter formed by entrapped gas during the solidification of molten metal.
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.
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.
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

These will have large surface area but low volume, so they are essentially two-dimensional defects (2d) 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).**

VOLUMETRIC DEFECTS

These will have a comparatively small surface area but a large volume (3 dimensional, 3d); 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.

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 i.e. 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 i.e. 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:

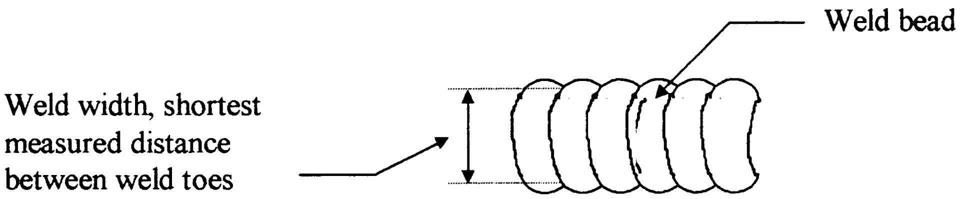


Figure 7.20 Measurement of weld width

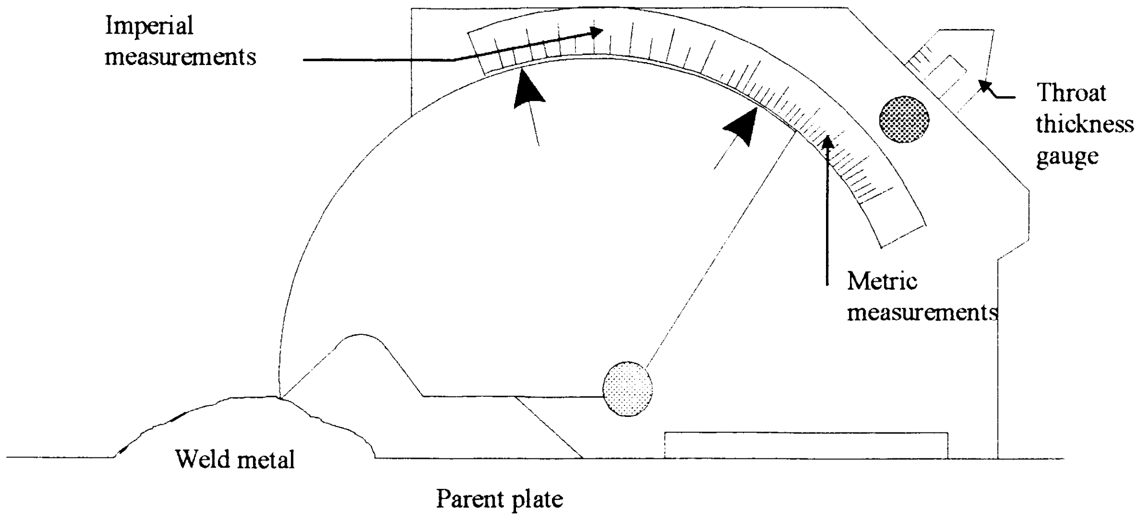


Figure 7.21 Welding Institute gauge measuring Excess weld metal

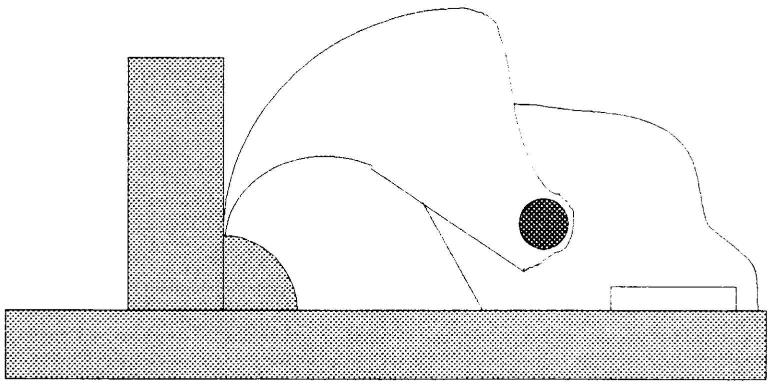


Figure 7.22 Measurement of leg length of a fillet weld

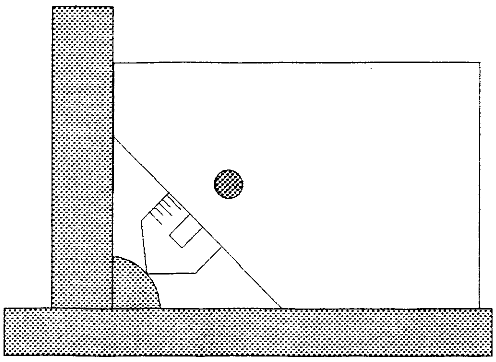


Figure 7.23 Measurement of Throat Thickness of a fillet weld

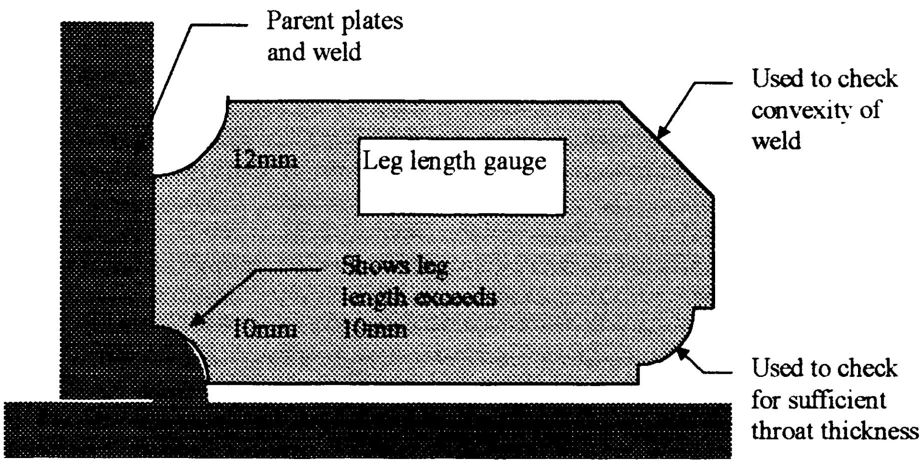


Figure 7.24 Leg Length gauge Showing leg length greater than 10mm

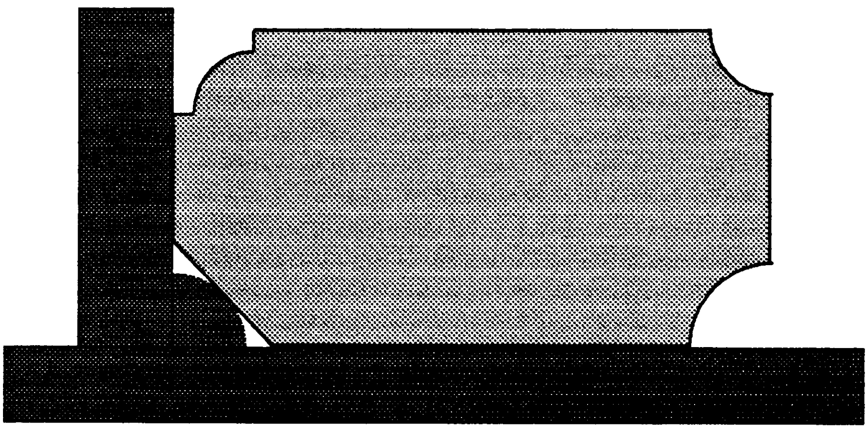


Figure 7.25 Leg length gauge showing Convexity not exceeding gauge

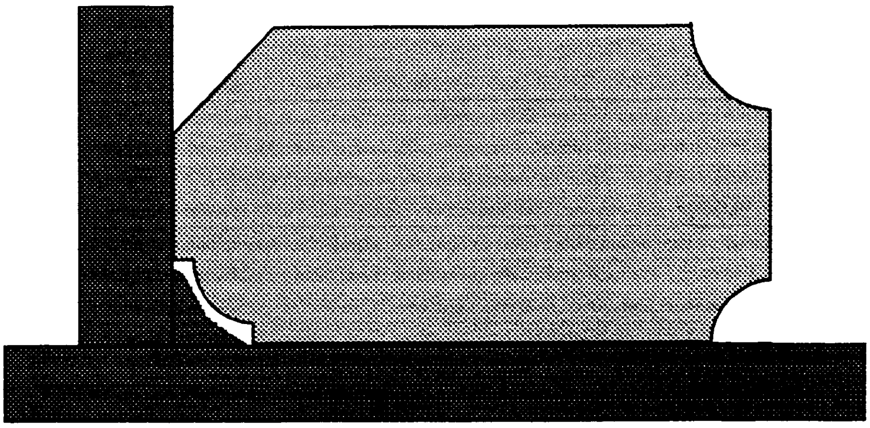
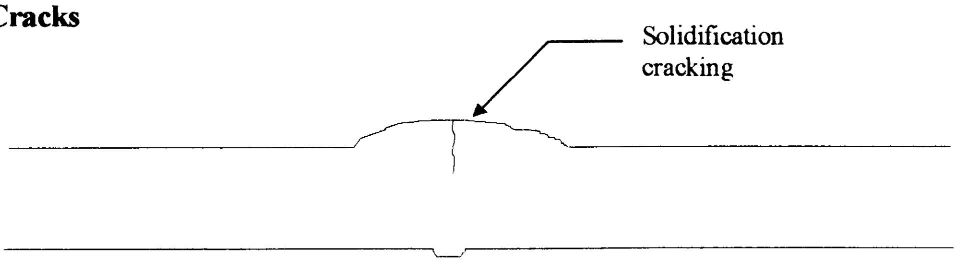
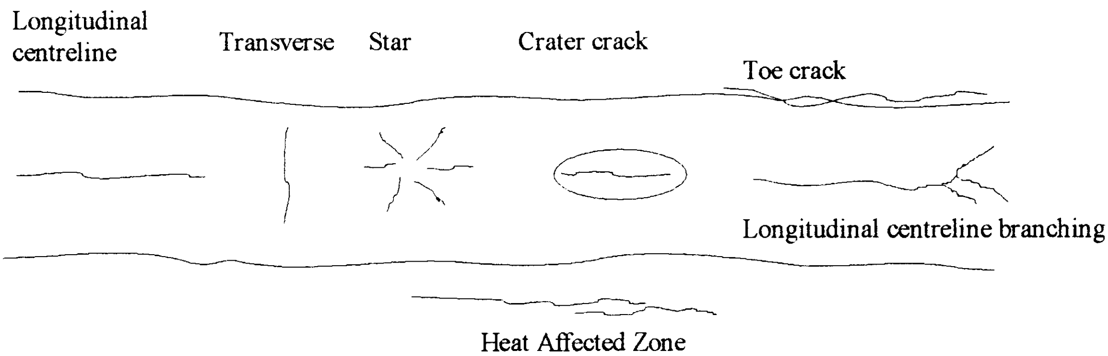


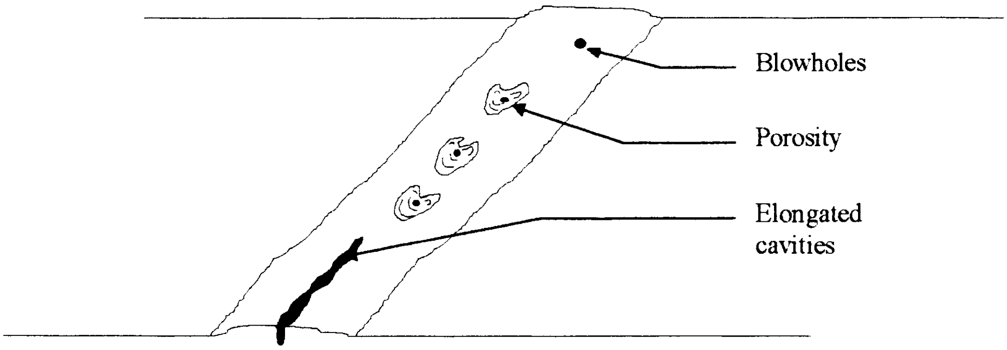
Figure 7.26 Leg length gauge showing Convexity exceeding gauge (Throat thickness too little)

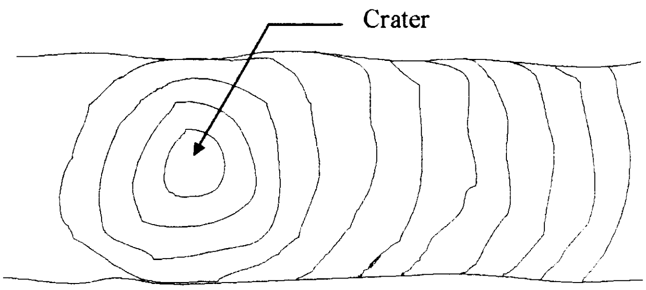
1 Cracks

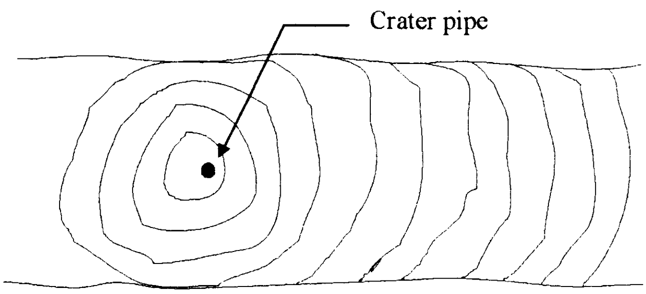




2 Cavities



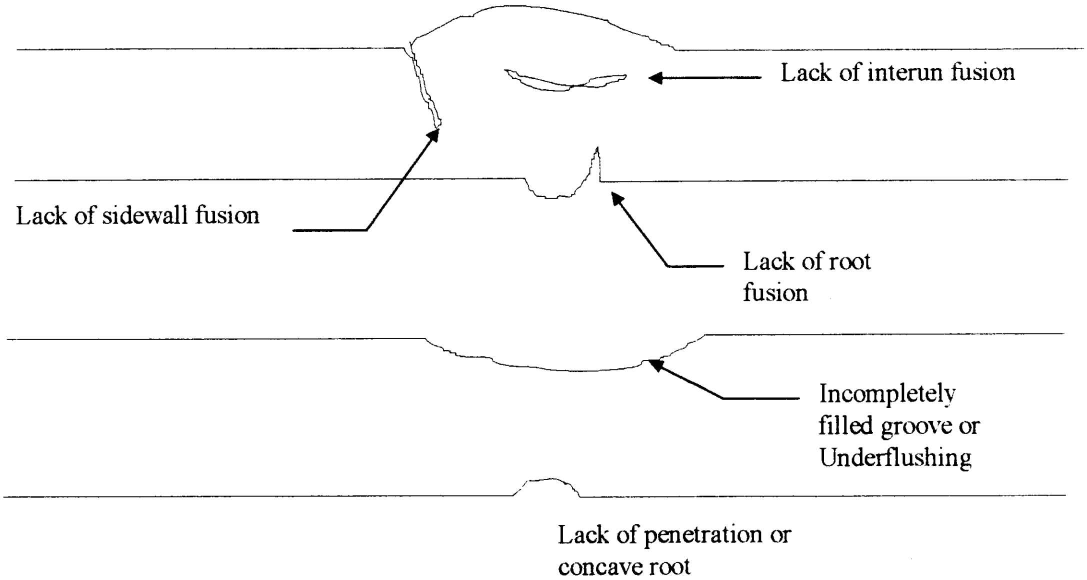




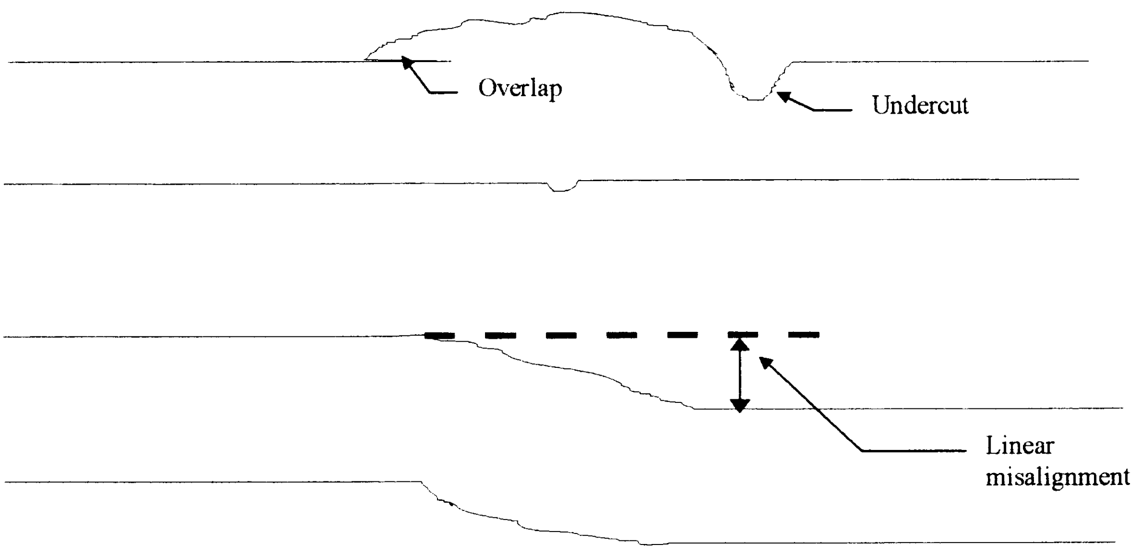
3 Solid Inclusions

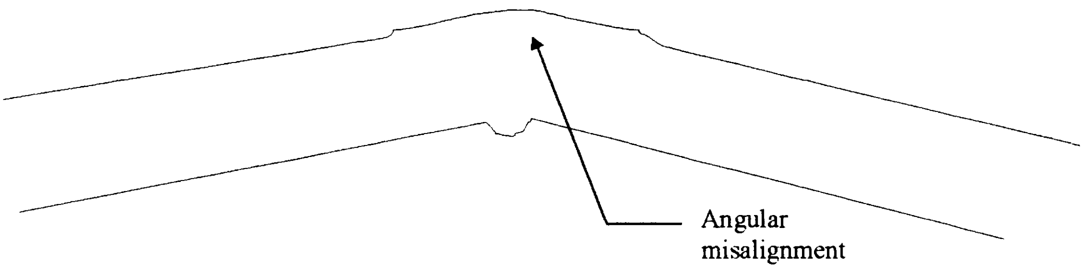
Solids trapped in the weld when the metal is still molten, from a visual inspection point of view, apart from slag inclusions these will not normally be visible.

4 Lack of Fusion and Penetration

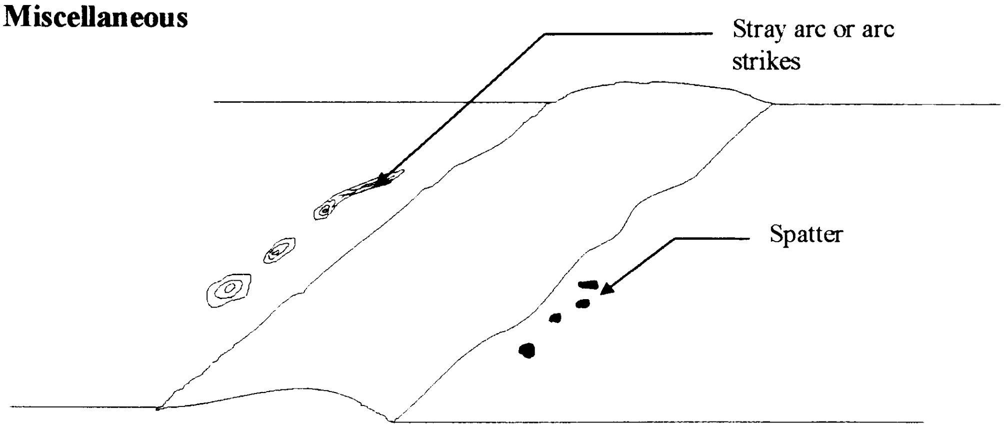


5 Imperfect shape





6 Miscellaneous



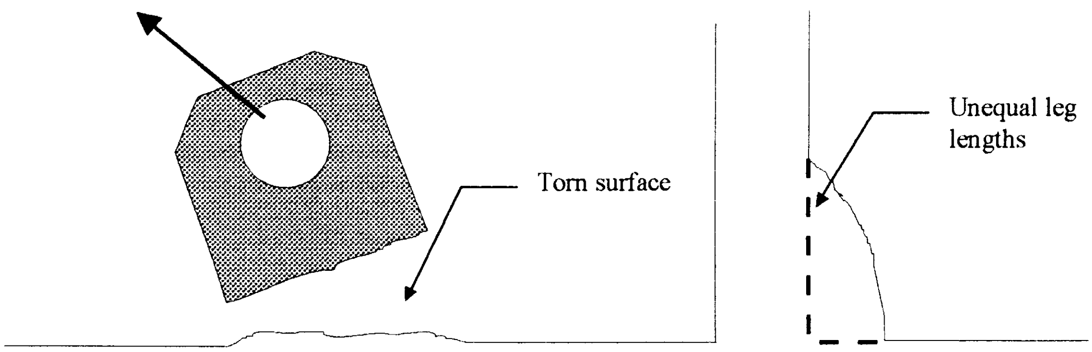


Figure 7.27 Weld Defects and Locations according to BS 499

CHAPTER 8

Damage & Damage Survey

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 the majority are discovered by routine inspection, in fact very few are located during 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 **anything** 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 (provided visibility is reasonable).
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 tends to be good.

Disadvantages of visual inspection

1. No permanent record.
2. Open to interpretation.
3. Cannot assess sub-surface (internal) defects.

Visual inspection makes it very difficult to acquire quantitative data and relies greatly on the individual divers experience.

Procedure for close visual inspection of welds:

1. Carry out surface checks of equipment.
2. Obtain the appropriate permits to work.
3. Locate the correct weld on the drawings and ensure the diver/ROV is at the correct position.
4. General visual inspection looking for gross structural damage and assessing marine growth.
5. Clean to SA 2.5 or SA 3 at least 75mm either side of the weld.
6. Establish the datum point (at 12 o'clock) and mark up the weld (using a tape and clock positions).
7. Measure and report complete weld length, this must be given for the required part of the weld, the client may require the length to be measured on the brace, weld cap or chord side, each of these measurements will be quite different.
8. Close visual inspection looking for fine defects.
9. Record and report defects relative to the datum point.
10. Back up the inspection with CCTV and photography.
11. Once back on surface, wash all equipment in fresh water, cancel permits and submit results to the client.

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:	Component ref:	
Detail:		
Signed:		
Supervisor:	Inspection engineer:	Diver:

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 over 1.5m.

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 extremely high levels of accuracy, and the methods used are improving all the time.

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.

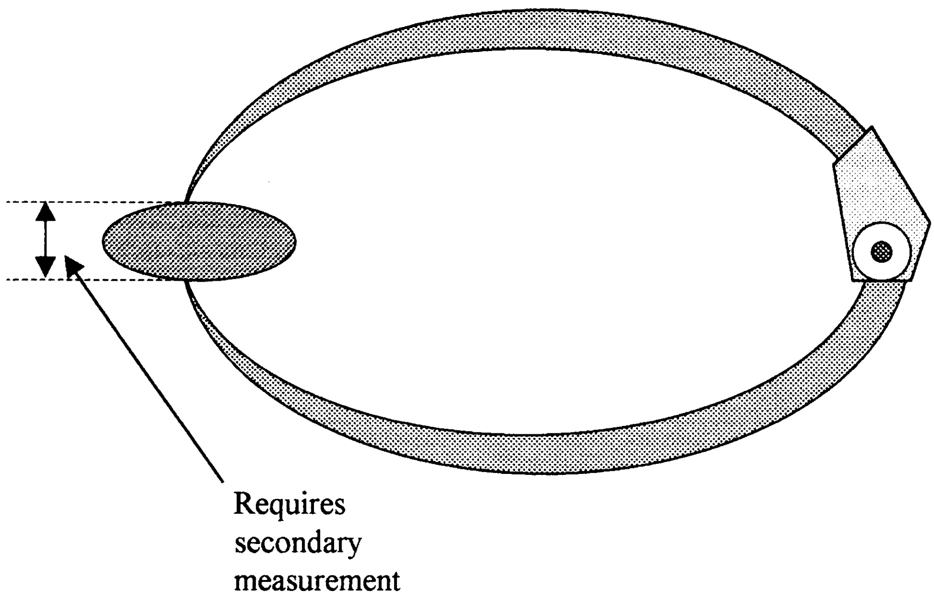


Figure 8.1 Callipers

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.

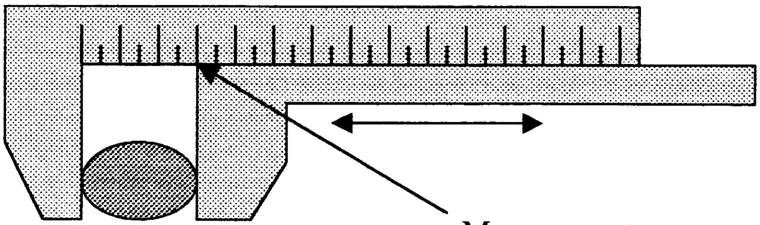


Figure 8.2 Vernier Gauge

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.

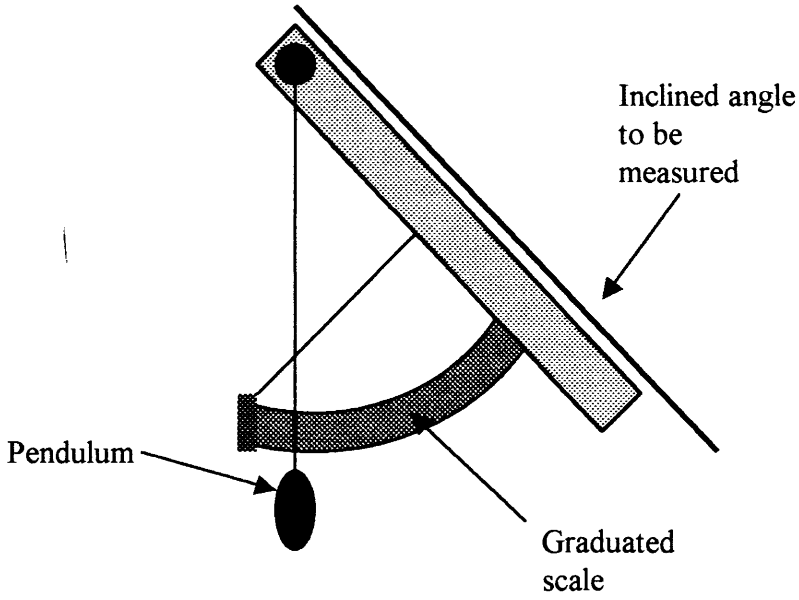


Figure 8.3 Pendulum Gauge

4. **DENTS AND DEFORMATION OF MEMBERS**

a) PROFILE GAUGES (Mimic Gauge)

For small areas of deformation we can use a profile 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 could 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.

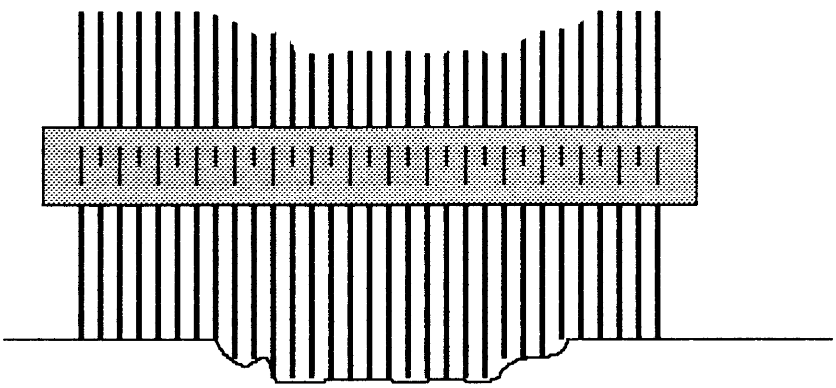


Figure 8.4 Profile Gauge

b) CASTS

There are a number of different materials, which have been used to take casts underwater such as plasticine, 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 its 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:

i) Cleaning must be sufficient to ensure no faults are missed, such as tears at the impact point (SA 2.5)

ii) 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).

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

iv) Wire must be at the correct tension.

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

vi) Wire must not be deflected in any way.

vii) All measurements must be taken perpendicular to the undamaged member, and the wire standoff measurements must be subtracted from each of the readings.

viii) 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.

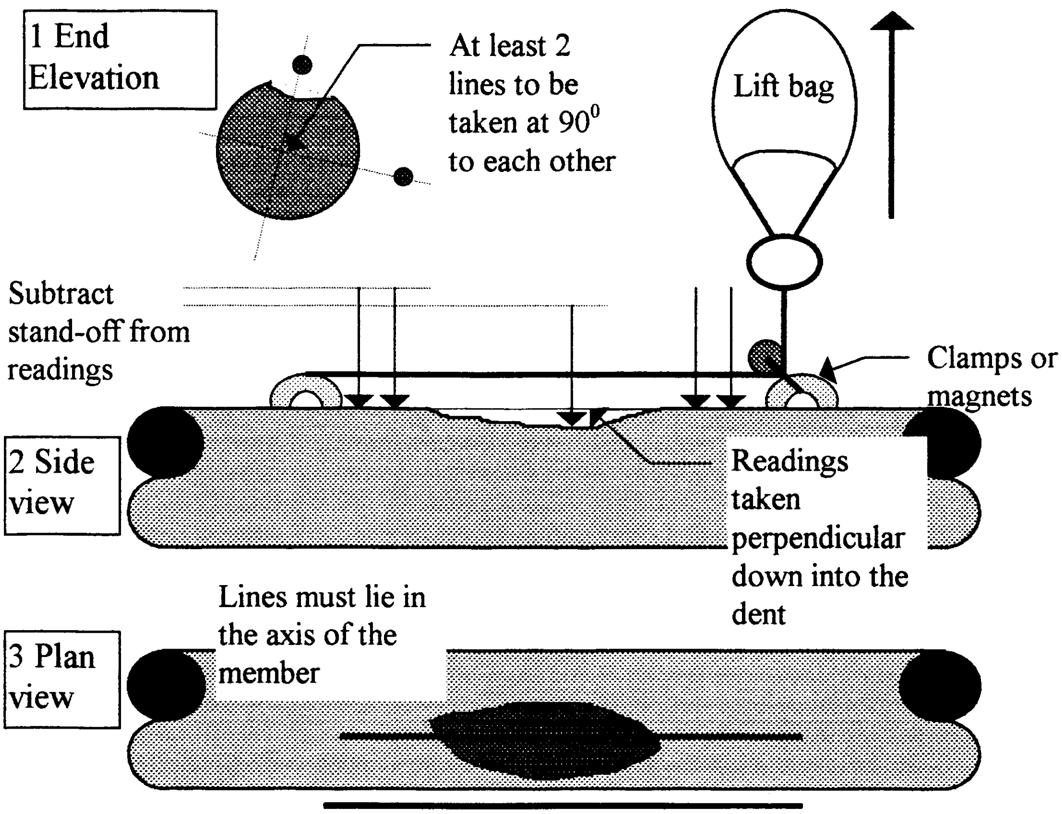


Figure 8.5 Taut Wire Survey

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.

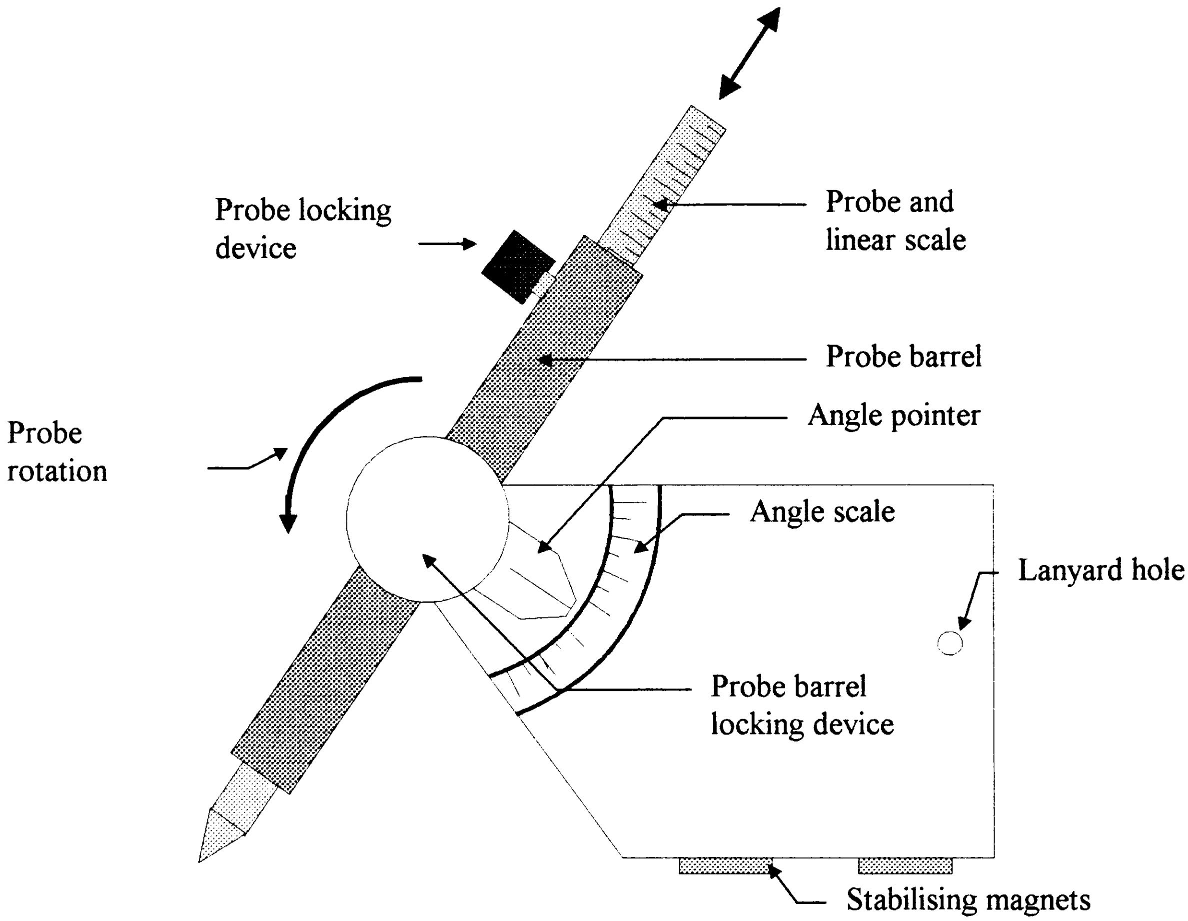


Figure 8.6 Linear Angular Measurement (LAM) Gauge

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).

CHAPTER 9

The Importance Of Documentation And Record Keeping

Operators keep extensive records for the following reasons:

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

2. Records allow engineering assessments to be made regarding the structures continued 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. (It is the responsibility of the Duty Holders engineering department to 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 and repair programme can be planned and implemented.

6. To evolution of future structural design criteria.

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, maintenance and repair.

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 record.

The design will call for materials of specific standards to be used in the construction. These will also be supplied 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 carried out on 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 and every individual component on all of their structures.

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, and 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.

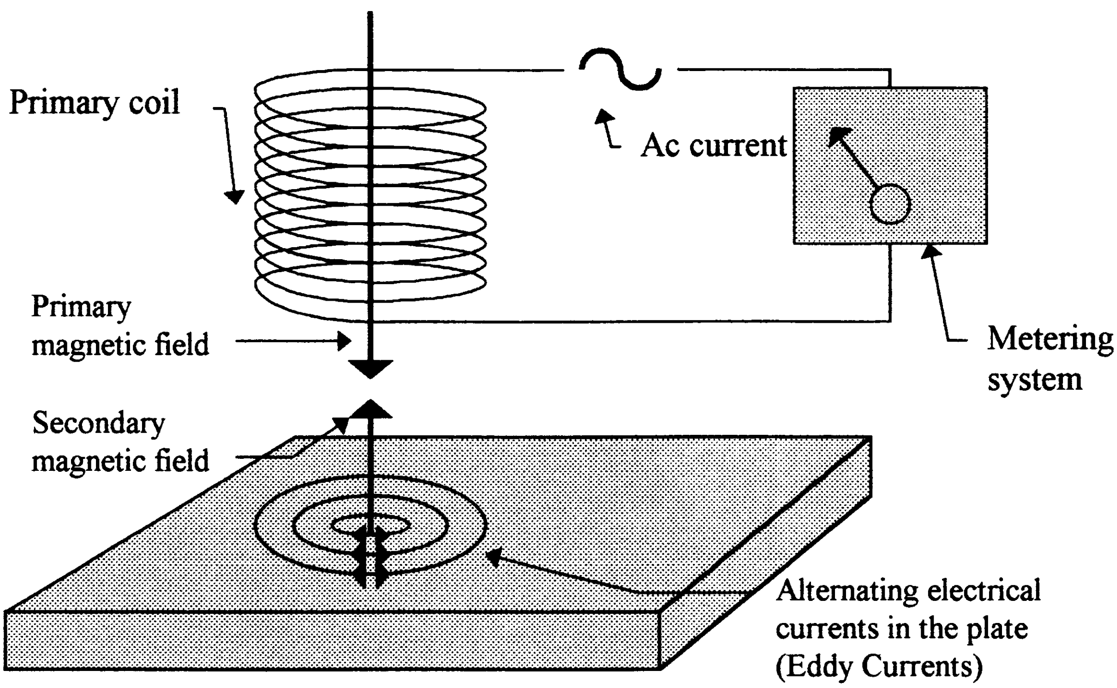


Figure 10.6 Electromagnetic Detection Technique (eddy current)

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)

FMD is **used to assess the integrity of tubular members in the offshore structure**. It can be achieved by the use of ultrasound, radiography or thermal methods.

In the case of radiography a gamma-ray sensor would be placed on the opposite side of the member to the source and then exposed for a given time. The number of counts per second produced is varied according to whether the member is air or water filled.

Thermal FMD 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 position 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).

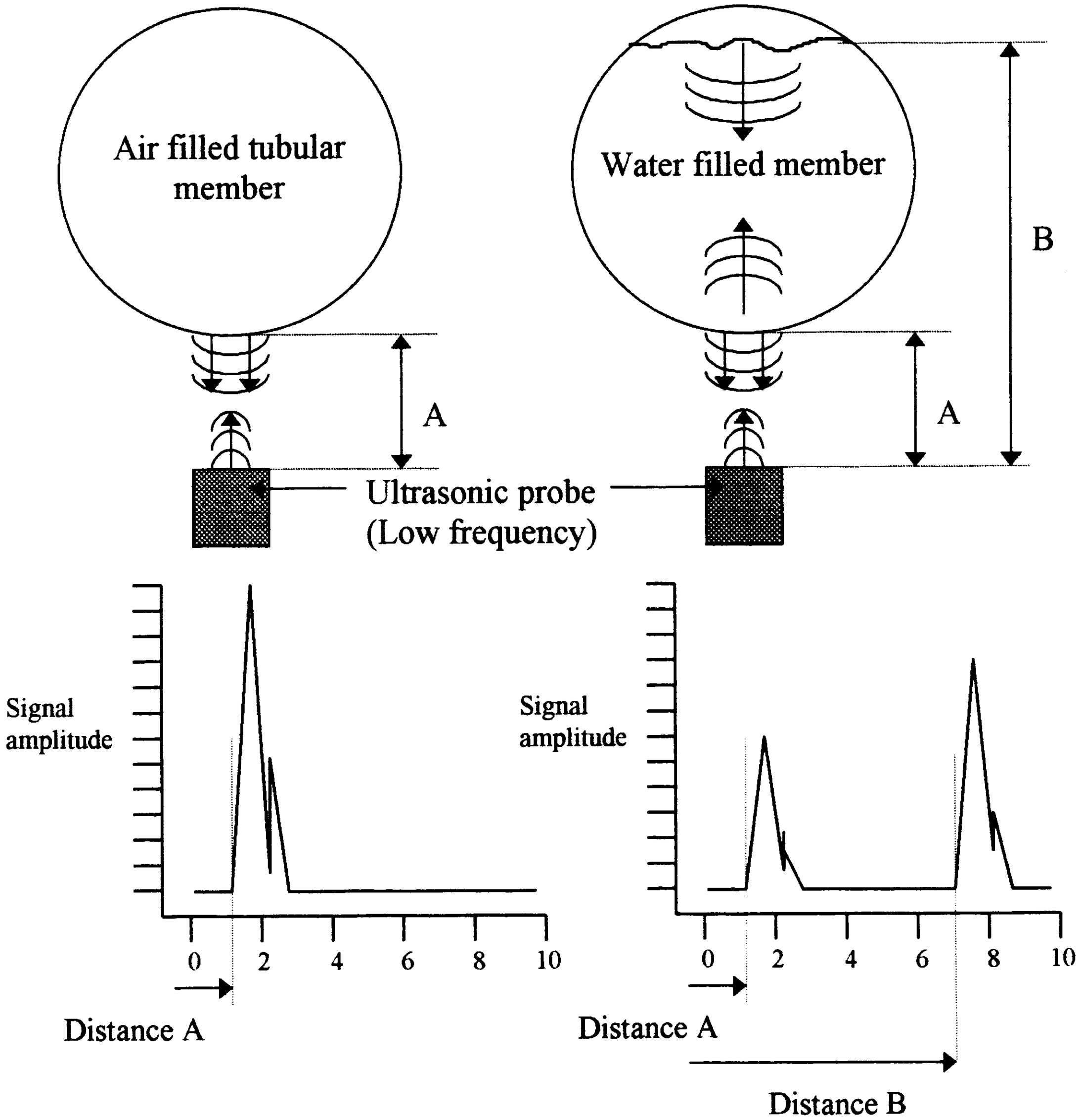


Figure 10.7 Flooded Member Detection (FMD) using the Ultrasonic Method

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

There are two main methods that can be adopted as far as reporting and recording of inspections are concerned, the first is a **Full Reporting system**. A full reporting system will require that any and all defective parts of a structure are reported in full, this will mean that there are no allowances made, for instance every corrosion pit would need to be recorded etc. This will of course be very time consuming and will produce very large reports, however most of the information included in the report may well be of little relevance to the actual safety of the structure. This system is hardly ever used as it will be very time consuming and expensive to implement however it does not rely on the offshore personnel being familiar with how serious a feature has to be before it needs to be recorded as all defective features are automatically recorded.

The system normally used will be an **Anomaly Based system** of reporting, this will mean that the offshore personnel are given specific guidance by the **"Duty Holder"** on what needs to be recorded and what can be ignored, this information is presented to the offshore personnel as the **"Criteria of Non-Conformance (CNC)"**, this will mean that an item would only be recorded if it exceeds or is outside of the "CNC". This system is much quicker to implement as only information considered relevant to the structural safety need be recorded and this will of course make the inspection contract much cheaper, however it does put more pressure on the offshore personnel as they have to be familiar with the specific "CNC" for the inspection being carried out and then they will need to recognise a defect before it would be recorded and this could lead to defects being missed if the personnel are not properly trained or briefed.

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.

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:

    a) Geographical location
    b) Component reference
    c) Client
    d) Diving company
    e) Divers name
    f) Inspection controllers name
    g) Task undertaken
    h) Equipment used
    i) Date of inspection
    j) Video tape reference number

5. **Summary** - Should be a highly condensed précis 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.

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.

7. Conclusions - May not be required, if they are required they should follow from the facts logically. Opinions can be included 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 drawn on to provide additional background data or support.

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

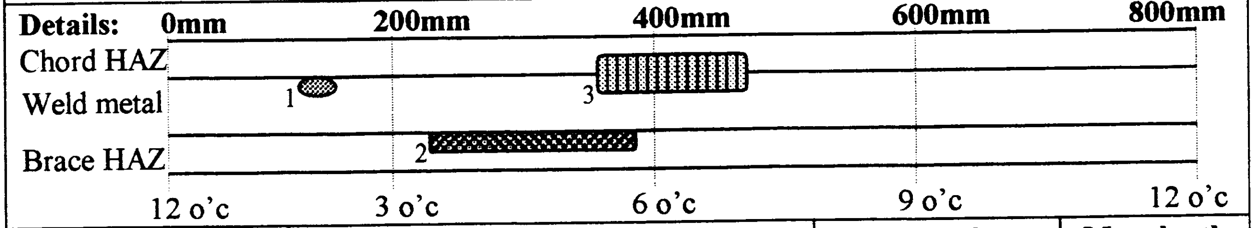
Most clients will of course supply inspection report sheets, which must be filled out correctly. It is of absolute paramount importance that the sheet is filled out in the proper manner using correct techniques, if this is done the report sheet will draw attention to all of the relevant points quickly 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

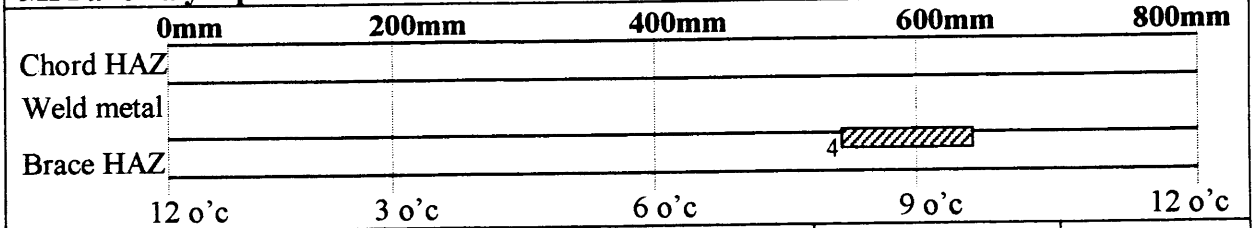
CP readings:	12 O'clock	3 O'clock	6 O'clock	9 O'clock
	-0.95V	-0.93V	-0.90V	-0.93V

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.

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.

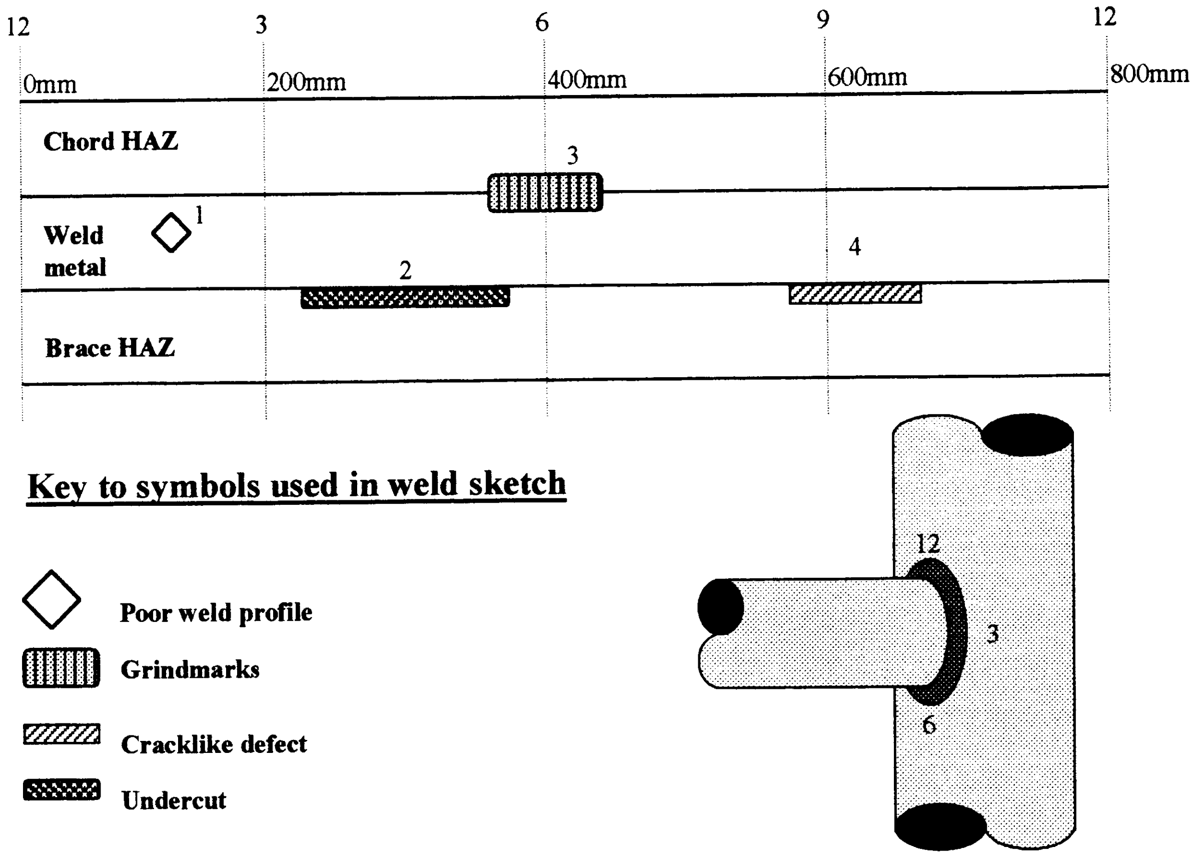


Figure 11.2 Weld Reporting using Graphics

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)?
    b) Where the inspection is being carried out.
    c) What is to be done (General or close inspection).
    d) When the commentary is being done.

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

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.

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

Datasheet design

When designing a data sheet it will be imperative to take the following into account:

1 Introductory information
2 Types of inspection to be carried out
3 Aims of the inspection
4 Criteria of non-conformance
5 Type of component to be inspected
6 Extent of the inspection

Introductory panel

The introductory panel would commonly contain the following information:

1 Client
2 Contractor
3 Geographic location (Platform)
4 Component type and reference
5 Dive spread
6 Dive number
7 Date
8 Data sheet reference number
9 Sheet ___ of ____
10 Type of inspection carried out
11 Equipment used
12 Videotape or Photographic reference number
13 Cleaning standard
14 Diver/ROV pilot
15 Inspection controller name

Main Body of the Datasheet

The data sheet itself will then contain the following:

1 Boxes or areas for each individual type of inspection or special requirement
2 Comments box for unexpected developments
3 Sketch of the component
4 Signatures of the client's rep & the controller
5 Anomaly report area

When designing the data sheet ensure you take into account the following:

1 Look at the procedure/workscope & drawings to locate the depths of relevant features, elevations, clamps etc.
3 Find the Identification of the features.
4 Make up the sheet to suit.

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 client's requirements.

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.
7. Proven technique.
8. Easy to deploy.
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 photosensitive 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) [E 6 Colour Reversal Developing Process]

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) [C 41 Developing Process]

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 photosensitive 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 photosensitive part of the photographic emulsion is 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).

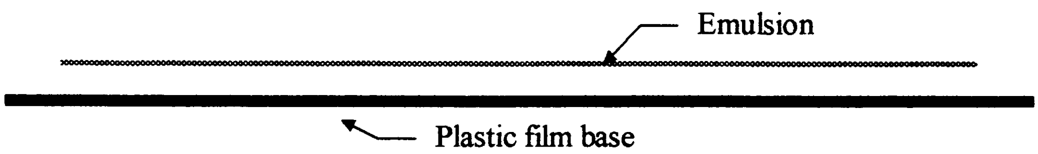


Figure 13.1 Monochrome Film

In the case of a colour film the emulsion is more complicated in that it will have a number of photosensitive 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).

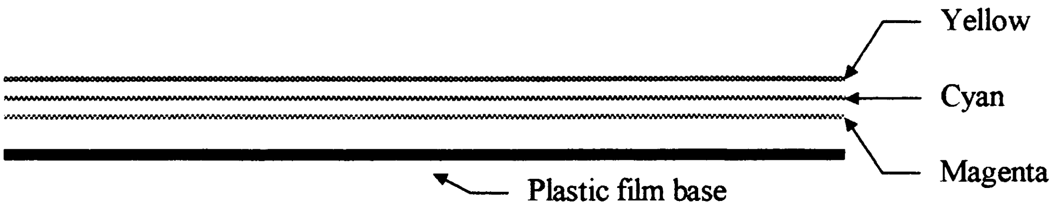


Figure 13.2 Colour Film

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 (High density).

LARGE CRYSTAL - FAST REACTION - POORER QUALITY (Low density).

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:

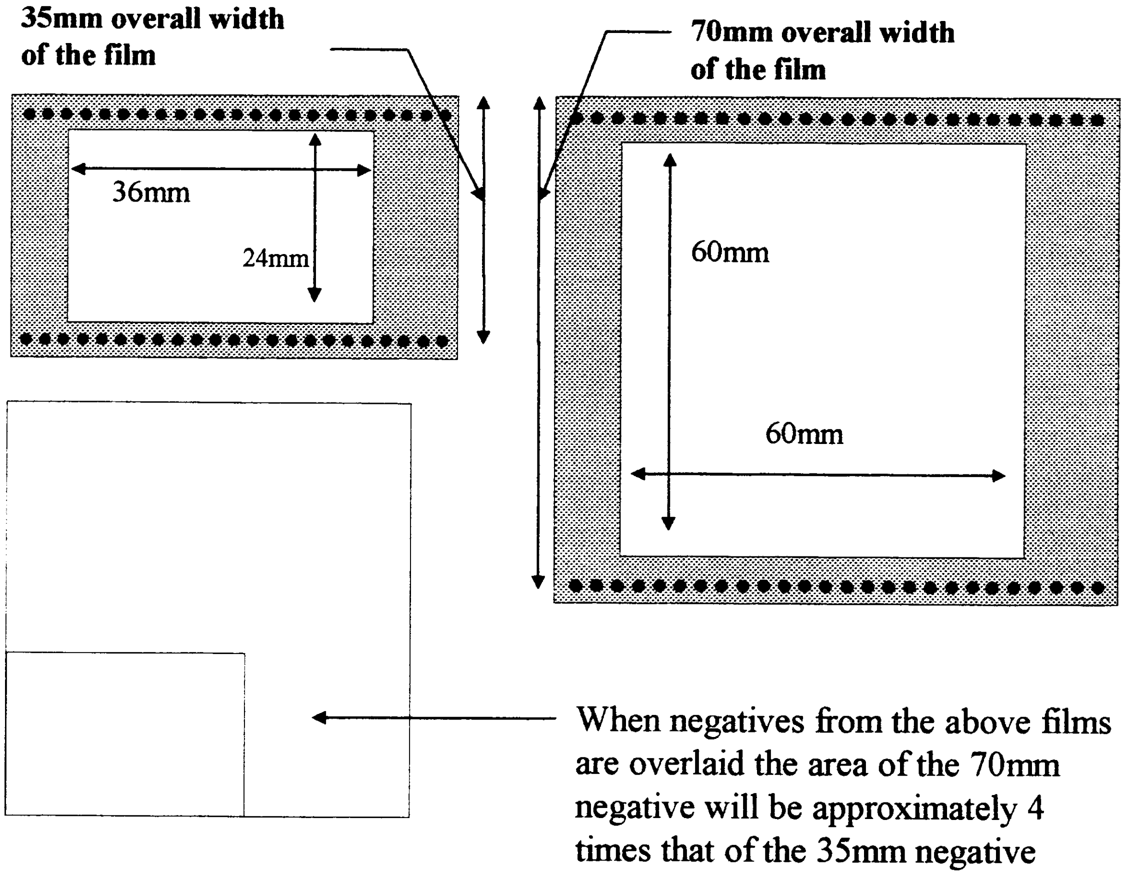


Figure 13.3 Small and Medium format Film

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 lightproof box, which will allow light to fall on to a photosensitive surface in a controlled fashion. In its simplest form a lightproof 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 that 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.

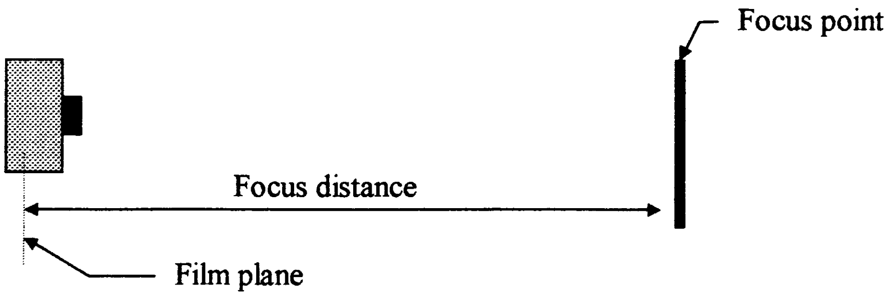


Figure 13.4 Focus

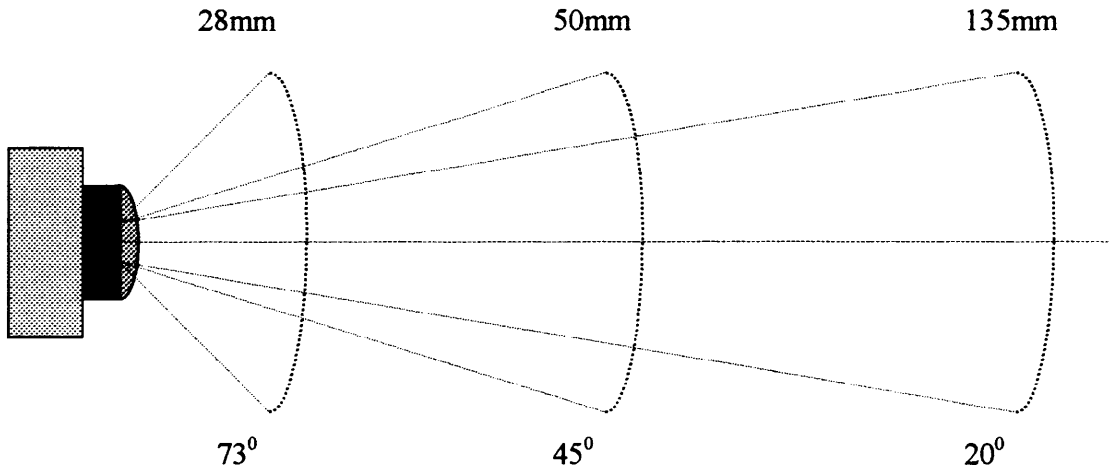
FIELD OF VIEW

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.

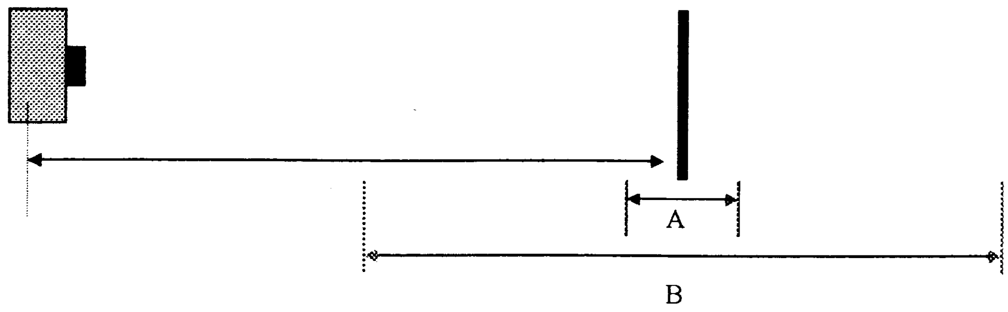
ii) The focal length of the lens:

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.

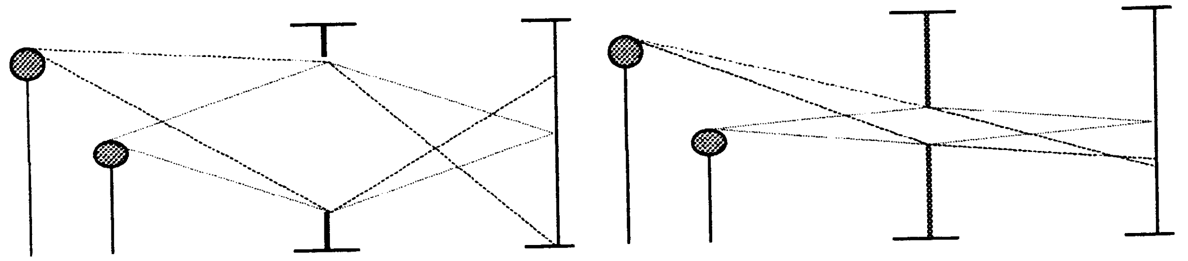


Figure 13.7 The Relationship of Aperture to Depth of Field

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.

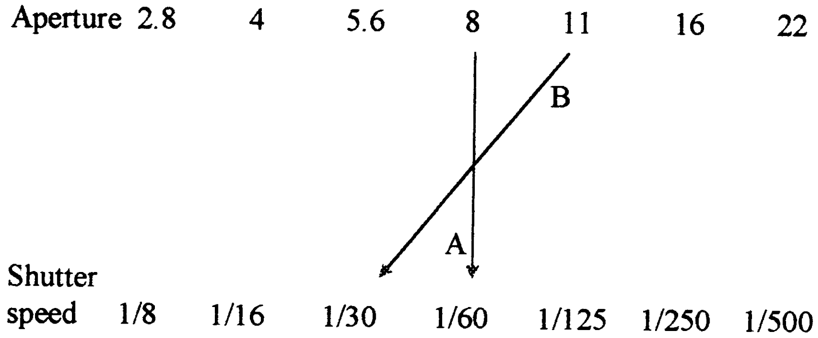
The relationship is much more obvious, this is because we are all used to dealing with time, typically the speeds will be as follows:

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.

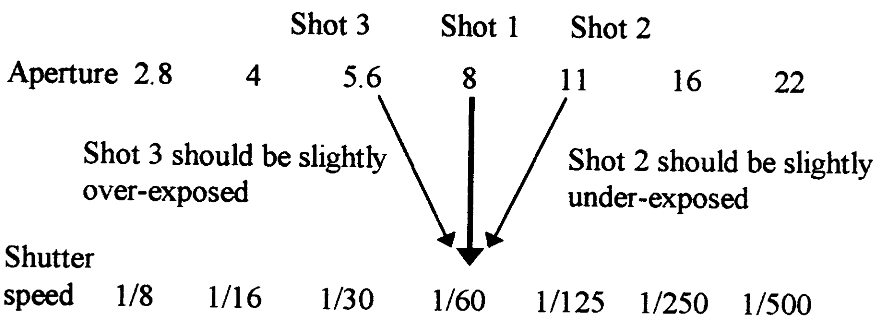
Relationship between Aperture and Shutter Speed



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 photograph, 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).

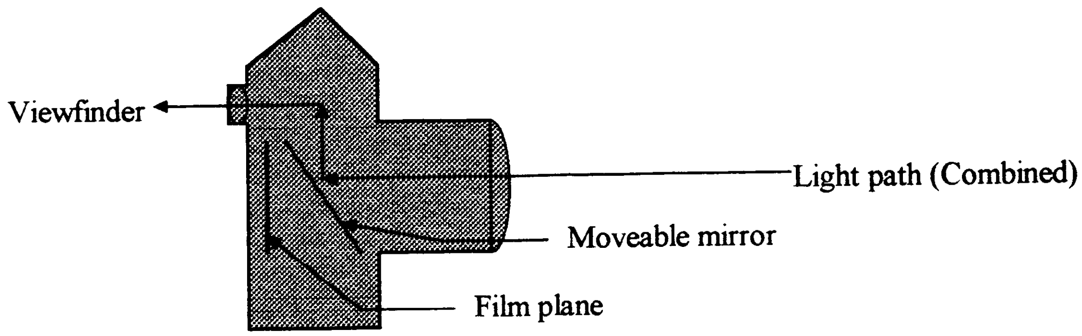


Figure 13.8 Single Lens Reflex Camera

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.

However some ROV systems will use a derivative of the above, this is the TeleVision Photography (**TVP**) or Through Lens View (**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.

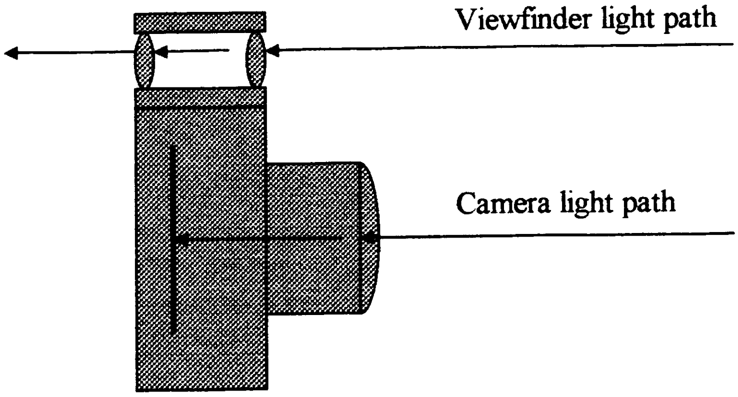


Figure 13.9 Parallax Camera

When the camera is being used for stand off photography it is important to never stand off more than **<u>1/3 rd of the visibility</u>**, 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.

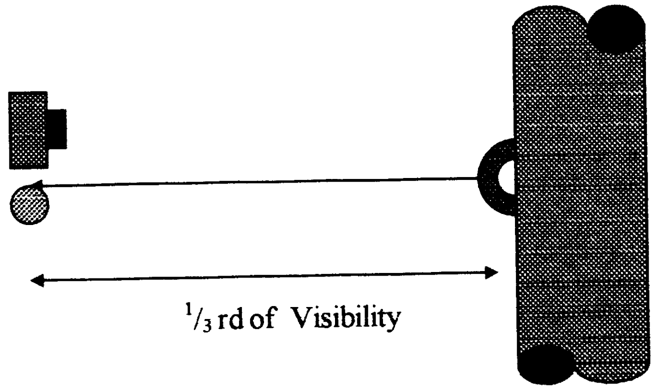


Figure 13.10 Visibility and Distance Assessment in Water

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, and thus the frame is best suited to photography of flat surfaces such as concrete and marine growth surveys.

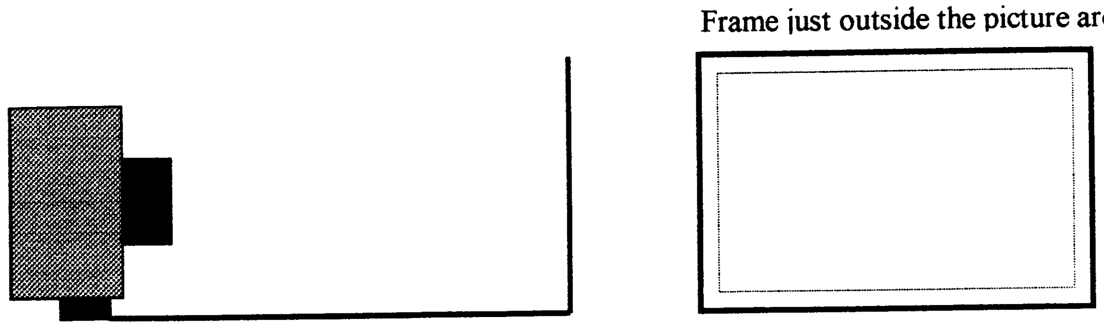


Figure 13.11 Close up Frame Attachment

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.

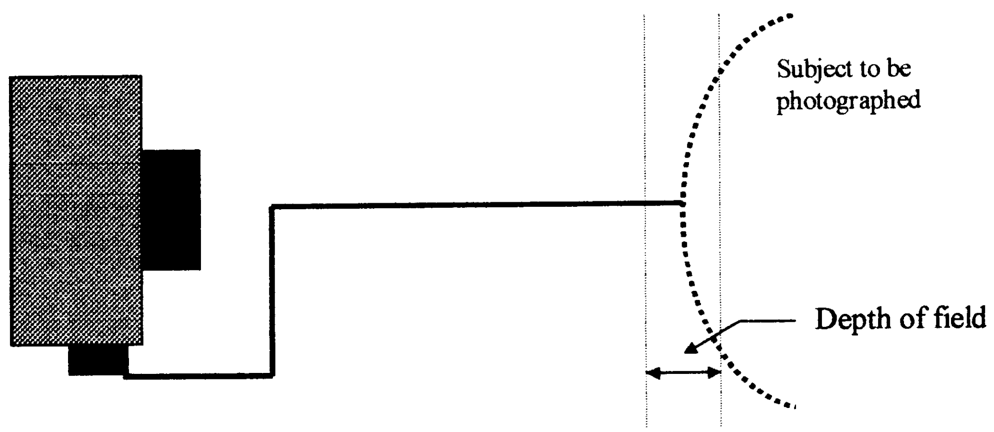


Figure 13.12 Close up Prods

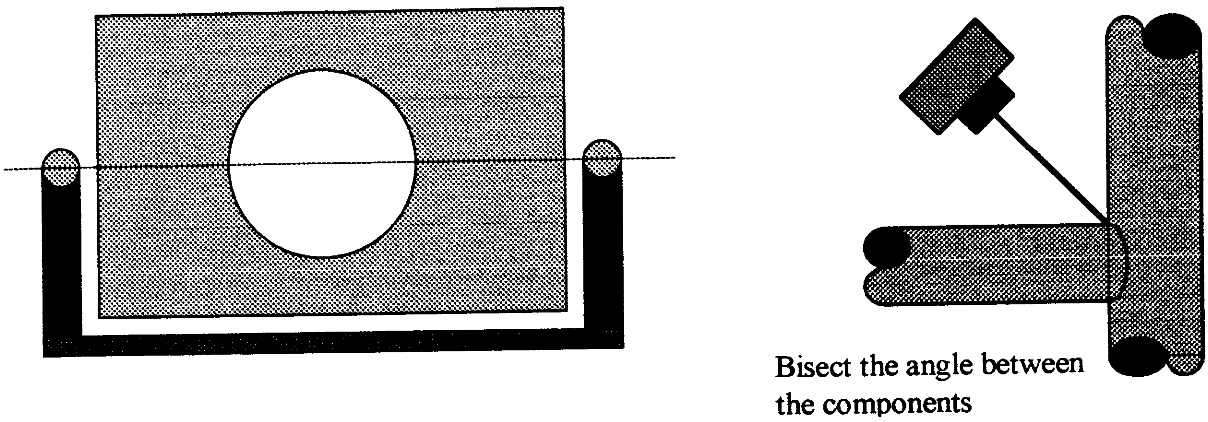


Figure 13.13 Prods Bisect the Angle Between the Components.

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.

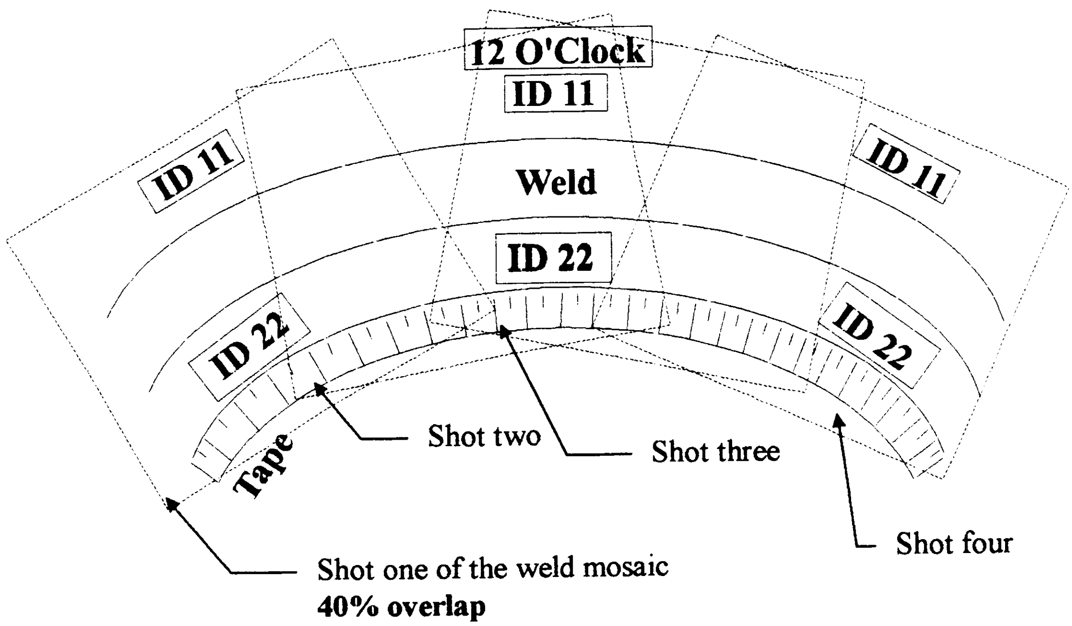


Figure 13.14 Weld Mosaic Showing 40% Overlap, Scale and Identification included

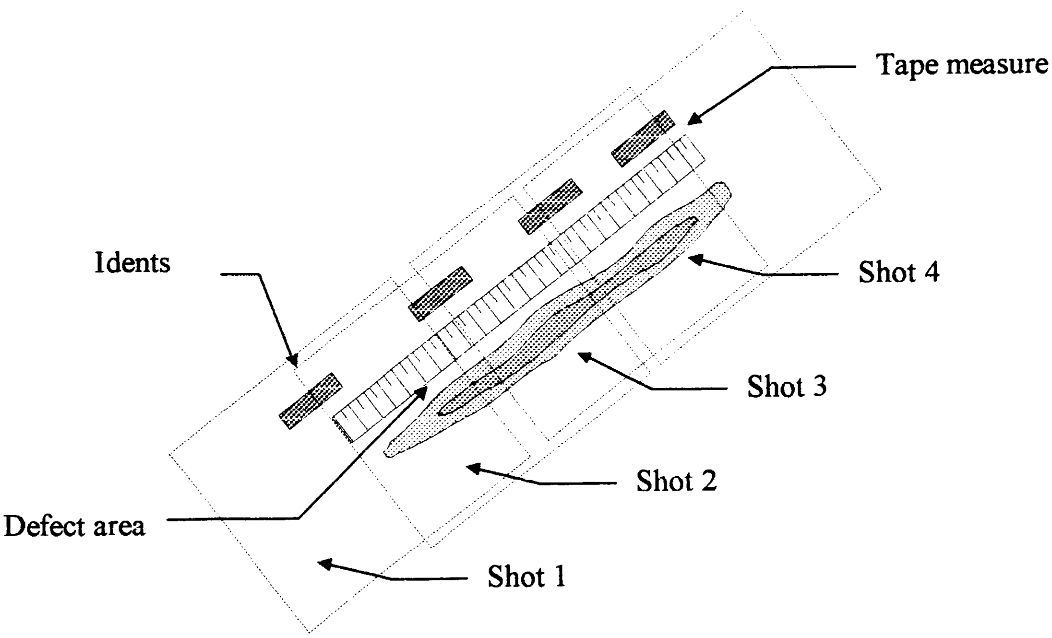


Figure 13.15 Defect Mosaic Showing Scale and Identification

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:

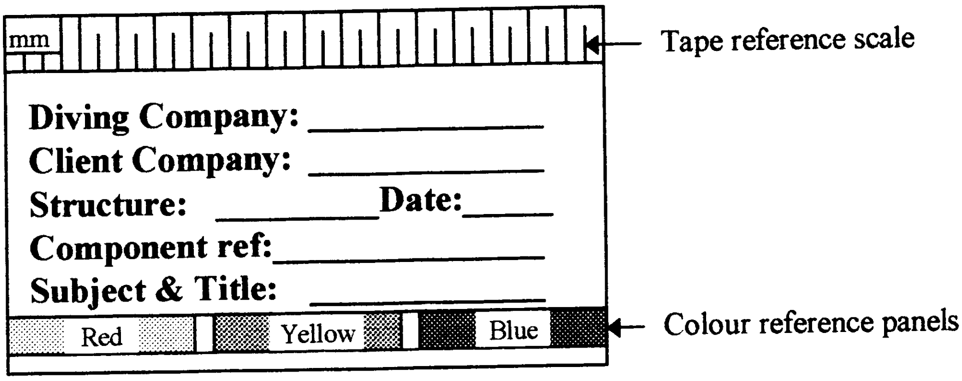


Figure 13.16 Photographic Identification Board layout

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

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:

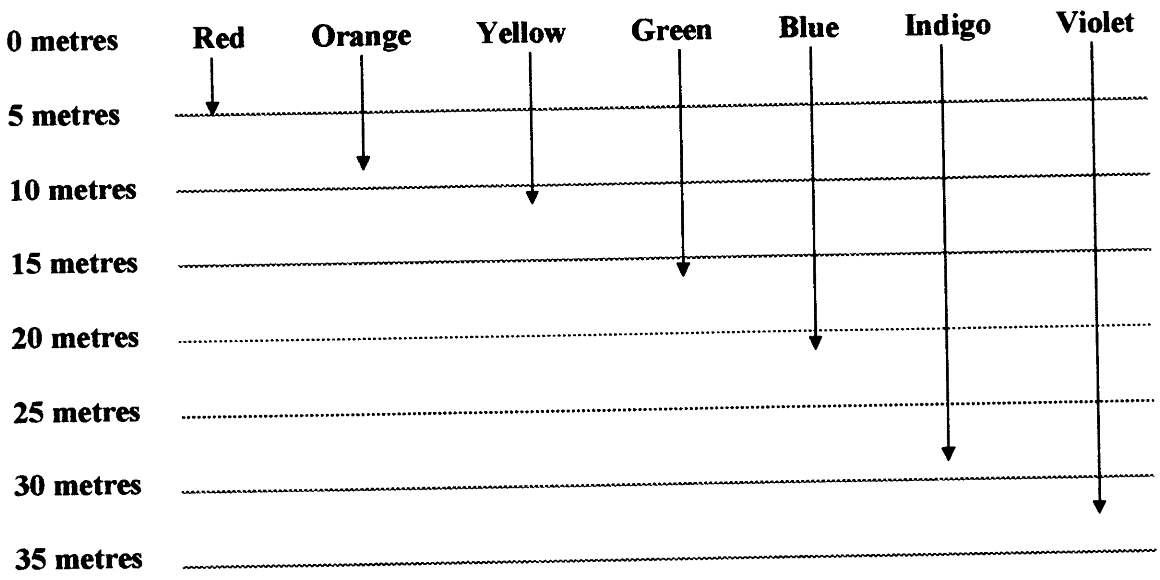


Figure 13.17 Absorption rates of light in seawater

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.

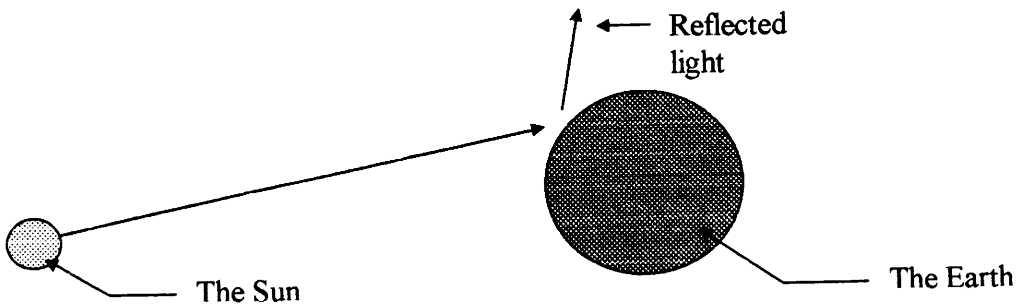


Figure 13.18 Reflection

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

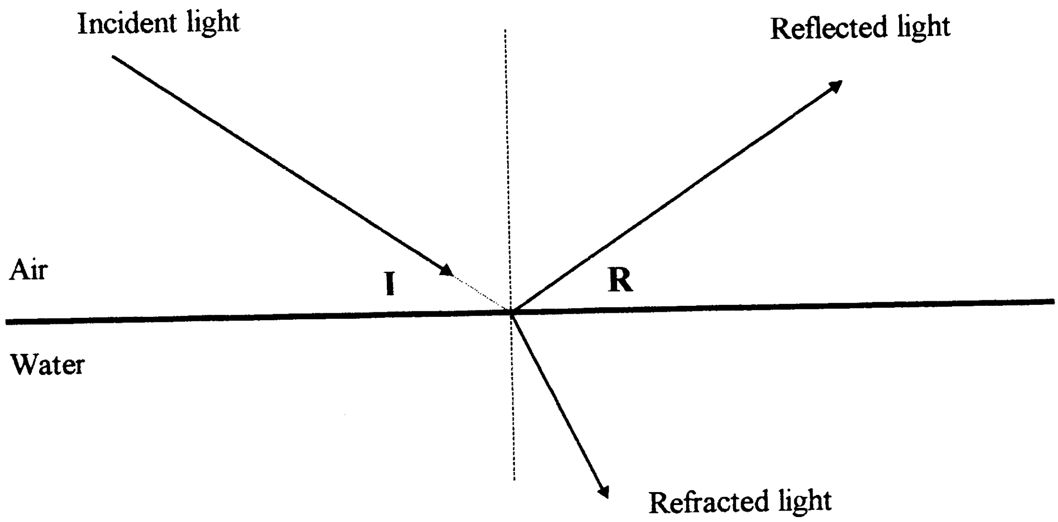


Figure 13.19 Refraction

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 facemask 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

The normal method of lighting used when taking photographs underwater is as follows:

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:

$$\text{“f” stop to use for the photograph} = \frac{\text{Guide number}}{\text{Distance to the subject}}$$

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

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

f-stop to be set will be f11

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.

When using both 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.

LIGHT PLACEMENT

When using 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 off 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.

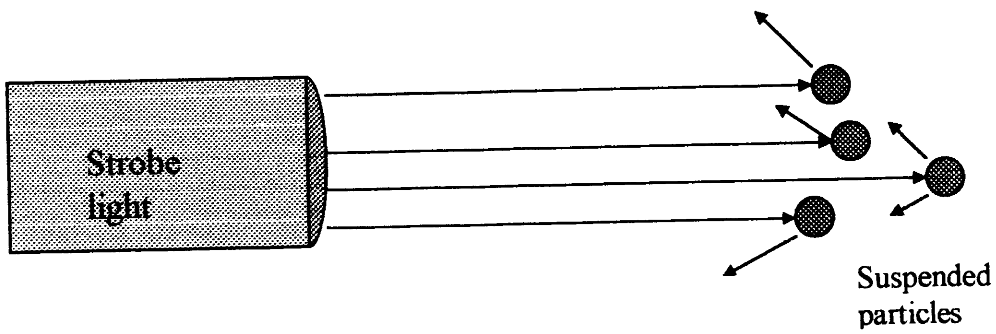


Figure 13.20 Backscatter

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 would not enter the camera.

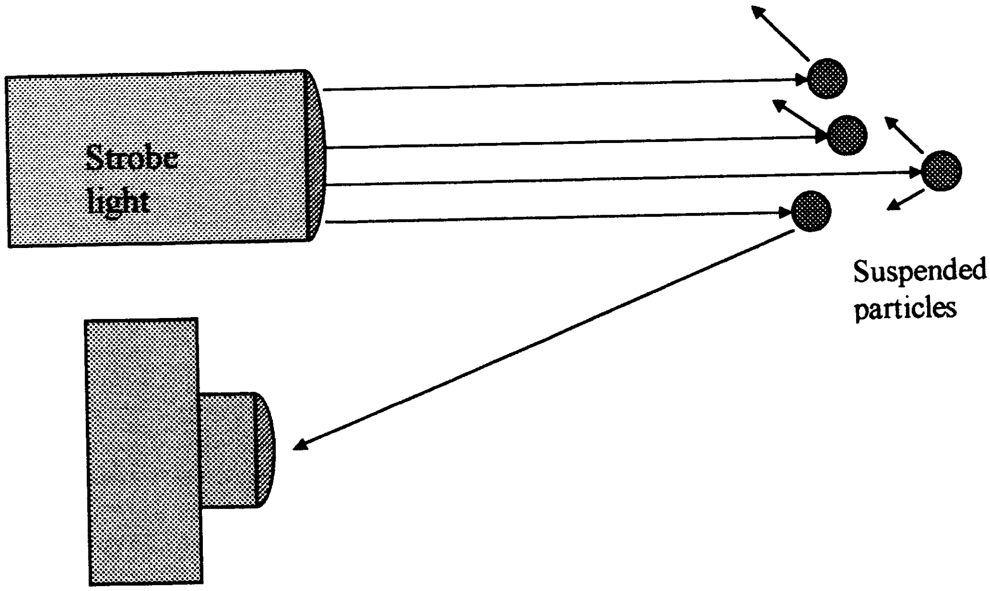


Figure 13.21 Backscatter the reflected light can enter the camera lens.

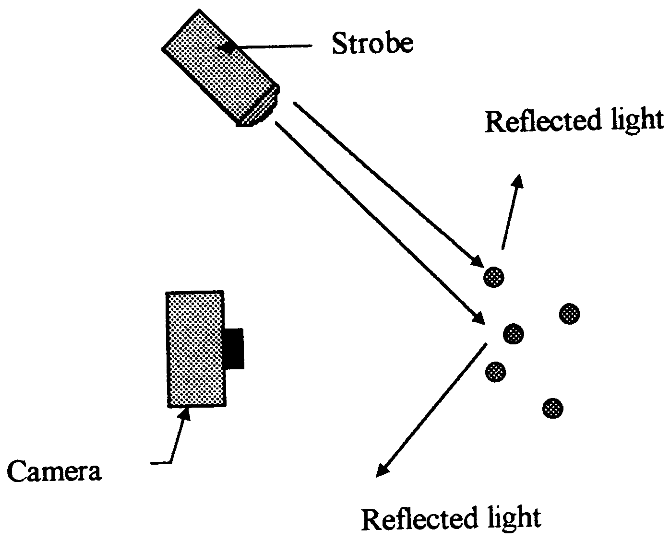


Figure 13.22 Avoidance of Backscatter

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

Photogrammetry is stereo photography that is assessed by using computers, it 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.

Photogrammetry 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.

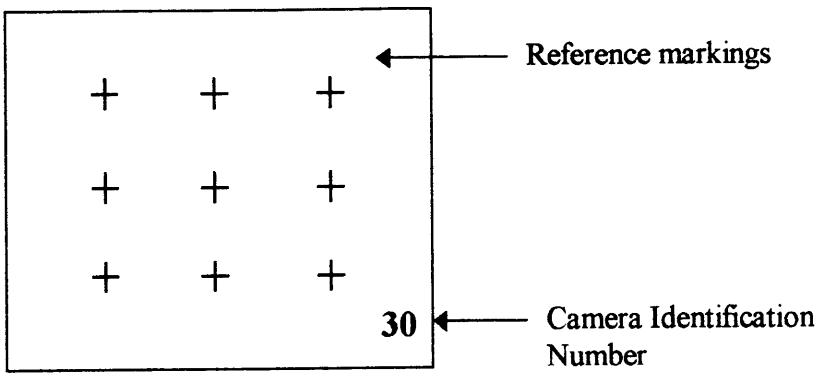


Figure 13.23 The Reseau plate, note that sometimes the plate may even have a scale printed on it to aid referencing

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. The point at which both lenses are aimed is termed the Principal Point.

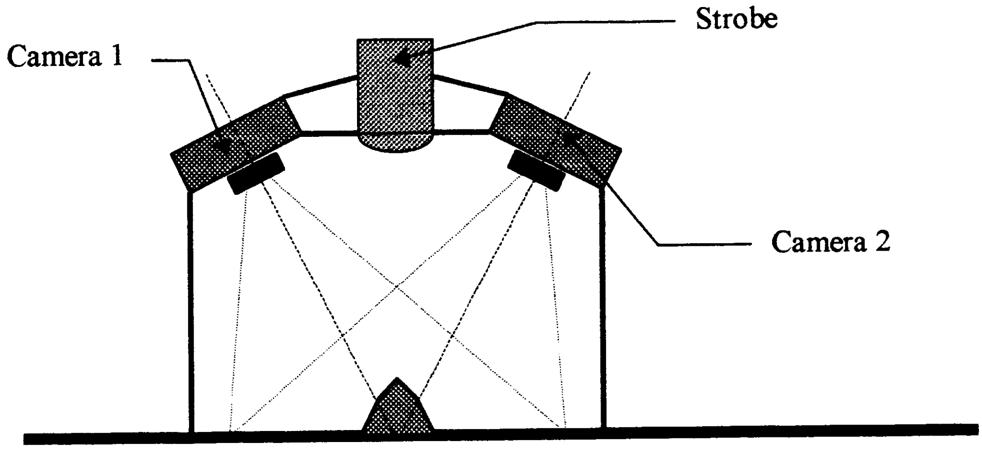


Figure 13.24 Photogrammetry Camera Arrangement

The Principal Point is the point at which both of the cameras or lenses are aimed.

When using the above system it will normally be important to include a block of known dimensions in the pictures, this will be used to scale other features evident in the photographs.

Regardless of the type of photography it will be imperative that all settings are correct before taking any photographs, this should include ensuring that the flash synchronisation is correct. Also an accurately completed photographic log sheet must always 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)**
Signed:	**Client:**	**Controller:**

Figure 13.25 Photographic Log Sheet

Care of a camera for in water use

Prior to use:

1 Charge batteries and fill out any charging log sheets
2 Select film
3 Pre set camera as required ("f" stop, Shutter speed & Focus)
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 Set up Data chamber (Day, date etc)
8 Inspect and maintain all camera and strobe seals and sealing faces
9 Close camera and strobe and ensure watertight integrity
10 Take test shots of photo board with colour reference etc & log them
11 Fit to vehicle or give to the diver as required
12 Switch on the camera and strobes as required
13 Remove the lens cap

Post Dive:

1 Switch off strobe & camera
2 Rewind or wind on the film
3 Wash the system in fresh water
4 Dry thoroughly
5 Open & remove film, label the film
6 Lightly grease O'rings (with the appropriate lubricant)
7 Store in a clean dry environment
8 Process film
9 Complete photolog sheet
10 Re-charge batteries as appropriate

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.

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 brace 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:

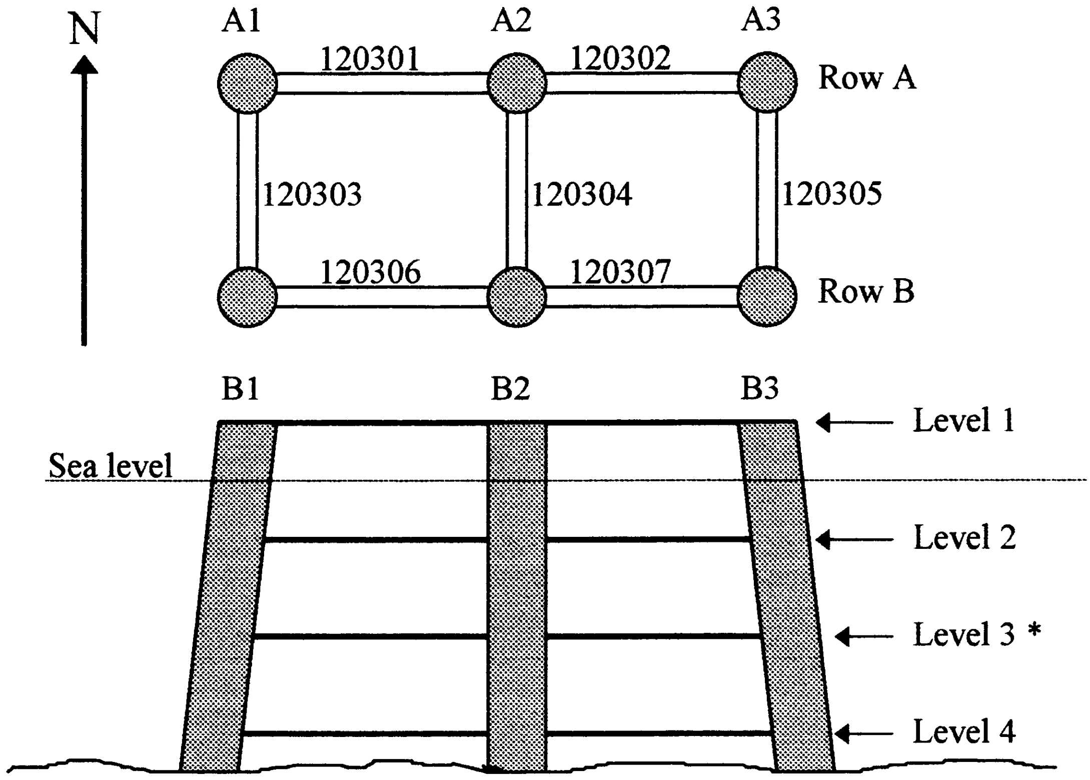


Figure 14.1 Structural Numbering Method

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.

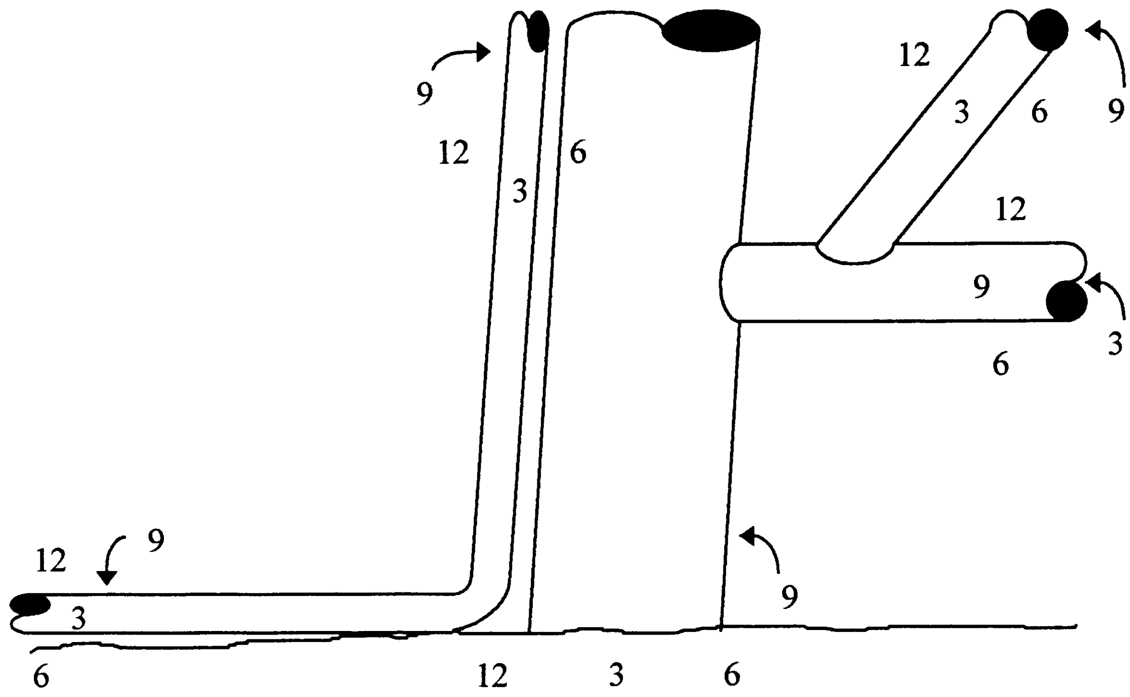


Figure 14.2 Typical Clock Position Markings

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

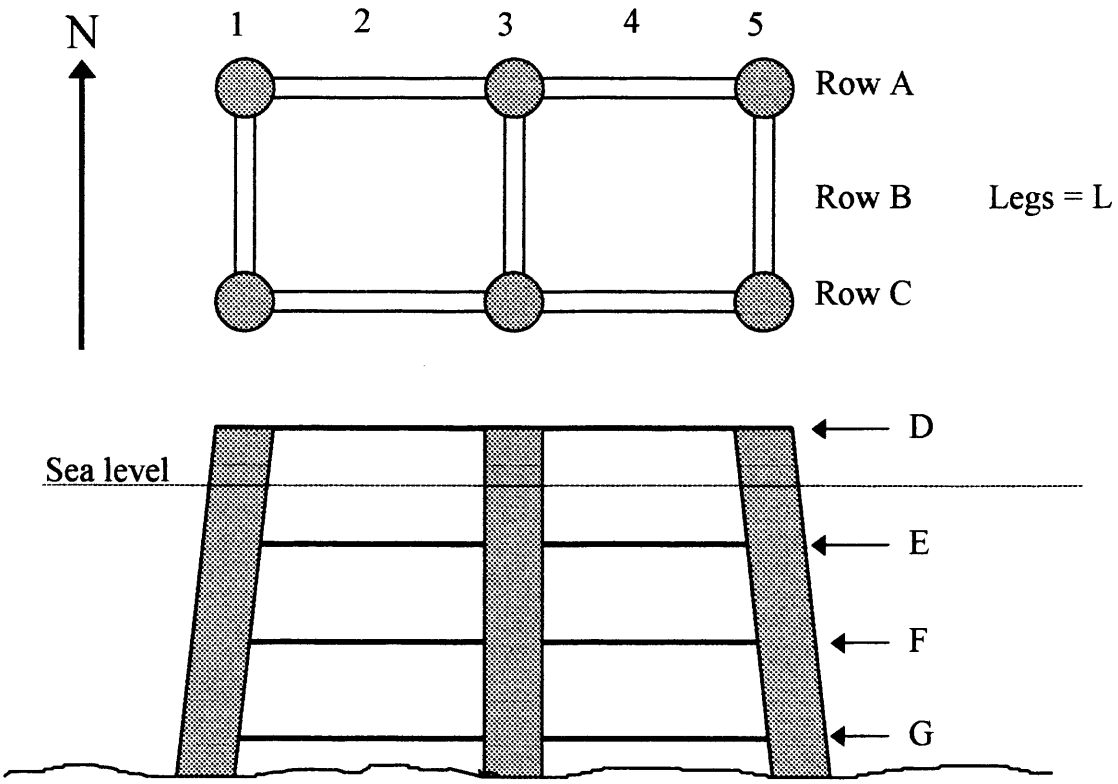


Figure 14.3 The Alpha Numeric Numbering System

It will be relatively easy to locate a component, for instance LC3 will be a leg on side C 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:

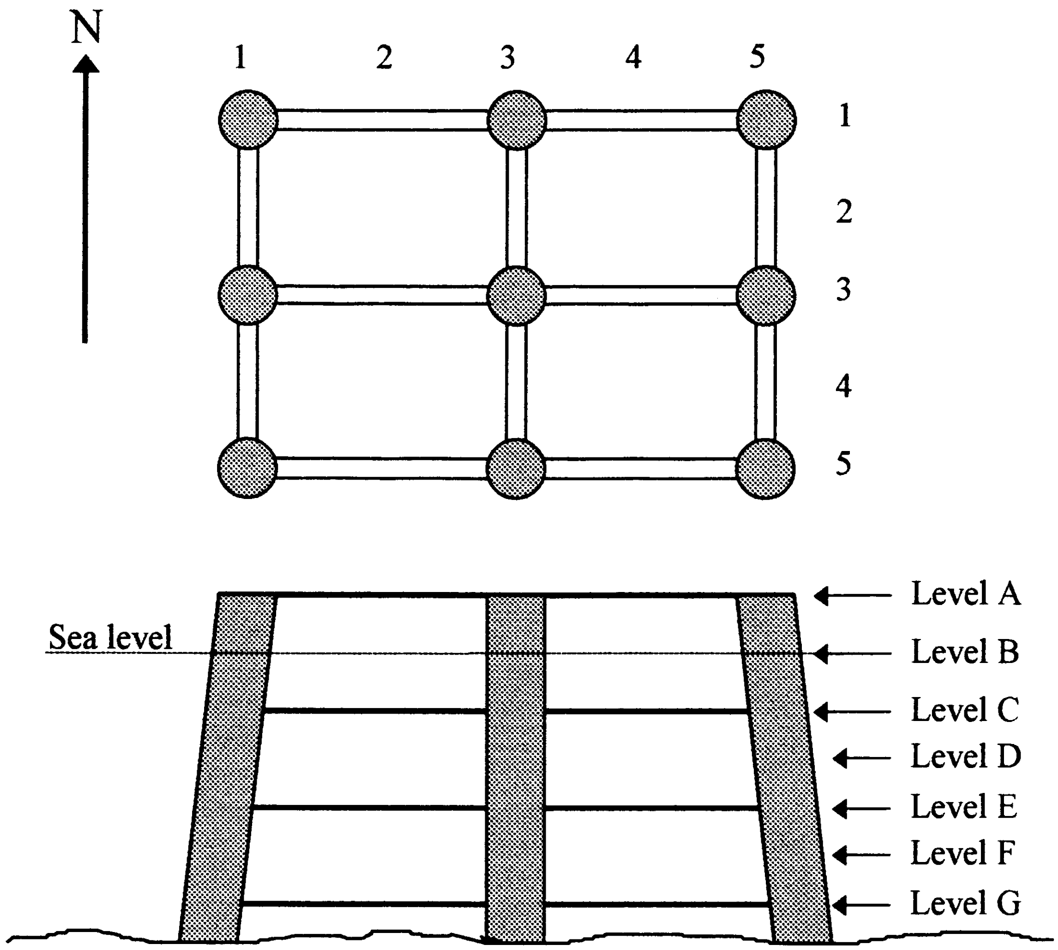


Figure 14.4 The Box Matrix System

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, features will normally be located with reference to the top edge and the left hand edge as shown in box B2 below:

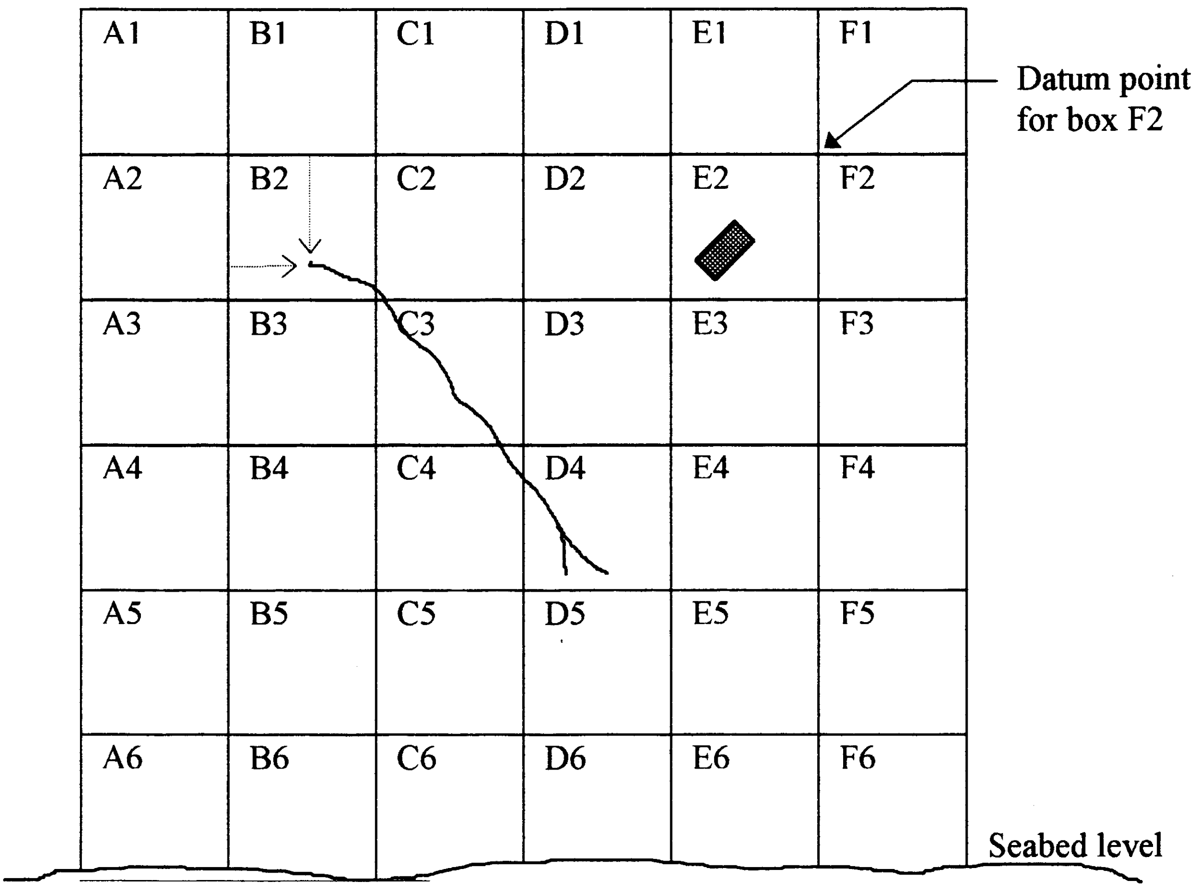


Figure 14.5 The Grid System

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:

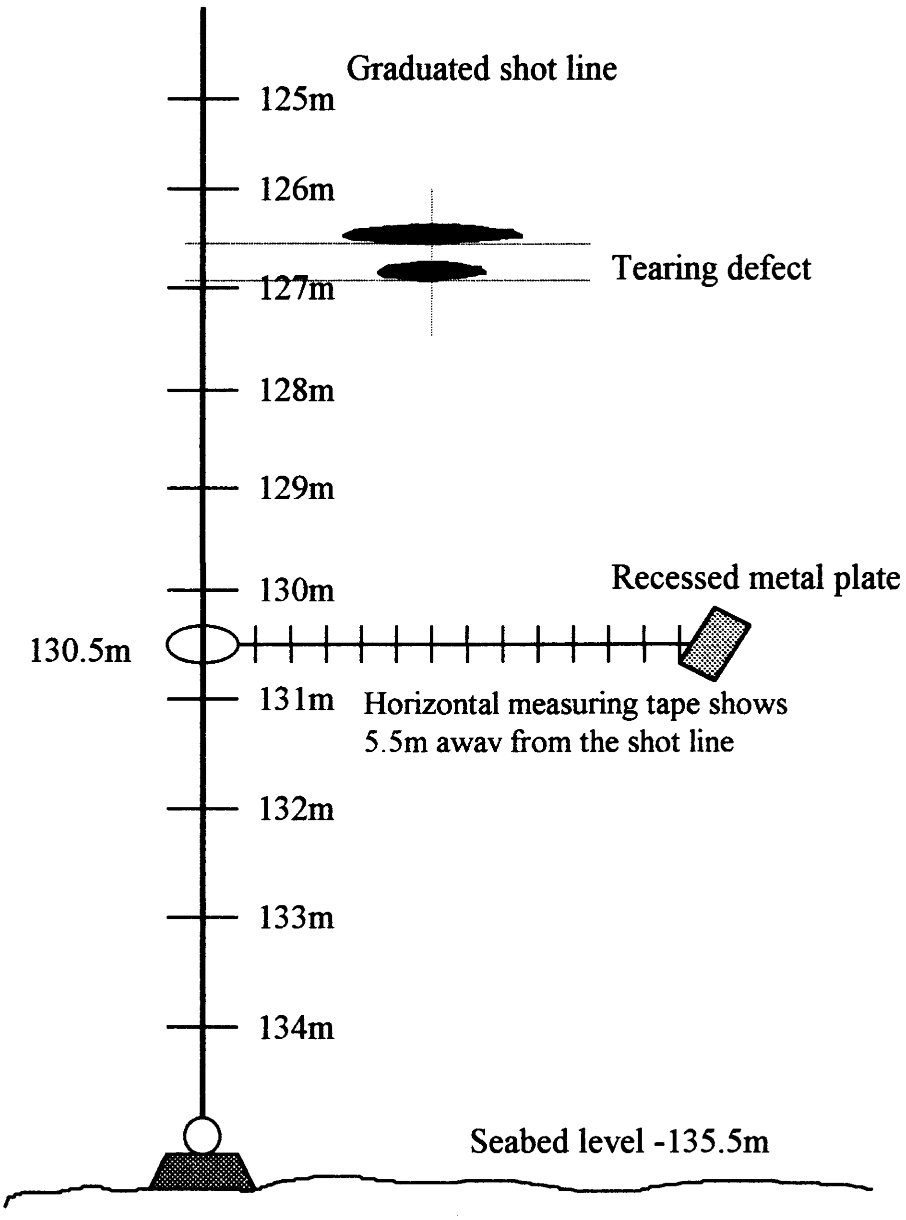


Figure 14.6 Shot Line and Tape System

3. Hydro-Acoustic Referencing (HPR)

As described in chapter six, the diver or ROV could be fitted with a transponder that can be accurately tracked using HPR, this is probably the easiest method currently available for accurate positioning of divers and ROV on a concrete structure.

THE USE OF STRUCTURE MARKINGS

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

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**	**1 41**
	Petroil Charlie Underwater	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.

CHAPTER 15

Video Inspection (CCTV)

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 when used with video recording techniques.

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, and 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.

iii) **Video Printer** - these are widely used today and will enable a "hard copy" to be made of an individual frame from the video, this is not going to produce such high resolution results as photography but this may not be of primary concern.

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. Silicon 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	

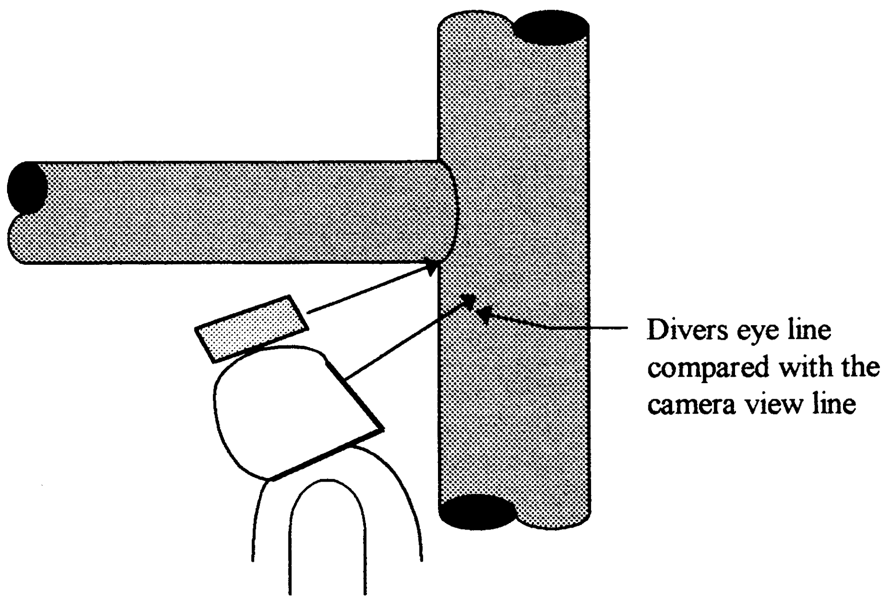


Figure 15.1 Hat Mounted Camera used for Close Work showing the problems of Parallax with close inspection using hat-mounted cameras.

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 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.

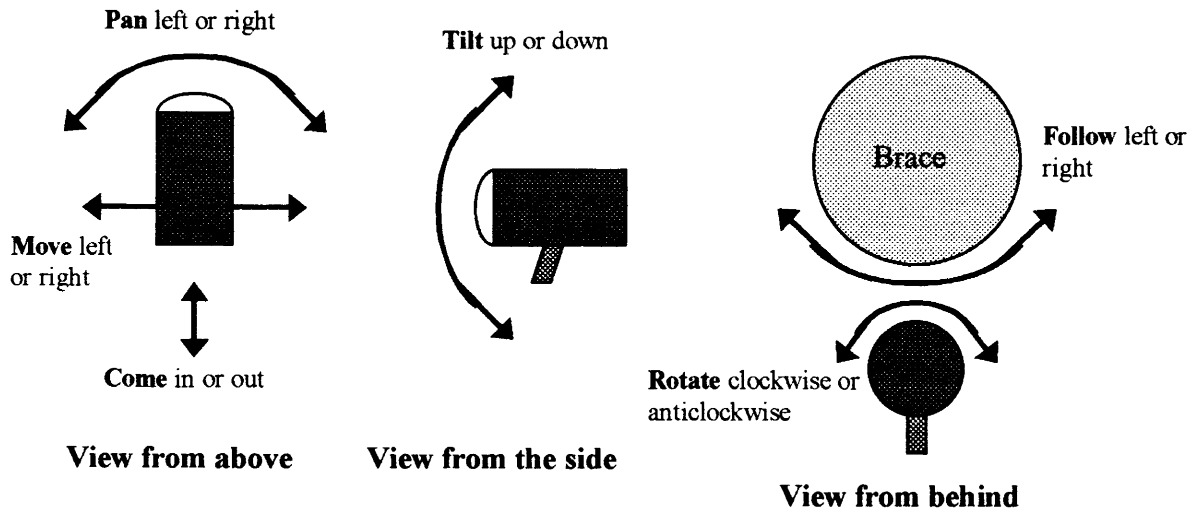


Figure 15.2 Camera Movement Terms

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:

<table>
<tr><td colspan="2">Company name:</td><td>Structure Id:</td></tr>
<tr><td colspan="2">Client name:</td><td>Video tape number:</td></tr>
<tr><td>Date:</td><td>Dive No:</td><td>Task group number:</td></tr>
<tr><td colspan="2">Location:</td><td>Dive spread/Diver name:</td></tr>
</table>

<table>
<tr><td rowspan="2">Task list code:</td><td colspan="2">Counter</td><td>All times and pauses must be logged</td></tr>
<tr><td>From</td><td>To</td><td>All CP measurements etc to be logged</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
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<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Client signature:</td><td colspan="2">Controller signature:</td></tr>
</table>

Figure 15.3 Video Log Sheet.

Care Of Video Equipment In The Offshore Environment

It is essential to ensure all equipment is maintained properly, this will ensure that the above-mentioned equipment is always ready for immediate deployment. The basic steps to ensuring the equipment is always in good condition are as follows:

1. Wash after use, using fresh water.
2. Inspect for physical damage prior to use, particularly seals etc.
3. Store in a warm dry environment.
4. Leave a lens cap on at all times when not in use.
5. Protect from physical abuse (dropping).
6. Do not leave the power on to the camera for long periods while the camera is not immersed as this can damage the seals.
7. Similarly with the lamp, do not leave the power on while on the surface.
8. Ensure any recording equipment is kept in a warm dry environment at all times.
9. Keep magnets away from tapes and video recording equipment.
10. Ensure all tapes are marked properly according to company policy.
11. If the pressure housing has been opened, ensure all seals are properly lubricated and seated prior to the equipment being used.
12. Ensure that two first generation copies are made if possible (2 tape machines running concurrently) or if not possible then the tape must be copied as soon as it is complete.
13. Break off the tabs, which allow over recording to ensure no accidental erasure.

CHAPTER 16

Corrosion, Corrosion Protection & 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 seawater 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.

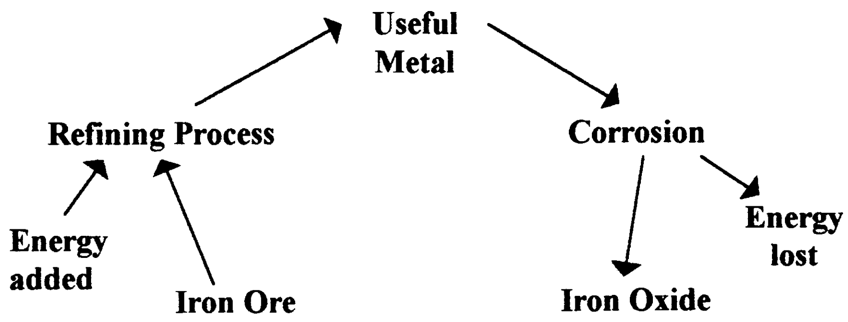


Figure 16.1 The corrosion circuit

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)

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).

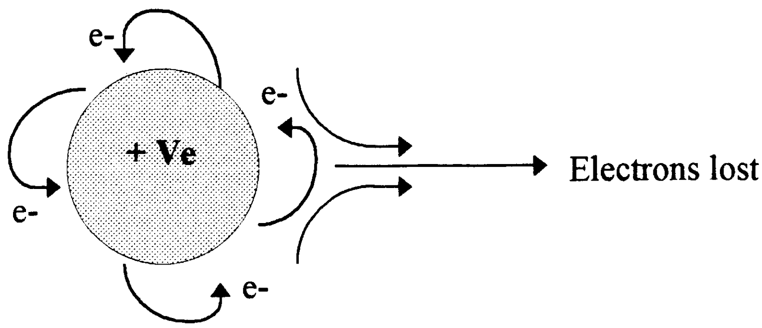


Figure 16.2 The Anodic Reaction

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).

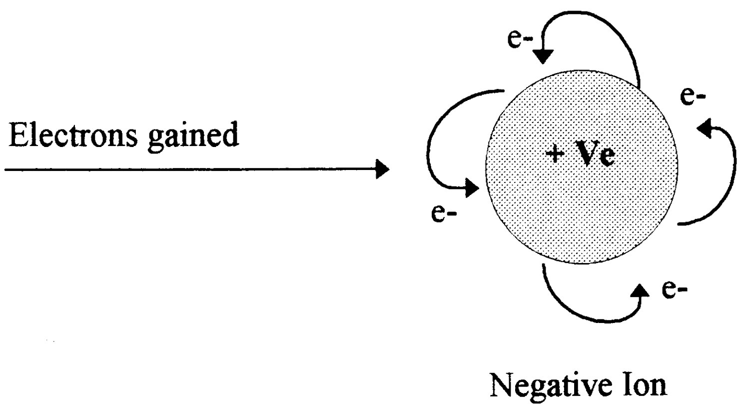


Figure 16.3 The Cathodic Reaction

This is called a reduction reaction. There are three reactions possible at the cathode they are as follows:

i) In an acidic solution:

$$2\,H^+ + 2\,e^- \Leftrightarrow H_2$$

ii) In addition if there is oxygen present in the electrolyte:

$$O_2 + 4H^+ + 4\,e^- \Leftrightarrow 2\,H_2O$$

iii) If the solution is neutral or alkaline then:

$$O_2 + 2\,H_2O + 4\,e^- \Leftrightarrow 4\,OH^-$$

The presence of Oxygen is very important, it governs the velocity of reaction and without it the Cathodic reaction could not occur in a conventional sense.

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.

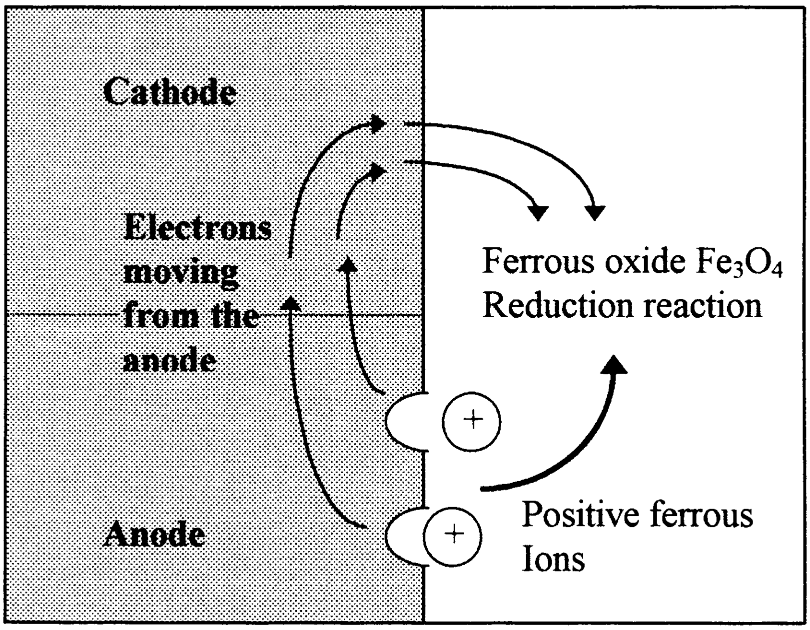


Figure 16.4 The Corrosion Circuit

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 brought 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
ii) Concentration cell corrosion
iii) Crevice corrosion
iv) Corrosion fatigue
v) Inter granular corrosion
vi) Grain boundary corrosion
vii) Stress corrosion
viii) Fretting corrosion
ix) Erosion corrosion
x) Biological corrosion

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 voltmeter across the two then there would be a measurable potential difference; in effect we have a battery.

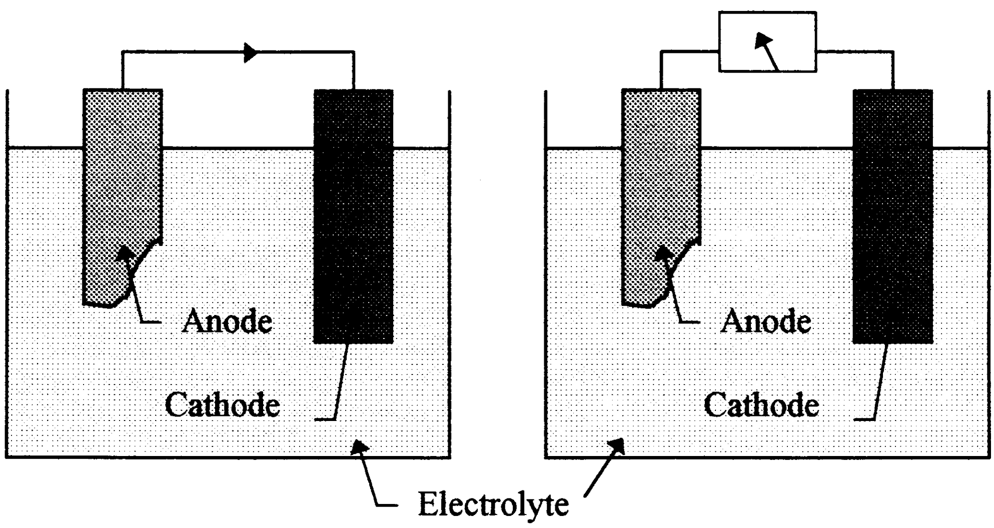


Figure 16.5 Dissimilar Metals in an Electrolyte

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 exists 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 **GALVANIC SERIES** 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	
Aluminium	↑
Zinc	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 16.6 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. When underwater this type of corrosion will be very difficult to detect during an inspection.

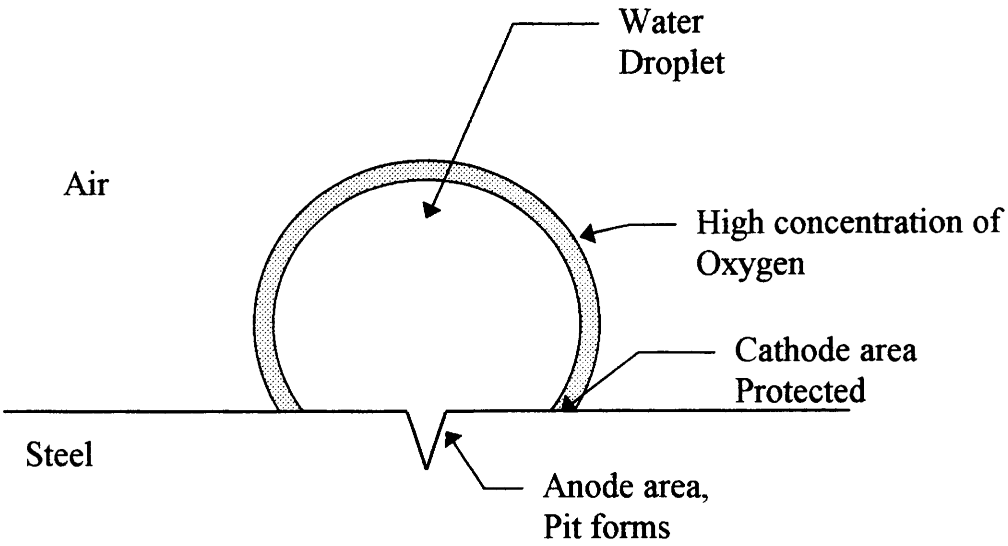


Figure 16.6 A Concentration Cell

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

The origin of crevice corrosion is an ionic imbalance caused by Cl^- increase, which may be as a result of restriction of flow in a crevice:

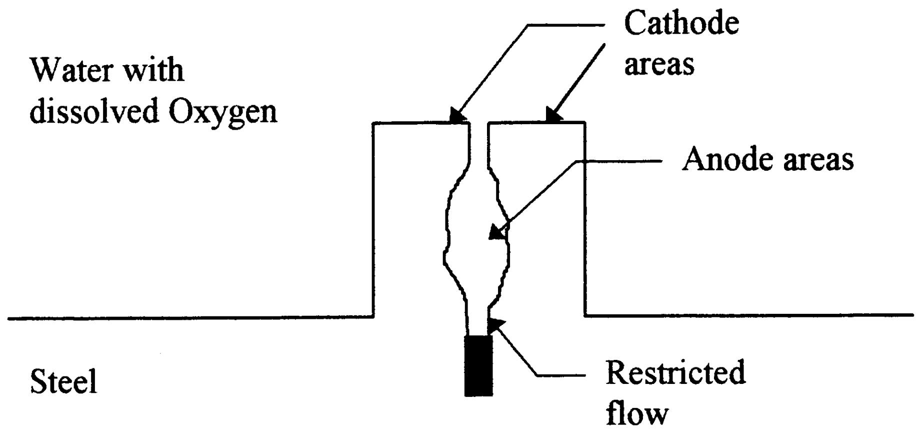


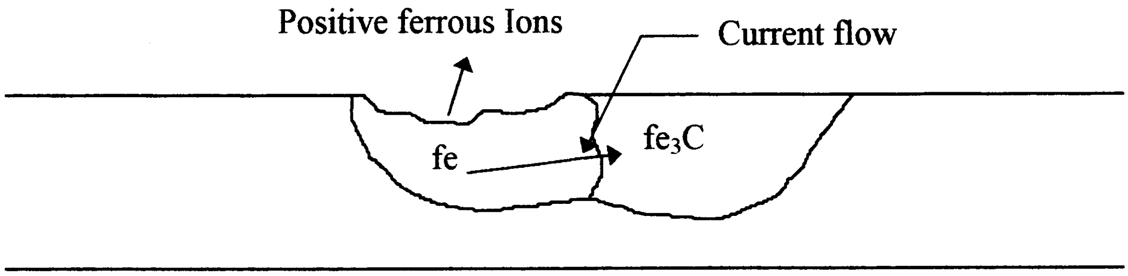
Figure 16.7 Crevice Corrosion on flange faces

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

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$_3$C = ferric 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.

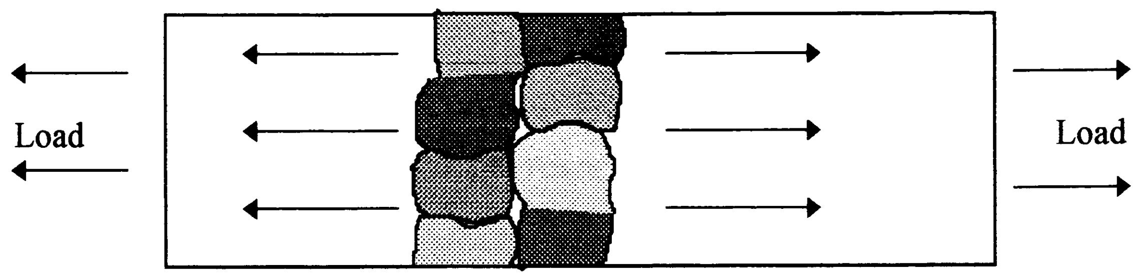


Figure 16.9 Stress Corrosion

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.

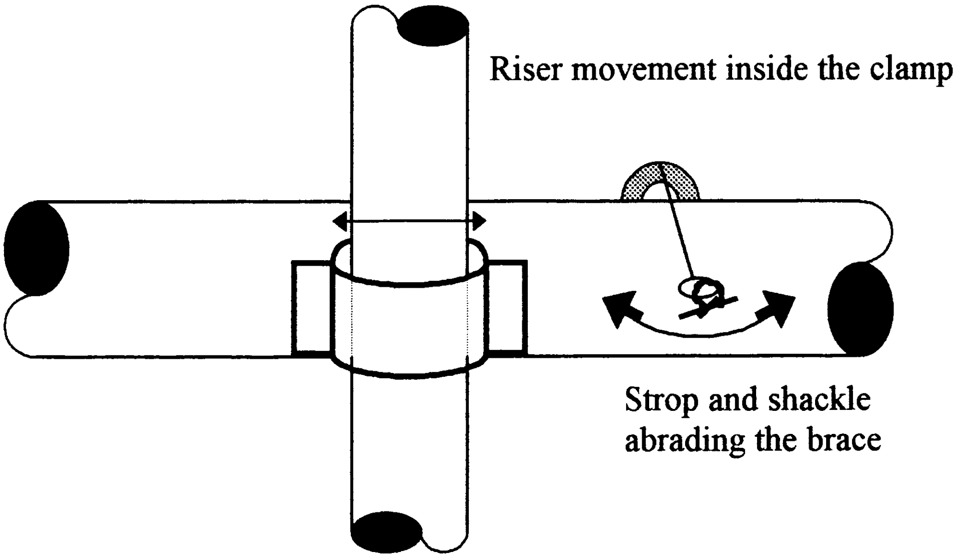


Figure 16.10 Fretting Corrosion

EROSION CORROSION

Erosion corrosion is essentially the same as the above but the abrasion is caused by particles carried in the fluid.

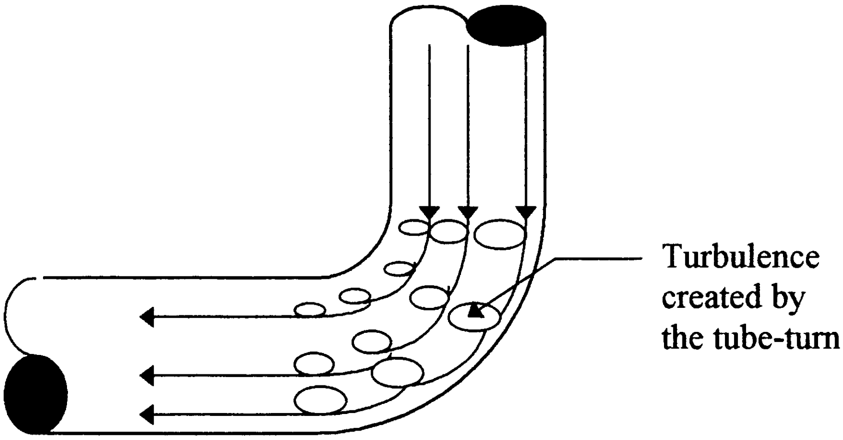


Figure 16.11 Erosion Corrosion

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 five 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)

Certain sulphate reducing organisms (SRB's) such as Desulfuvibrio Desufuricans 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 excludes the water from the structure there will not be a renewable supply of oxygen getting to the metal, so the area beneath the animal will become the anode and the ring around the edge will become the cathode.

v) By Creating Crevice Corrosion Between Hard Marine Growth

A crevice is any area where there is a restriction of access; this will reduce the amount of water flow, which can enter the area. Inside the crevice there will be a low oxygen area and outside the crevice there will be renewable oxygen available for reduction reactions, therefore inside the crevice becomes the anode supplying the outside of the crevice with electrons.

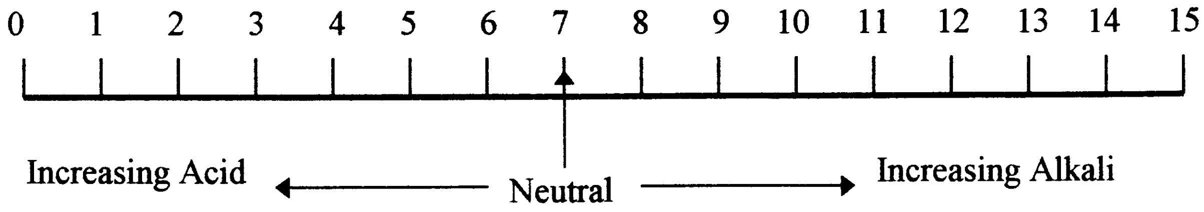
FACTORS AFFECTING CORROSION

The factors affecting corrosion are as follows:

i) pH level of the environment
ii) Temperature
iii) Flow rate of the water
iv) Oxygen content

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 pH 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 pH 11; this method of protection is termed passivation.



The above shows the pH scale.

ii) Temperature

In general an 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.

iv) Oxygen content of the water

As dissolved oxygen levels in the water increase, there will be a corresponding increase in the corrosion velocity. This will be the case unless the oxygen is completely absent, in which case anaerobic corrosion may well become very vigorous.

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 16.12), this is a result of laboratory testing using no flow and a constant temperature:

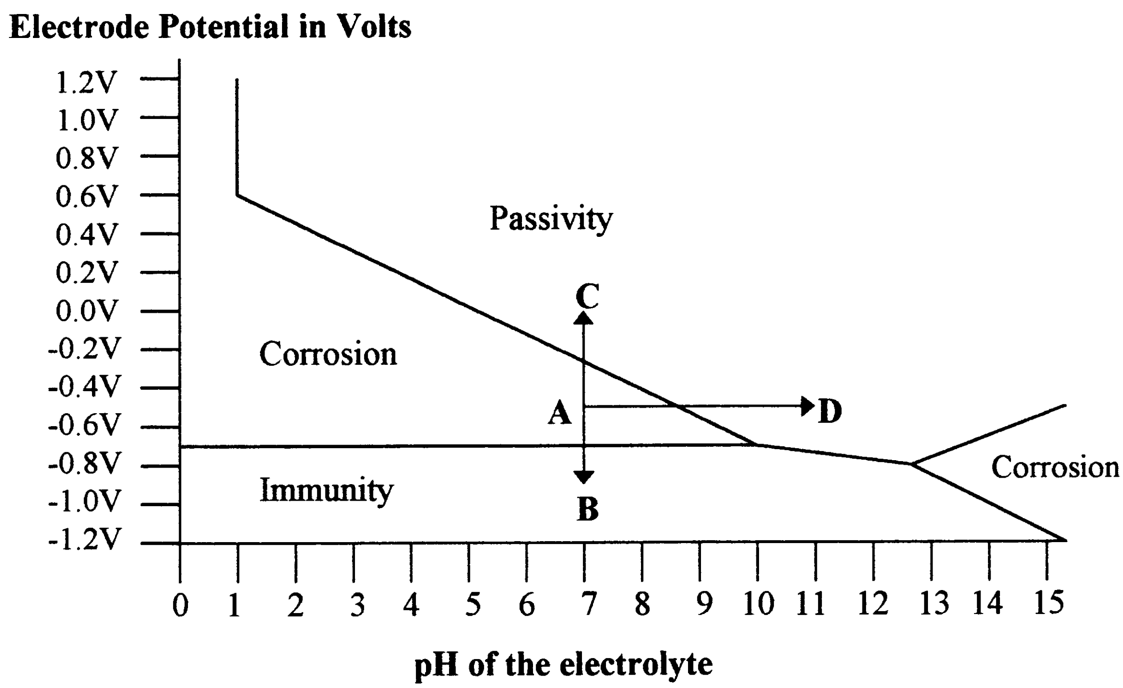


Figure 16.12 The Pourbaix Diagram for Iron in Water

CATHODIC PROTECTION

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:

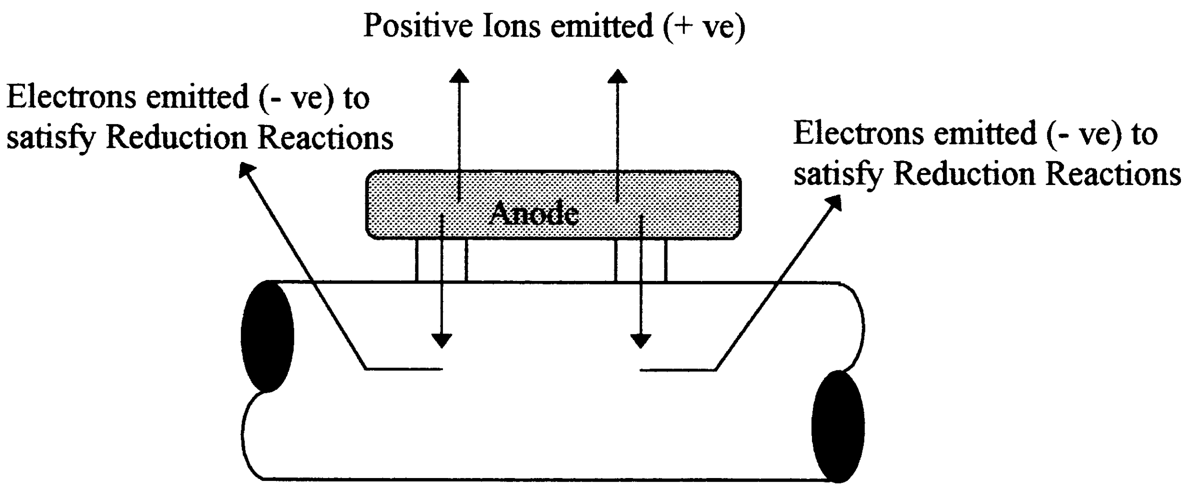
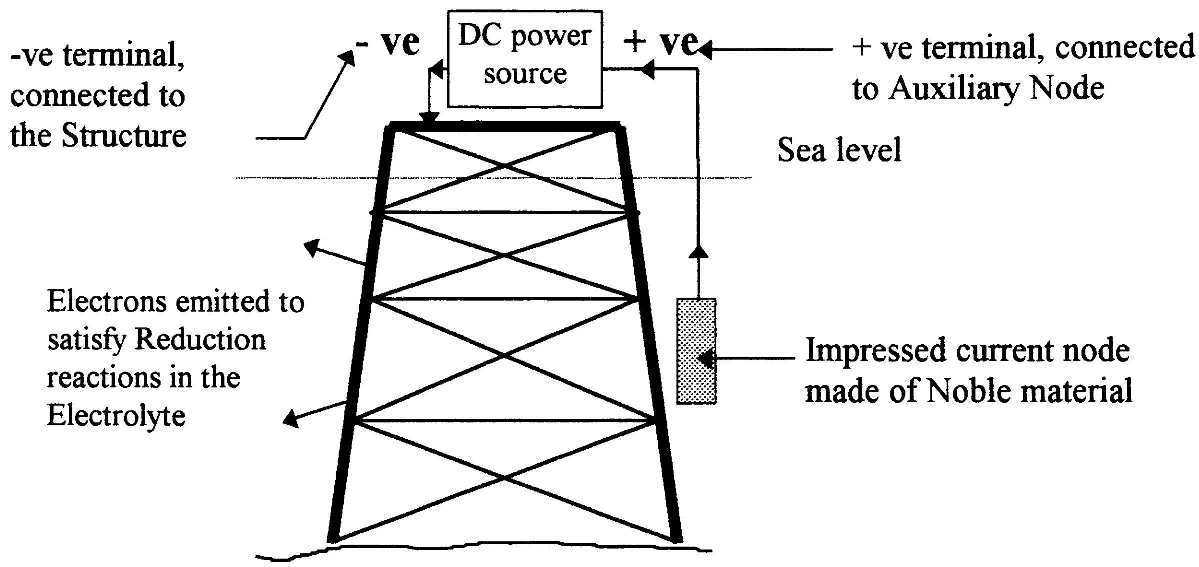


Figure 16.13 Sacrificial Anode Protection System.

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 and Tantalum**, perhaps the most commonly used substances are **Platinum sheathed Titanium and Lead Silver alloys.**

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.



Note: -ve means Negative and +ve means Positive.

Figure 16.14 Impressed Current Protection system

There are two ways in which an impressed current system can be installed on a structure:

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.

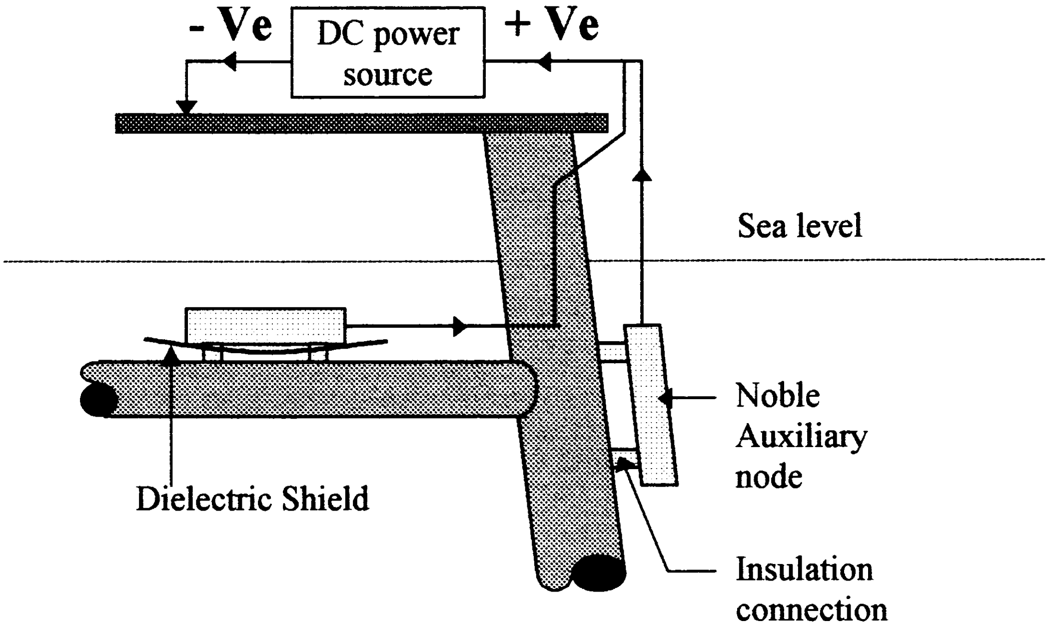


Figure 16.15 Platform Based Impressed Current System

Dielectric Shield

This is a device placed between the auxiliary node and the structure, it is used to ensure the electricity is directed in the right direction, it will not allow "short circuiting" of electrons from the structure to directly to a platform based auxiliary node.

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).

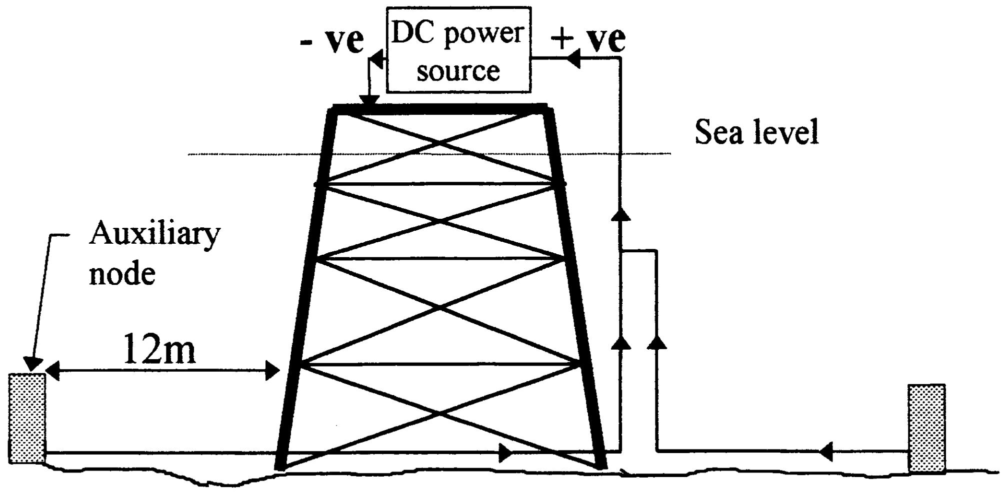


Figure 16.16 Remote Impressed Current Protection System

, Sacrificial and Impressed Current Protection systems are used extensively, they can often be employed simultaneously on the same structure, this is termed a “Hybrid” system. 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.

Electrical Measuring Methods

When measuring electricity during corrosion protection monitoring, we normally measure two variables, these are:

1. Voltage
2. Current flow

Voltage

The Voltage is a measurement of electrical potential. This is the Potential for electrical current (Electrons) to flow from one point to another. The unit is the Volt (1 Volt = 1000 millivolts).

Current Flow

The Current is a measurement of electrical flow. This is actually a count of the number of Electrons passing a given point per second. The unit is the Ampere (1 Amp = 1000 milliamps).

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:

Inspection Requirements

1) Visually assess the anode condition, noting the presence of any deposits, their type and extent.
2) Note anode wastage, this may be an estimate but should really be measured.
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) Location of metallic debris as this will increase the corrosion on the structure.
7) Local Cathodic Potential readings and photographs taken at intervals around the structure.

Cathodic Potential (CP) 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.

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 Buckleys 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.

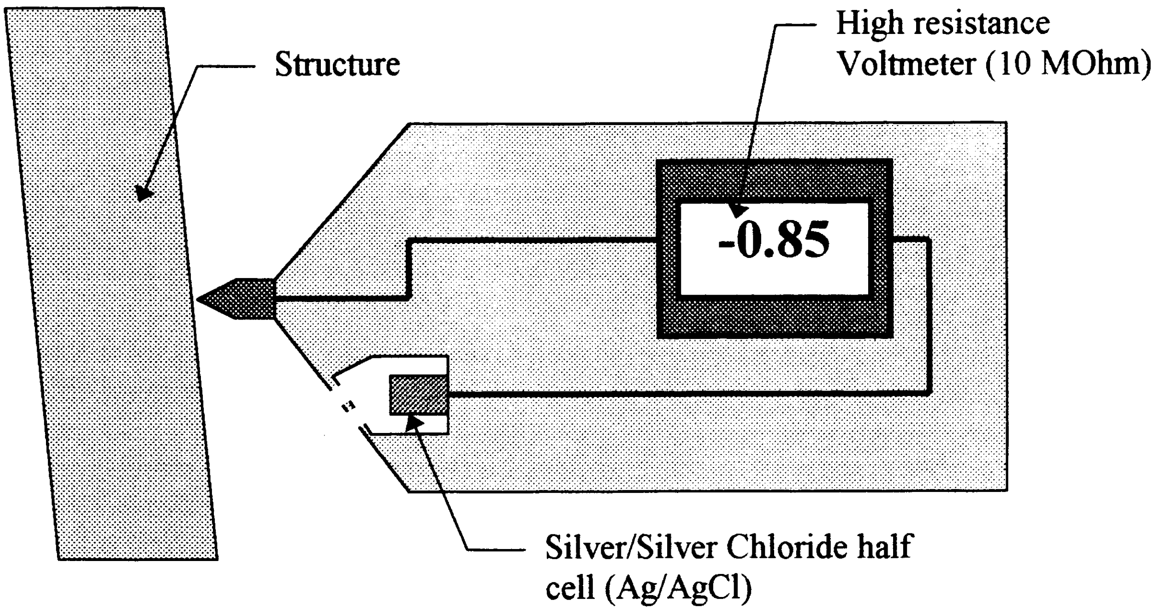


Figure 16.17 Self Contained Diver held Silver/Silver Chloride (Ag/AgCl) half-cell

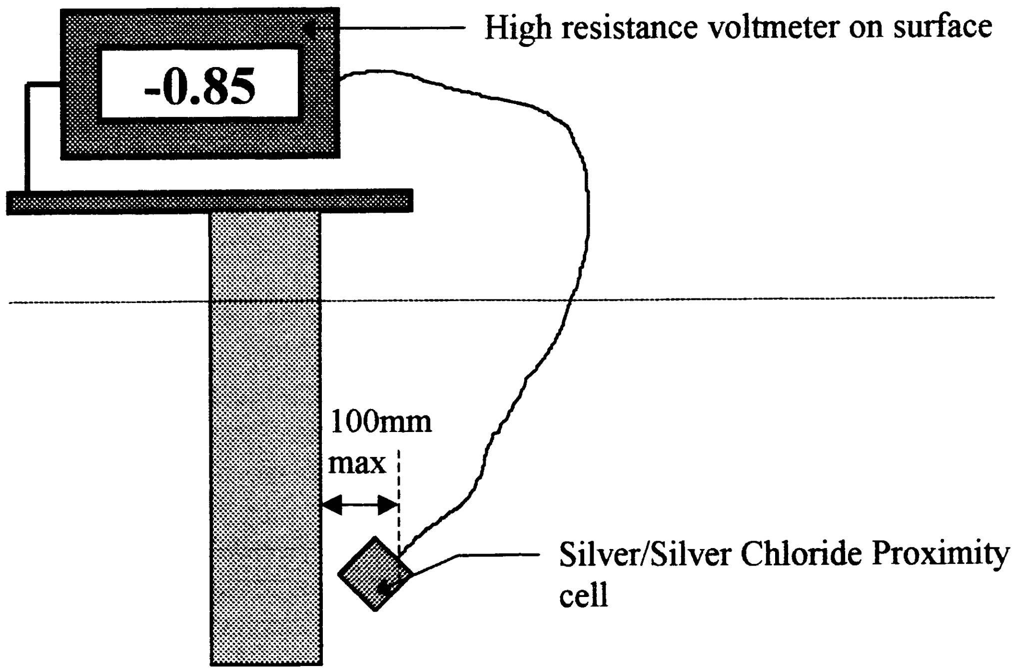


Figure 16.18 Proximity Probe using Silver/Silver Chloride half cell

Procedure For The Use Of Diver Held Cathodic Potential Meters (Cp)

In order for any meter or inspection technique to be used properly and thus achieve the correct results, 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 & ensure that a qualified diver is available to take the readings.
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 seawater, which has not come from a fire main for a minimum of **<u>THIRTY MINUTES</u>**. 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 a Zinc block; there may also be a requirement to test on a corroding mild steel block. From time to time a Saturated Calomel Electrode will also need to be used to check the zero of the meter, but this is normally not done on a daily basis, the frequency of testing with Calomel will be to client requirements. (Note: see calibration using calomel electrodes at the end of this chapter). **All calibration readings must be recorded on the log sheet**. (All of the expected readings can be found at the end of the procedure). **Ensure the CP meter and calibration block serial numbers are recorded.**

5. When the meter is at the survey site the calibration on zinc 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 and recorded** against zinc 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.
11. Submit the results to the client.

Note: Buckleys 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.

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.

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. However this system would not normally be used for pipelines due to the problems of obtaining the contact on the surface.

CALIBRATION PROCEDURES USING CALOMEL ELECTRODES

Equipment needed:

3 Calomel Electrodes
High Impedance Voltmeter (10 Mega Ohm), this will be a Digital Voltmeter (DVM)
Zinc Block with Clamp and Lead (Zinc should be 99.99% pure)
Plastic Bucket full of Seawater (not from a fire main)
Log sheets

First we must check that the calomel electrodes are in good condition, this is done by using 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 may often be plastic and so 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 Voltmeter.

e) Rinse the electrodes in fresh water.

f) Repeat the test with each of the possible permutations of electrodes.

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, 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 seawater (not from a fire main).

b) Remove the stainless steel tip from the meter.

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 seawater 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 **0 to –10mV**.

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.

When using ROV for CP readings, there will normally be a requirement for the readings to be displayed on the TV monitor in the ROV control room. The reading on the monitor is generated by electronics this will involve changing the actual reading from the probes into a digital reading for display on the monitor therefore the analogue to digital generator must be checked as part of the calibration procedure. This can be done by applying a known voltage to the input for the digital display and recording the resulting voltage displayed on the monitor. The displayed reading should be correct and if there are any inaccuracies there may be a need to create a calibration curve using various voltages prior to the equipment being used.

CALIBRATION OF THE DIRECT CONTACT PROBE ROV DEPLOYED

a) Ensure Calomel electrodes have been properly calibrated (As described above).

b) Soak contact CP probe 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.**

f) Disconnect the clamp from the Zinc block.

g) Take the Zinc block to the contact probe on the vehicle and while the probe is still immersed make contact with the Zinc block, record the reading given by the ROV CP system.

h) Compare both of the readings from the zinc block, there should be little or no difference, i.e. **0 to -10mV**.

CALIBRATION OF Ag/AgCl PROXIMITY CELL

If a proximity cell is to be used part of the calibration procedure may require that the whole cable length from the proximity probe to the topside unit be immersed in seawater while the calibration check is carried out in order to ensure that the insulation of the cable is complete. If there were a break in the insulation of the cable this could expose copper to the seawater and the result would be an inaccurate reading.

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 to 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)

Another method that can be used to assess the structures potential is to use a **high purity Zinc** electrode; this consists of a piece of zinc, which is placed at a specific location on the structure. This location may be at an area where the stress is high or where the protection is thought to be marginal, ZRE's 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.

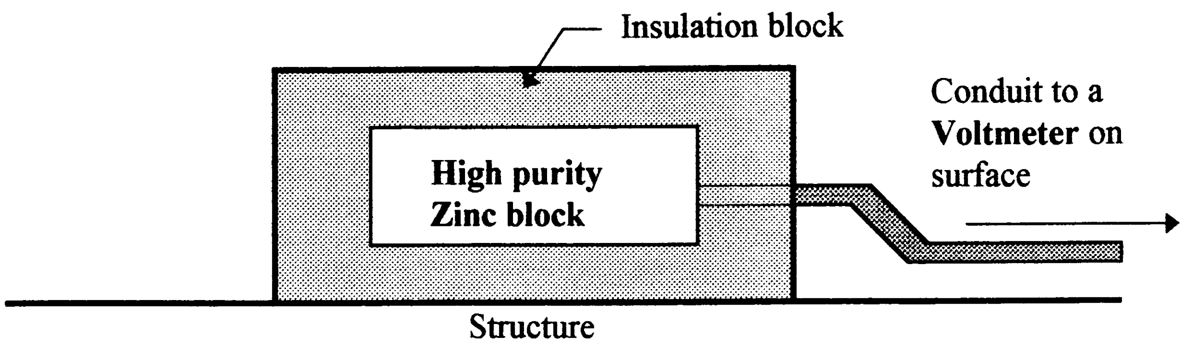


Figure 16.19 High Purity Zinc (Zn) Electrode (ZRE)

Monitored Anode

One other method by which an Impressed Current corrosion protection system can be monitored is by the use of a monitored anode, this is simply a sacrificial anode, which is insulated electrically from the structure at the anode location, it is only in electrical contact with the structure via an Ammeter (measuring electron flow, or current) that is placed in the topside control room. 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.

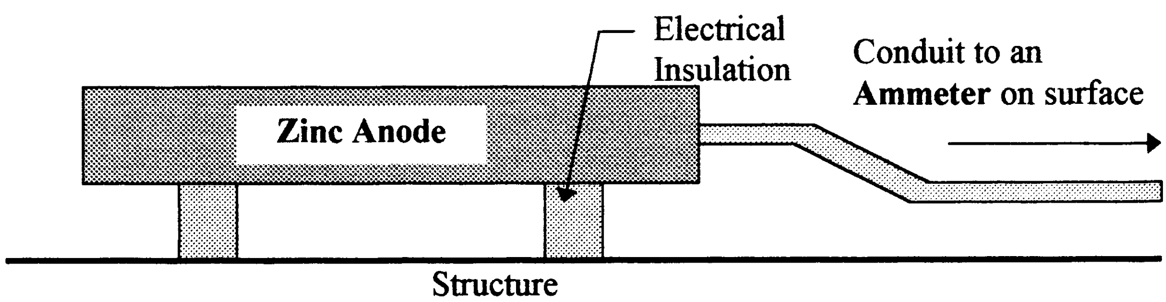


Figure 16.20 Monitored Anode System

The following is a sketch to show a summary of the various methods of protection monitoring mentioned above:

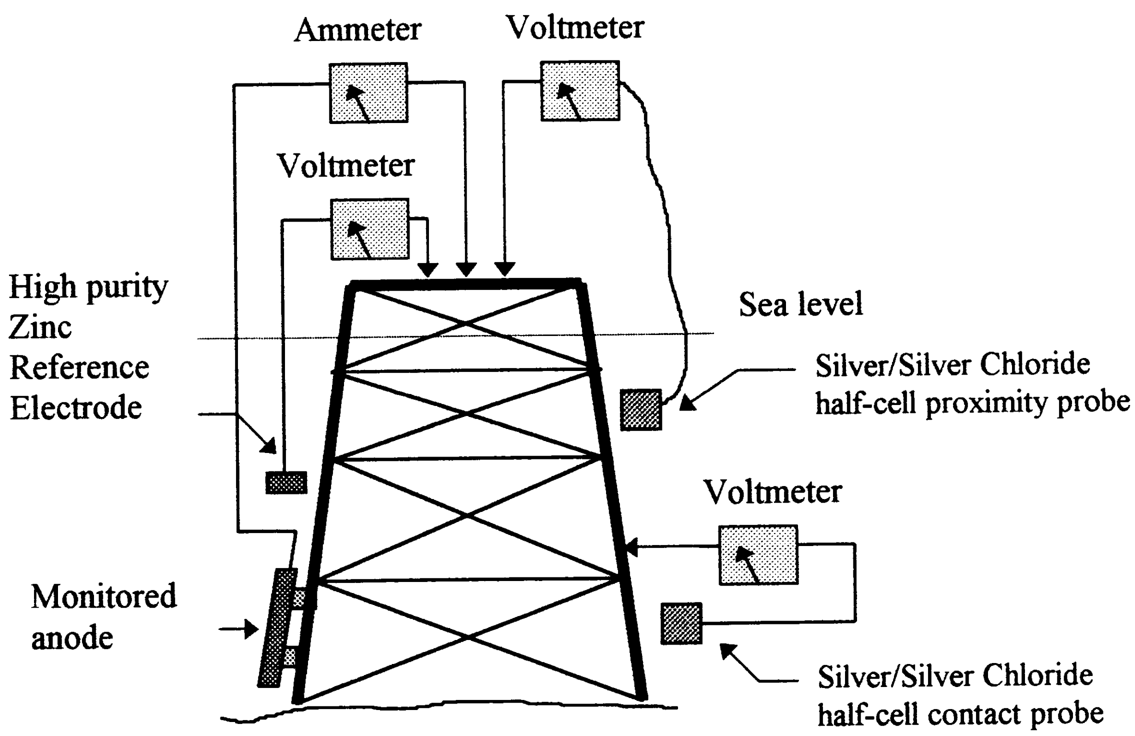


Figure 16.21 Summary of protection monitoring methods

CURRENT DENSITY

The current density needed to protect a structure is affected by local environmental conditions and can vary with time. For instance, according to recommended practices the initial current density required for a structure in the North Sea may be as high as 200mA/m^2 whereas in the Gulf of Mexico the level is two times lower (110mA/m^2) once the a North Sea structure has stabilised the density required may be 150 mA/m^2. This can be measured using a specialist probe either by a diver or by a Remote Operated Vehicle, if this is to be used; there is a need for the current density probe to be applied to the structure using the correct techniques and procedures.

ANODIC PROTECTION

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. **This method is never used to protect steel.**
All of the above are fine where the structure is constantly submerged but where the structure is not always under water (splash zone) 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 of 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.

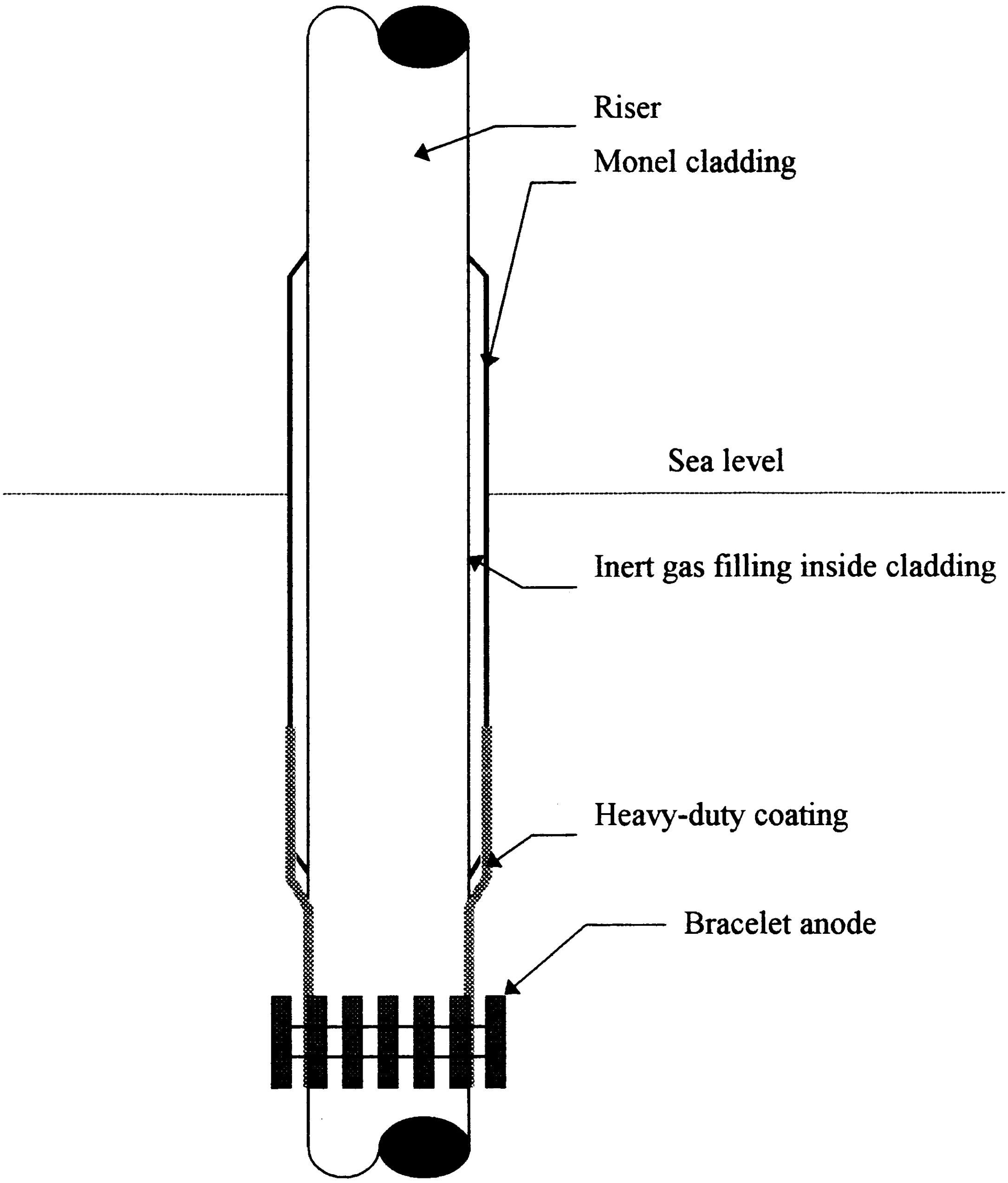


Figure 16.22 Monel Cladding

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 and normally even then the amount of steel exposed will be small so it will not require a large electron flow to give it the protection it needs. This is an effective method for smaller items as can be seen from the length of time some household items can withstand corrosion if they use this method. The problem is that it is not feasible to coat large structures in the same way, as the structure normally needs to be dipped in a bath and electroplated.

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 topcoat, 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.

When asked to inspect coatings the following will need to be noted: -

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 (Anaerobic Corrosion).

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.

CHAPTER 17

Ultrasonic Digital Thickness Meters (DTM) And Their Use.

Digital thickness meters will be used primarily for thickness measurement and will give the distance to the major reflector only; this is seen as their major limitation.

Sound

A series of mechanical vibrations, which result from the back and forth particle motion in the material. It can travel through solids liquids and gases although it will travel at different velocities depending on the density and hardness of the material.

Cycle

The movement of a particle, from rest to its maximum deflection one way, and then back through its mid-point, and out to the maximum deflection the other way, finally returning to the start point, therefore **one cycle is one complete particle vibration** (see figure 17.1).

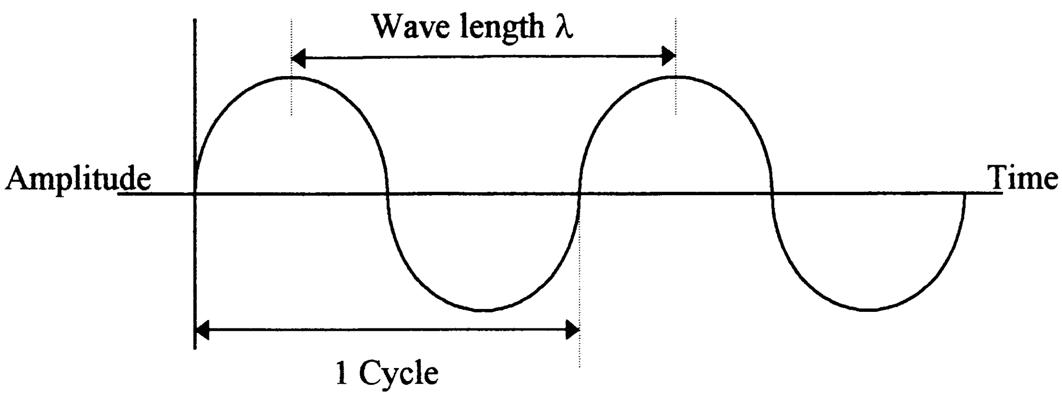


Figure 17.1 The Cycle

Frequency

This is the number of complete particle vibrations in a given time (cycles occurring per second), usually expressed as <u>HERTZ</u>; one Hertz is one cycle per second.

$$\text{Frequency (f)} = \frac{\text{Number of cycles}}{\text{Time for that number of cycles}}$$

1 Cycle per second = 1 HERTZ (1 Hz.

1,000 Cycles per second	=	1 KILOHERTZ (1 KHz.
1,000,000 Cycles per second	=	1 MEGAHERTZ (1 MHz.

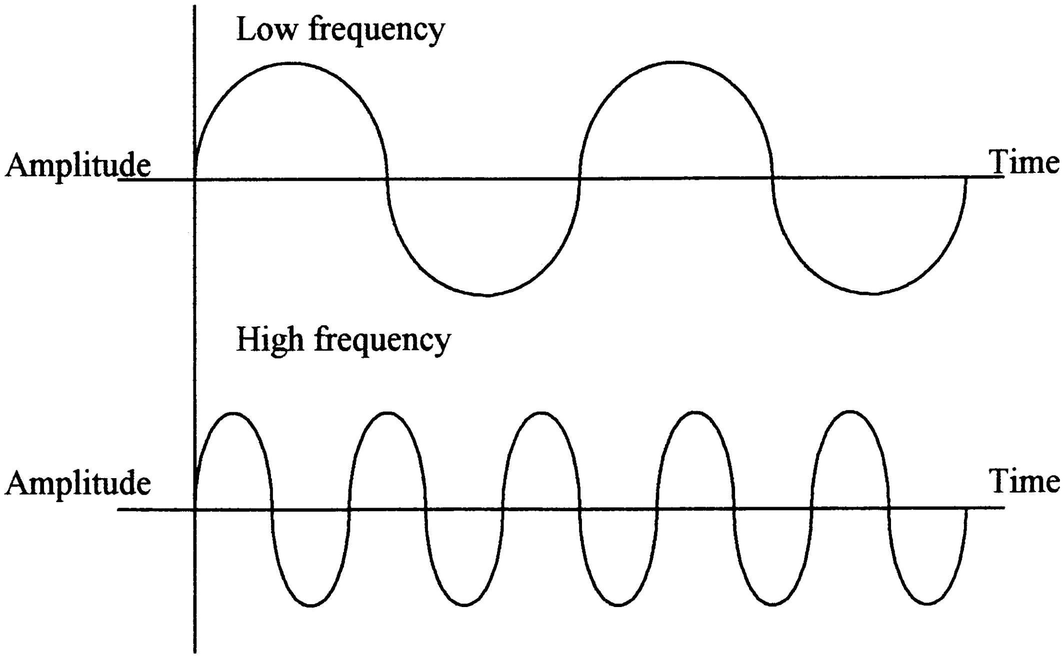


Figure 17.2 High and Low Frequency Comparison

Sound can be split up into three categories as follows:

1. Infra sound - 0 to 16 hertz (below audible range).
2. Sonic sound - 16 hertz to 20,000 hertz (audible sound).
3. Ultrasound - 20,000 hertz and above (above audible range).

We use ultrasound because high frequency sound will have superior penetrating power. Also Ultrasonic sound, being inaudible, allows us to use very high power levels which would cause damage to our ears if the audible range were to be used. The maximum sound level allowable for continuous exposure is 90 decibels (db); exposures to sound above 120 db will cause permanent damage to our ears.

The normal frequency used for the testing of steel is between 1 MHz and 6 MHz.

Period

The time taken for one complete particle vibration (one cycle). Symbol used for period is T.

$$T = \frac{1}{f\,(Hz)}$$

Velocity (speed of the wave)

The distance travelled in a unit of time, i.e. miles per hour, kilometres per hour or in our case metres per second (m/sec). Some useful velocities from our point of view are: -

Air (@ 1 bar)	= 330 m/sec
Water	= 1480 m/sec.
Perspex	= 2730 m/sec (compression wave).
Steel	**= 5960 m/sec (compression wave).**
Steel	= 3245 m/sec (shear wave).

Wavelength (λ Lambda)

The distance travelled by the beam during one cycle of energy. In different substances the sound will travel at different rates due to the differing densities and hardness of the material. **The smallest detectable defect will be one half of one wavelength**. The formula for working out the wavelength of an ultrasonic beam is as follows: -

$$\text{WAVELENGTH } (\lambda) = \frac{\text{VELOCITY OF SOUND IN THE MATERIAL}}{\text{FREQUENCY OF THE ULTRASOUND}}$$

OR

$$\lambda = \frac{V}{f}$$

For example, if we have a 3 MHz probe working in steel (velocity of 5960 metres per second).

Note: When working out this formula all of the values should be in base units. This means that the velocity will need to be in millimetres, so we need to multiply the 5960 by 1000. The frequency will need to be in cycles per second or Hertz, because the wavelength worked out will be in millimetres.

$$\lambda = \frac{5{,}960{,}000}{3{,}000{,}000}$$

$$\underline{\lambda = 1.986 \text{ mm}}$$

SOUND OBEYS THE LAWS OF LIGHT WHICH ARE:

a) REFLECTION

The angle of incidence is equal to the angle of reflection, (i = r) with no loss of intensity at the reflected face.

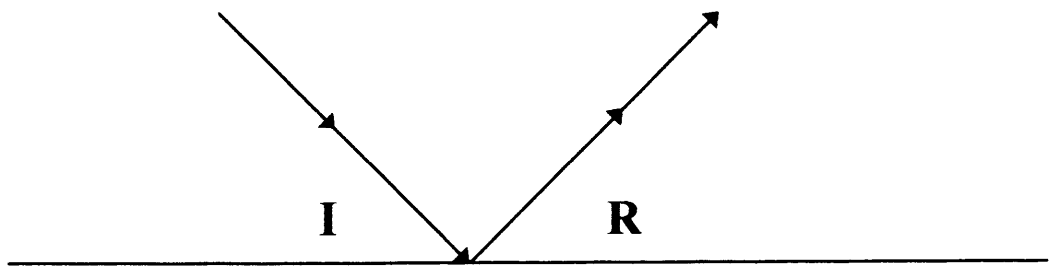


Figure 17.3 Reflection

b) REFRACTION

As a sound beam crosses the interface (boundary between the two materials), from one medium to another it will either slow down or speed up, resulting in a change of direction.

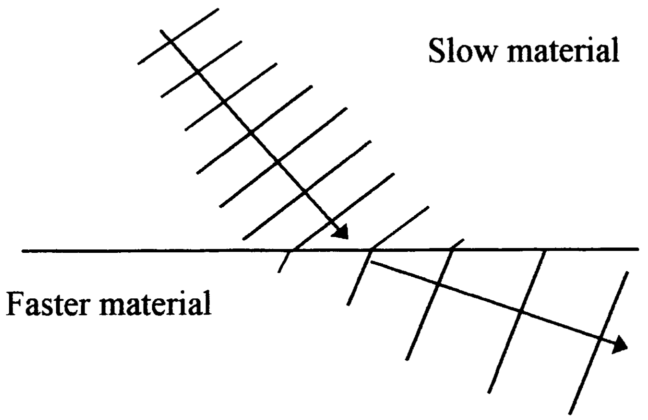


Figure 17.4 Refraction

c) ATTENUATION

The loss of sound energy due to its passage through a material, this will be primarily due to scatter and absorption.

a) Scatter

This is the sound being reflected away or prevented from returning to the probe, this can occur due to the following:

i) Incorrect coupling material between transducer and material.
ii) Rough surface of the material under test.
iii) Grain boundaries in the material under test causing scatter.
iv) Non-metallic inclusions causing scatter.

b) Absorption

Energy can neither be created nor destroyed all we can do is change it from one type to another. As the sound travels through the material it will have to move the particles as has been said previously. This movement will take a certain amount of energy from the beam and change it firstly to kinetic energy (movement) and finally the energy will be dissipated in the form of heat.

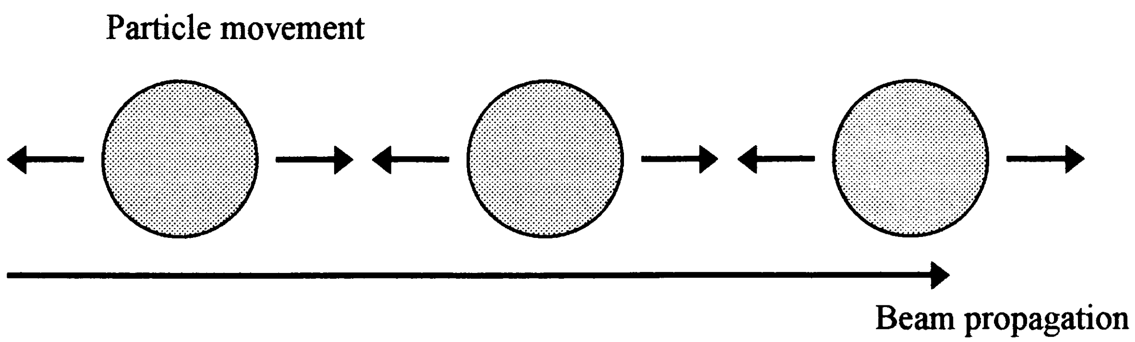


Figure 17.5 Attenuation

Both of the above will combine to result in ATTENUATION, which are the losses of sound caused by the resistance of a material to sound travelling through it. Different materials will attenuate the ultrasonic beam at different rates and this is called the **ACOUSTIC IMPEDANCE OF THE MATERIAL** and is primarily dependant on the density and the hardness of the material, and the velocity of the sound wave.

INTERFACE BEHAVIOUR (Acoustic mismatch)

Between Perspex and steel at least 87% of the energy produced will be reflected directly back and so will not penetrate, thus it will be lost. The net result of this being that only approximately 1 to 1.5% of transmitted energy returns as a signal for use by the meter.

COUPLANT

Between Perspex and air there is 100% reflection. If there is air between the probe and the steel under test then there will be no sound transmitted into the testpiece. We must consequently ensure that all of the air is excluded. This is achieved by the use of a liquid placed between the probe and testpiece commonly termed the "couplant", this can be grease, oil or in our case water.

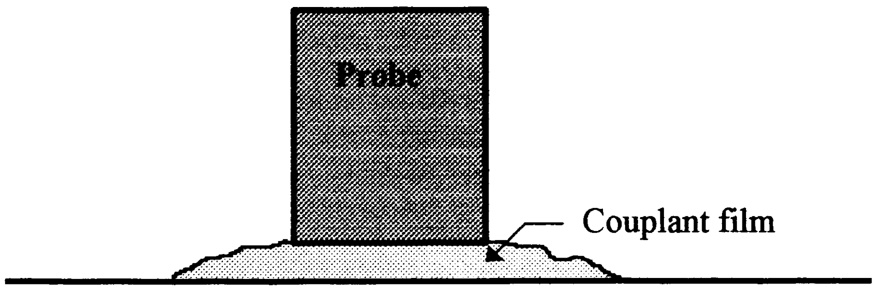


Figure 17.6 Probe and Couplant

THE PRODUCTION OF ULTRASOUND

In order to produce sound travelling in a material we will have to cause the particles in that material to vibrate. The simplest way in which this can be done is to strike the material with a hammer. If the hammer used is a rounded hammer then the source of sound will be a point source. The sound will propagate through the material in all directions, rather like the ripples on the surface of a pond after a rock has been thrown in. This kind of beam propagation will be of no practical use for inspection, what is needed will be for the sound to be produced in a beam that can be focused and directed in the material.

This is achieved by the use of a probe incorporating a vibrating crystal. Not being a point source the crystal will produce a beam of energy in the material, this beam will still diverge but only slightly and so can be used to locate areas of discontinuity in a material.

A machine, which can change one form of energy to another, is called a transducer. In our case we will be using a material, which possesses the **PIEZO ELECTRIC EFFECT** to accomplish this.

THE PIEZO ELECTRIC EFFECT

A material, which possesses this characteristic, will, when subjected to a mechanical vibration, produce an electrical potential and vice versa.

In the case of ultrasonic probes the crystal will have silvered faces to allow the electrical potential to be applied evenly across the crystal and also for the returning electrical potential to be detected by the machine:

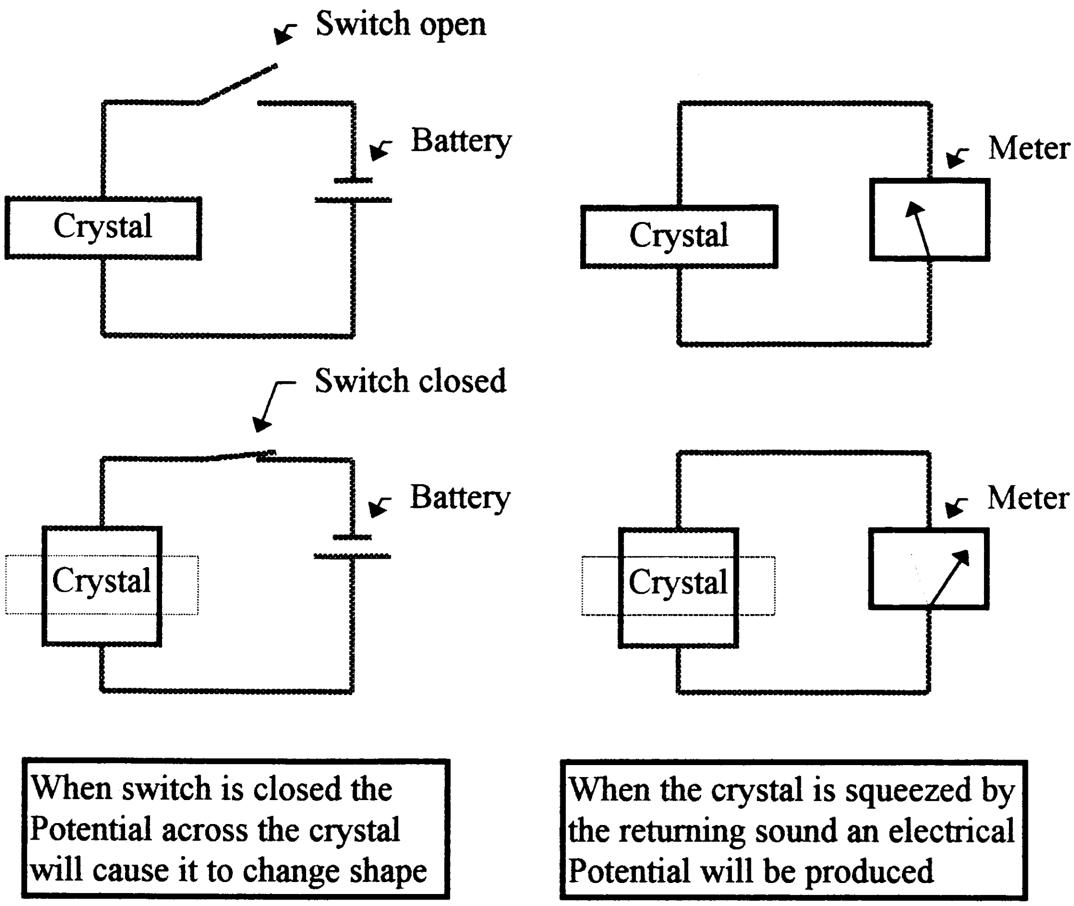


Figure 17.7 The Piezo Electric Effect

WAVE FORMS

There are four modes of propagation and waveform in ultrasound these are: -

i) LONGITUDINAL OR COMPRESSION WAVES

With the beam in compression the particle vibration will be along the same path as the propagation of the wave, see figure 17.8.

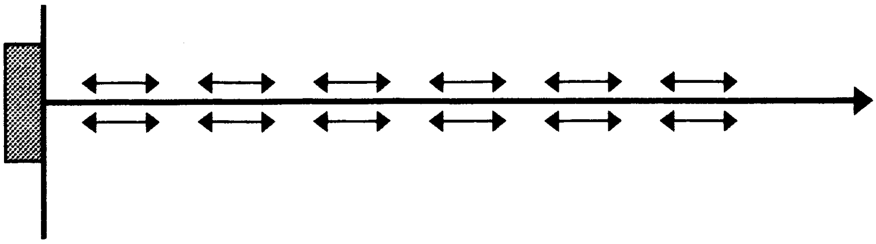


Figure 17.8 Compression Waves

ii) TRANSVERSE OR SHEAR WAVES

Shear waves can only exist in solids. Particle vibration is at 90° to the direction of propagation of the wave. The velocity of the wave in the material will be approximately half that of a compression wave in the same material.

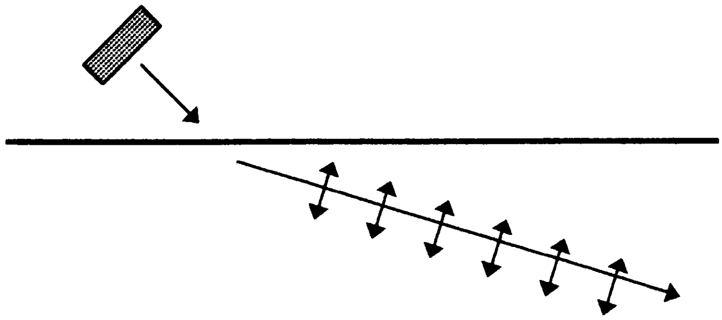


Figure 17.9 Shear Wave

iii) SURFACE OR RAYLEIGH WAVES

Particle vibration is elliptical with the long axis perpendicular to the surface of the testpiece. The wave will not penetrate further than one wavelength; waves on the sea are an example of this type of waveform.

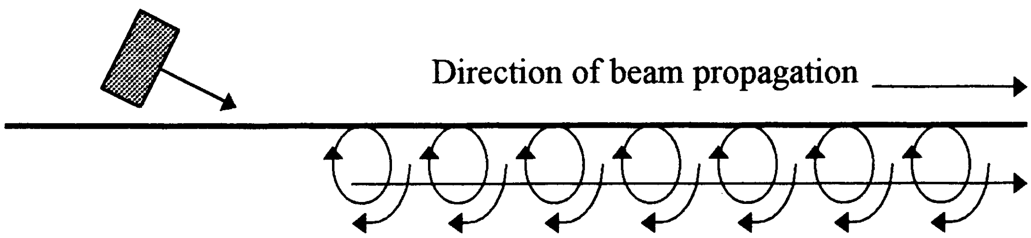


Figure 17.10 Rayleigh Wave

iv) LAMB OR PLATE WAVES

The whole of the plate is flexed; this is used in steel works for the testing of flat plate looking for laminations.

PROBE CONSTRUCTION

Ultrasonic probes are designed to produce the correct waveform for the test to be carried out. In the probe the crystal will have silvered faces to enable an electrical potential to be applied across it.

Single Crystal Probes

The simplest form of probe is the single crystal probe. In this probe the same crystal will be used to transmit the signal and receive it. The probe will produce the pulse of ultrasound and then will wait, "listening", in a quiet period for the returning sound. A single crystal probe will have a thin membrane covering the crystal and no "Perspex shoe" to protect it. Behind the crystal will be the acoustic damping designed to absorb the sound emerging from the back of the crystal, which would cause interference to the test.

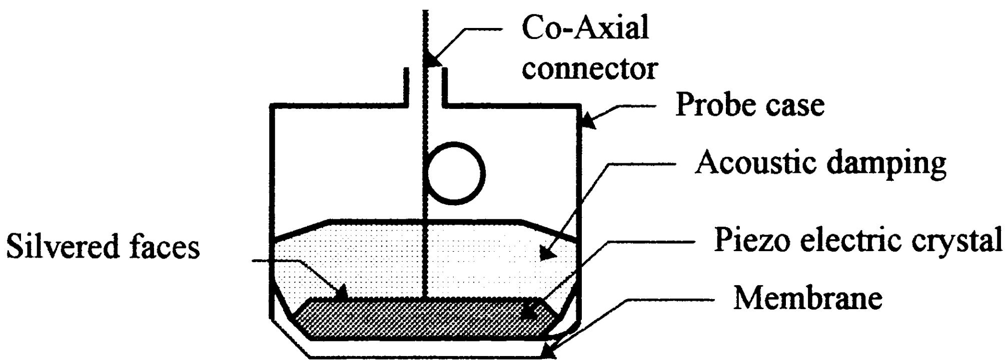


Figure 17.11 Single Crystal Probe

Advantages

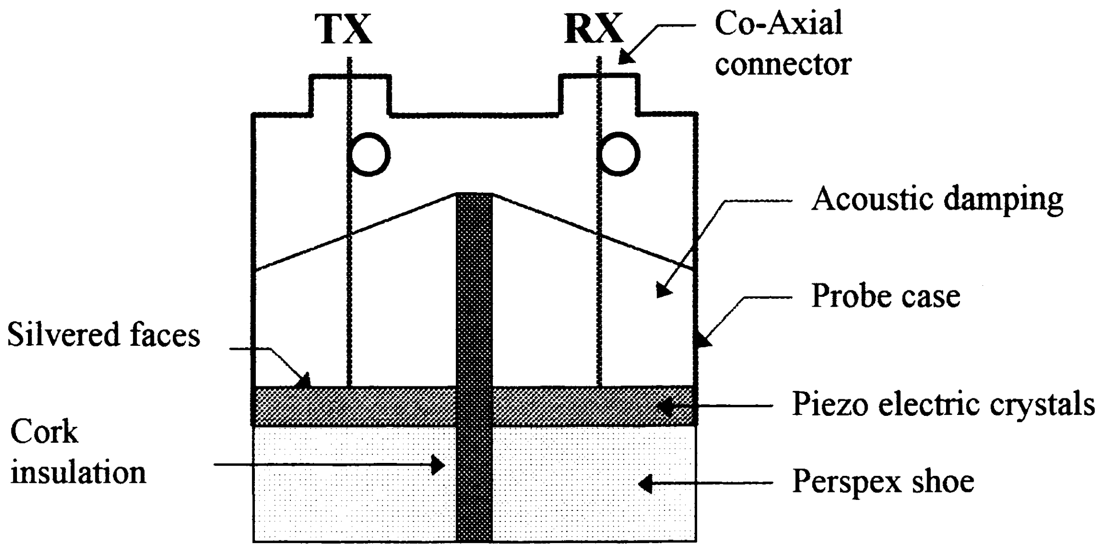
a) Good power delivery.
b) Better for thick plate (greater than 40mm).

Limitations

a) Poor near surface resolution.
b) Cannot measure thin plate accurately.

Twin Crystal Probes

The twin crystal probe is basically the same as the single crystal probe. The difference lies in the fact that whereas the same crystal was used to both transmit and receive in the single crystal probe, the twin crystal arrangement will make use of two crystals, one for transmission and one for reception. The twin crystal probe is in essence two single crystal probes working in conjunction with one another but not connected electrically or acoustically. They will be separated by a cork insulator designed to stop any "crosstalk" between the two crystals, and normally there will be a thick Perspex "shoe" in front of the crystals, which will make the probe a little more robust.



Note, Tx means transmit crystal
Rx means receive crystal

Figure 17.12 Twin Crystal Probe

Advantages

a) Good near surface resolution.
b) Initial pulse will be contained in the shoe and so will not affect the test.
c) Able to focus at any depth.
d) Able to measure thin plate.

Limitations

a) Thicker shoe reduces intensity.
b) Limited range.
c) Typically used on plate thinner than approximately 40mm thick.

Compression Wave Probes

These probes will send the sound into the testpiece at 90° or perpendicular to the surface, and as such there will be no refraction at the interface, only compression waves will result in the material. These probes are called zero degree or normal probes and may look as illustrated.

TESTING USING THE DIGITAL THICKNESS METER

The method, which a digital thickness meter uses, is called the **PULSE ECHO TECHNIQUE** (see figure 17.13). This means that there is a pulse sent out in to the material, the meter then waits for the pulse to be reflected back to the probe from the back wall of the material or alternatively perhaps from a discontinuity in the material.

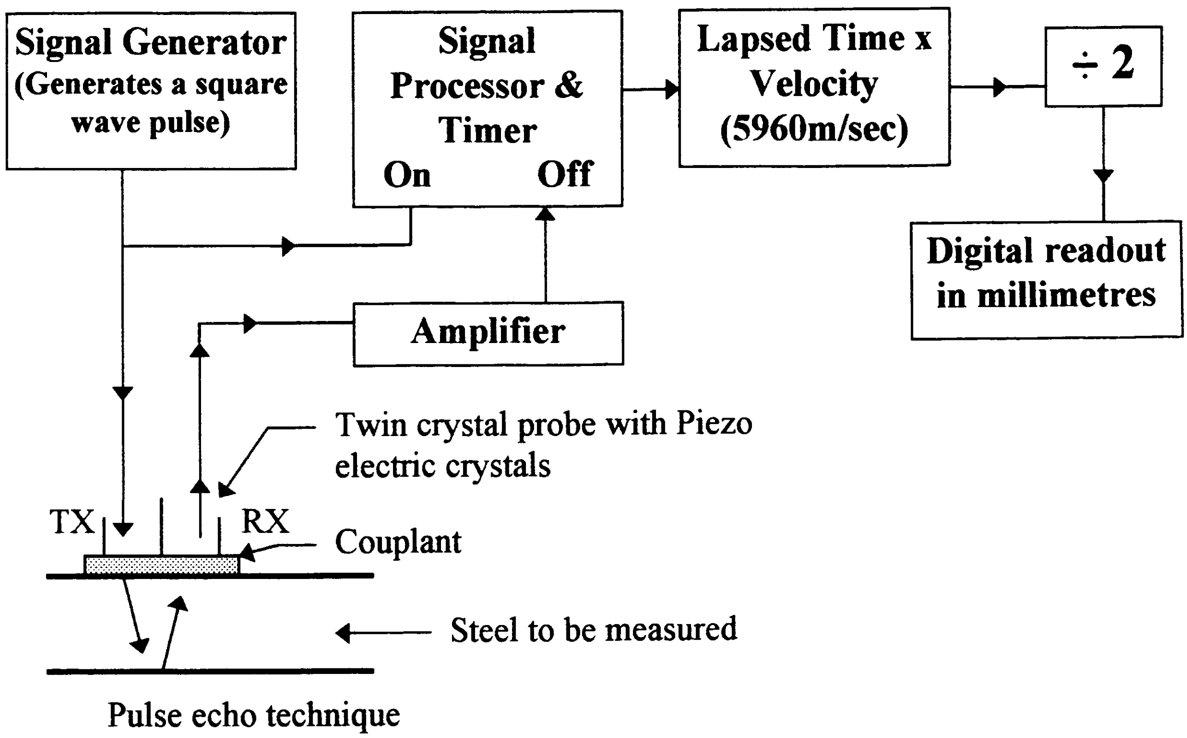


Figure 17.13 Block Diagram of the Digital Thickness Meter.

As can be seen the meter produces a pulse of electrical energy which is sent to the probe transmit crystal and also to the signal processor which will be timing the pulse. The transmit crystal will then produce ultrasound (using the Piezo electric effect), the sound produced will then enter the material under test providing there is a sufficient couplant between the probe and the test piece. The sound will then travel through the material and will bounce off the back of the test piece or a defect and will return to the probe via the couplant provided that the back wall is parallel with the probe surface and is not badly corroded.

The passage through the interfaces and the material will result in most of the sound being lost (at least 87% will be lost during each crossing of the interface between the materials), this will mean that typically only about 1 to 1.5% of the sound will reach the receive crystal. The receive crystal will then change the sound in to an electrical pulse which will be very weak, so the first thing that we must do is to amplify the pulse. It will then go to the signal processor where it will stop the clock and do the calculations involved i.e., multiply by the velocity and divide by two, (because we only want the distance to the back wall and not the distance both ways).

What the meter is actually reading is the **lapsed time** taken for the ultrasound to travel to the back wall and return to the probe. The way that the meter translates this to a distance is by "knowing the velocity of the sound in the material" or having the velocity of the sound travelling in the material programmed into it.

A digital thickness meter will not always give a true and accurate reading; it could be fooled by the following:

1. The sound could reflect off the back of an inclusion.

2. The sound could reflect off the back of an isolated pit.

3. The sound could reflect of either side of a machined fault.

4. The meter could give false readings if the back wall is corroded.

5. If the D.T.M. is not held squarely on to the surface under test, then because of reflection, the pulse will not return to the probe and so no reading will be displayed.

6. If the metal is hot then the sound will travel at a different velocity, this will cause the meter to interpret the results and give an inaccurate reading.

7. Will not be able to locate a small isolated pit due to the meter only being able to give the indication for the largest reflector.

8. If the front face of the metal is corroded or pitted the sound may not even enter the material.

9. If the backwall of the material is not parallel to the front scanned face the sound will not be reflected back to the probe.

The major limiting factor of a digital thickness meter is that <u>IT WILL GIVE THE DEPTH TO THE MAJOR REFLECTOR ONLY.</u>

Procedure for D.T.M. survey:

1. Ensure the meter is properly charged prior to use and that a properly qualified diver is available to take the readings.

2. Check calibration of the meter on the surface using a block of known thickness made of a material with similar velocity as that to be tested, the block will also have smooth and parallel faces. Ensure the reading is recorded and the serial numbers of the meter, block and the probe used should also be recorded.

3. Ensure the area to be surveyed is clean and smooth (SA 2).

4. At depth check the calibration again on a block of known thickness and of the same material as that under test with smooth machined faces and record the reading.

5. Carry out the thickness survey and record the results.

6. After the survey is complete or at intervals during an extensive survey, recheck the calibration on the block of known thickness and similar material to that under test and record the reading.

7. When back on surface wash the meter and recharge to the manufacturers specifications and submit results to the client.

CHAPTER 18

Magnetic Particle Inspection (MPI)

Magnetic Particle Inspection is a method of non-destructive testing able to detect surface breaking and slightly sub-surface defects in ferromagnetic materials.

Back in the early days of inspection the way to tell if a component was cracked was to strike it with a hammer if the tone produced was wrong then the item was suspect. It was noticed that when a railway wheel found to have been lying in a pool of oil for some time was picked up it would become covered in a thin layer of dust, which tended to draw the oil out of any cracks and cavities, which were in the wheel. This method of inspection became known as Penetrant inspection. It was soon found that if the item became magnetised then a more sensitive method could be employed, this method is called Magnetic Particle Inspection.

THE FOLLOWING ARE SOME ESSENTIAL TERMS USED IN MPI

1.	**Flux:**	This is the term used for the lines of force from a magnet.
2.	**Field strength**:	The strength of the external magnetising force (unit Ampere turns per metre, symbol H or possibly Oersteds).
3.	**Flux density**:	The number of flux lines per unit area, which emerge from a test piece (unit Tesla, symbol B the minimum flux density for the application of MPI is 0.72 Tesla).
4.	**Flux leakage**:	Any point where flux lines leave or re-enter a material or magnet such as poles, defects or discontinuities.
5.	**Poles:**	The point at which the flux lines leave or re-enter a magnet.
6.	**Consequential poles**:	Areas of flux leakage caused by flux lines being forced out of a material at a discontinuity or defect (this is the area that will be detected when using MPI).
7.	**Permeability (μ):**	The ease with which a material can be magnetised.
8.	**Vector field**:	The product of two magnetic fields working in a component simultaneously but at different angles producing a field in the material running at a vector to the original fields.

9.	**Hysteresis**:	A representation of the flux density built up in a material for a given field strength (flux density B, always lags behind field strength H), and Hysteresis means lagging.
10.	**Retentivity**:	The point on the Hysteresis loop, which relates to the residual magnetism in a material after the external field has been removed.
11.	**Residual magnetism**:	The amount of magnetism left in the material after the external field has been removed.
12.	**Reluctance**:	The opposition to flux flow in a material (reluctance is to magnetism what resistance is to electricity).
13.	**Coercive force**:	The amount of force needed to reduce the flux density in a material to zero.
14.	**Saturation**:	The point at which the material has no more room for extra flux lines and so the excess is forced to run outside the material.
15.	**Flux indicator**:	A device used to check that there is sufficient flux density in the material to enable an MPI test to be carried out.
16.	**Electromagnetism**:	The movement of an electrical charge will create a resulting magnetic force at right angles to the direction of electrical current flow.

All of these terms will be explained more thoroughly as we proceed through the text.

BRITISH STANDARDS RELATING TO MPI

An inspector must have an appreciation of the following British Standards:

BS 6072 1981 - Method for Magnetic Particle Flaw Detection
BS 4069 1982 - Specification for Magnetic Flaw Detection inks and powders
BS 4489 1984 - Measurement of UV/A radiation(Black Light) used in Magnetic Flaw Detection
BS 5044 1973 - Specification for contrast aid paints used in M P I
BS 499 1991 - Welding terms and definitions

In order for us to be able to use this method properly it is important that we understand some of the principles involved, firstly magnetism. This is a fundamental form of energy which is evident all around us indeed the earth itself exhibits a field of its own. This field is made up of lines of force, which we term magnetic lines of flux, they emerge from the magnetic north pole and re-enter the magnetic South Pole. Magnetic lines of flux exhibit a number of characteristics, which are vital to the function of magnetic particle inspection, they are as follows:

CHARACTERISTICS OF MAGNETIC LINES OF FLUX

The lines of flux will:

a) Never cross one another.
b) Be held constantly in tension (constantly trying to pull themselves into the magnet).
c) Repel one another.
d) Follow the path of least resistance.
e) Travel North to South external of a magnet

If it were not for these facts then Magnetic Particle Inspection would not work.

THE MAGNETIC FIELD

The idea that a magnetic field is made up of a number of invisible lines of force came initially from Michael Faraday, who saw this as a good way to visualise flux density and the shape and strength of a magnetic field. It can be said that the lines of flux run from North to South outside a magnet and in order to complete the circuit will run South to North inside the magnet.

MATERIALS AND MAGNETISM

In magnetism there are three categories of material and these are:

1. **Diamagnetic**

   These materials will repel magnetism slightly, examples of diamagnetic metals are copper and bismuth. As can be seen from the diagram below flux lines approaching a diamagnetic material will be deflected around the material and will not flow through it.

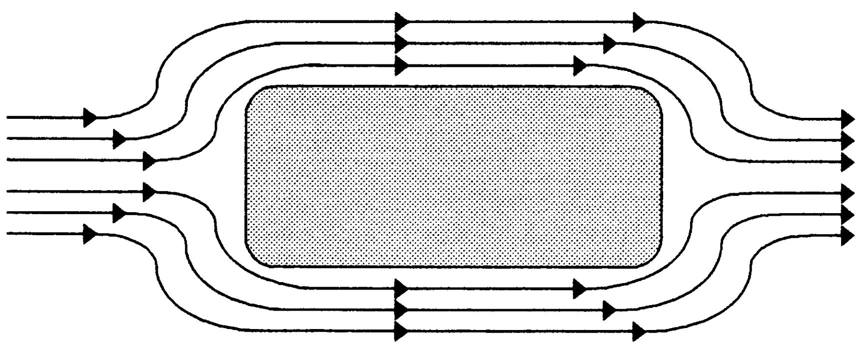


Figure 18.1 Magnetic Flux Lines Encountering a Diamagnetic Material

2. **Paramagnetic**

These materials will be slightly attracted by magnetism, almost all metals and some other materials fall into this group. Flux lines approaching these materials will not have their course changed significantly as the flux lines will be relatively unaffected by their passage through the material.

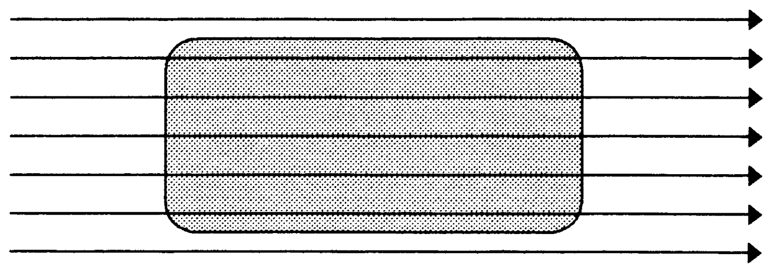


Figure 18.2 Magnetic Flux Lines Encountering a Paramagnetic Material

3. **Ferromagnetic**

These materials will be strongly attracted by magnetism and as such are the only materials which it is possible to magnetise to a sufficient level to allow the use of MPI, there are only three and they are **IRON, NICKEL AND COBALT** or alloys of these. As we build most of our structures from an alloy of iron i.e. steel, MPI is very useful to us. Flux lines approaching a ferromagnetic material will be drawn into the material in preference to running around it.

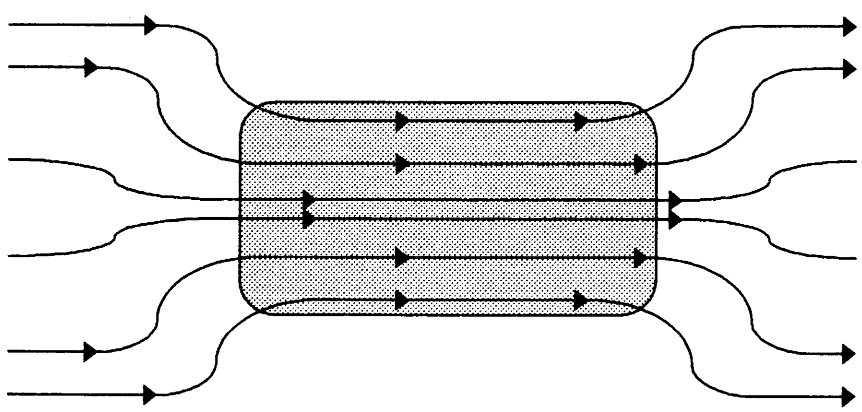


Figure 18.3 Magnetic Flux Lines Encountering a Ferromagnetic Material

So What Is Magnetism?

It can perhaps be best explained by the domain theory, which says that in a ferromagnetic material there are a large number of domains made up of a grouping of molecules. These domains act like tiny bar magnets, which are able to rotate inside the material. In the un-magnetised state they are randomly orientated and so there is no measurable flux density in the material, but if the material is placed within the influence of an external magnetising force then the domains will line themselves up along the external magnetising force flux lines which are travelling through the material.

When this happens the domains add their magnetism to the resulting field, the material can then be said to be magnetised. If we then remove the external force, the domains will not be held quite so rigidly and so the flux density in the material will reduce, the resulting external field is called the residual field.

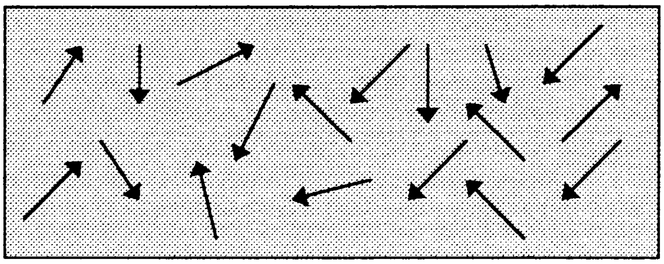


Figure 18.4 Un-Magnetised Random Domains (prior to the application of an external field).

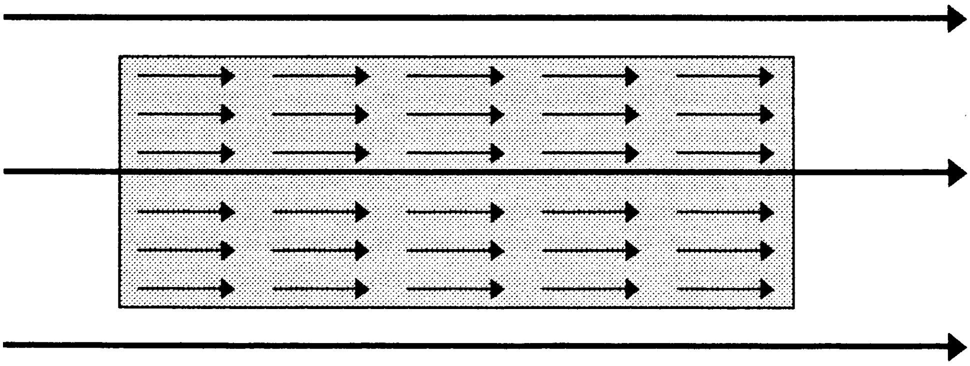


Figure 18.5 Magnetised Domains Rigidly Aligned (while an external field of sufficient strength is applied).

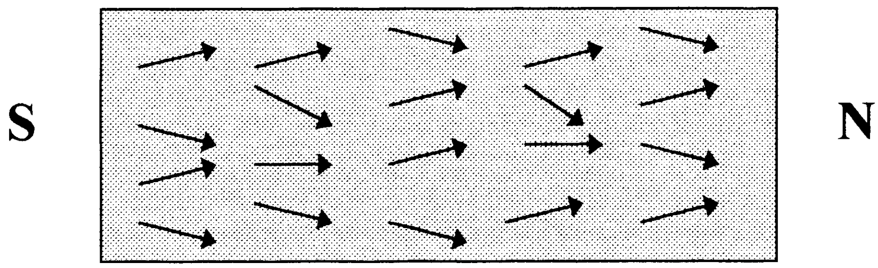


Figure 18.6 Residual Magnetism Domains Slightly Randomise (after the external field has been removed).

There are two ways in which magnetism can work in a material it will form either a longitudinal or circular field of magnetism; which one will be formed depends on the type and application of magnetising apparatus used. Whereas longitudinal magnetism leaves and re-enters the material or magnet and so forms poles at the ends, circular magnetism can circulate wholly inside the material and so there may not be any poles detectable, which can make it very difficult to detect.

LONGITUDINAL MAGNETISM

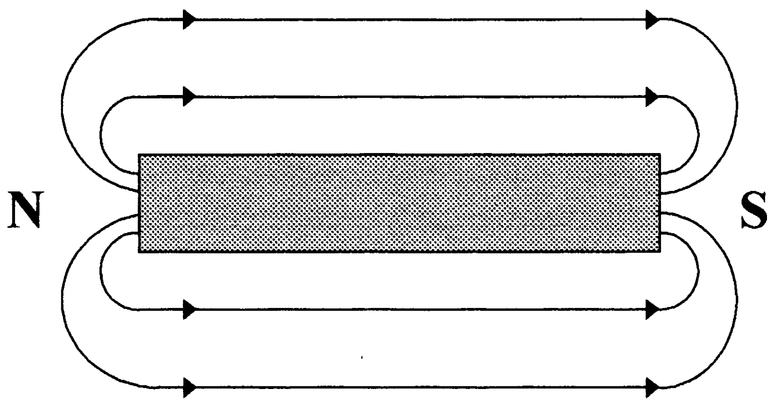


Figure 18.7 Longitudinal Magnetism

CIRCULAR MAGNETISM

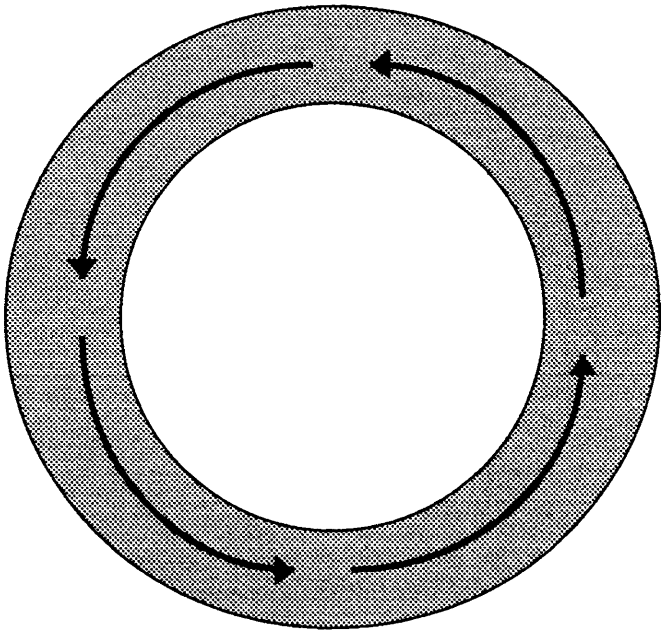


Figure 18.8 Circular Magnetism

FLUX DENSITY (B)

Flux density is defined as the number of flux lines emerging per unit area from a test piece. The unit used is the TESLA, 1 Tesla is equal to 10,000 lines of flux per square centimetre. The minimum flux density necessary for MPI is 0.72 Tesla (7,200 flux lines per square centimetre). It is this density of lines, which enables MPI to locate fine discontinuities. Flux density can be changed by either changing the strength of the external magnetising force or alternatively by changing the area of the testpiece.

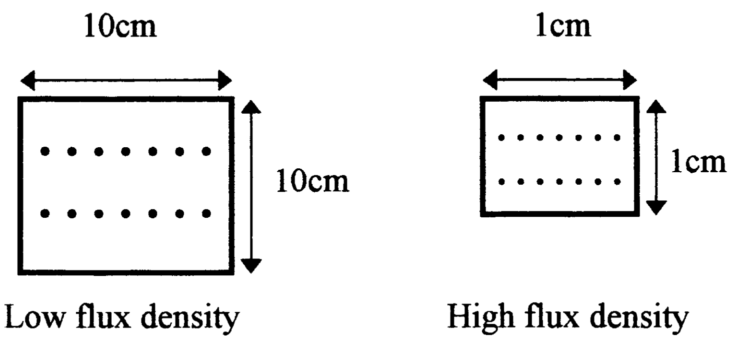


Figure 18.9 Flux density

FLUX INDICATORS (Portable cracks)

We need some method by which we can ensure sufficient flux density in a material, for this we use **FLUX INDICATORS**. There are a great variety on the market but for our application there are only three currently approved and they are:

1. The Berthold Penetrameter.
2. The Burmah Castrol Gauge.
3. Gauss meter (An electrical system for ensuring sufficient flux density)

Berthold Penetrameter

This is a flux indicator with adjustable sensitivity. As can be seen from the drawing the indication will be seen on the top of the flat plate in the centre, the amount of flux required to give that indication can be altered by unscrewing the plate from the base, so making it more or less sensitive as the case may be. The shape of the base draws the flux lines out of the material and past the graticules (small man made defects), which then give a flux leakage. The advantage of this type of indicator is that regardless of the angle the flux lines approach, provided there is enough flux density, there will always be an indication as there are two graticules at right angles to one another.

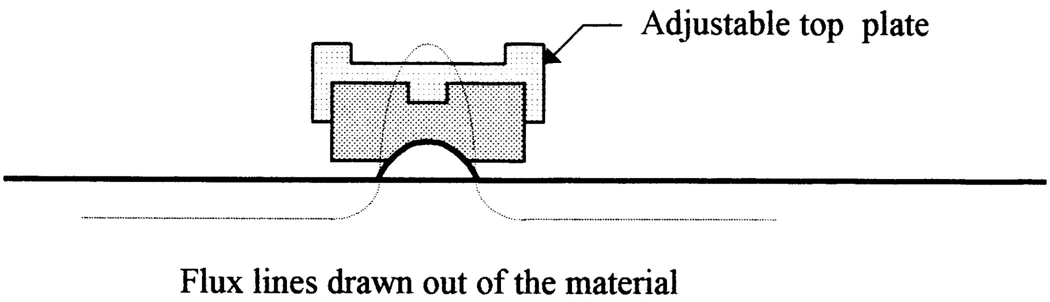


Figure 18.10 The Berthold Penetrameter

Burmah Castrol Gauge

This is the type of indicator, which is most frequently used. It is made up of a sandwich consisting of three layers of metal one of soft iron and the other two brass (this is for a general engineering strip, you need Silver facing plates for an aerospace strip). The soft iron layer has three slits machined into it and is placed between the brass strips, so being totally hidden from view. It is only when a flux flow at a density of 0.72 Tesla (30 Oersteds) or above, cross the strip at between 45 and 90 degrees and the detecting media (ink or powder) is applied, that we will see an indication of the location of the slits in the strip.

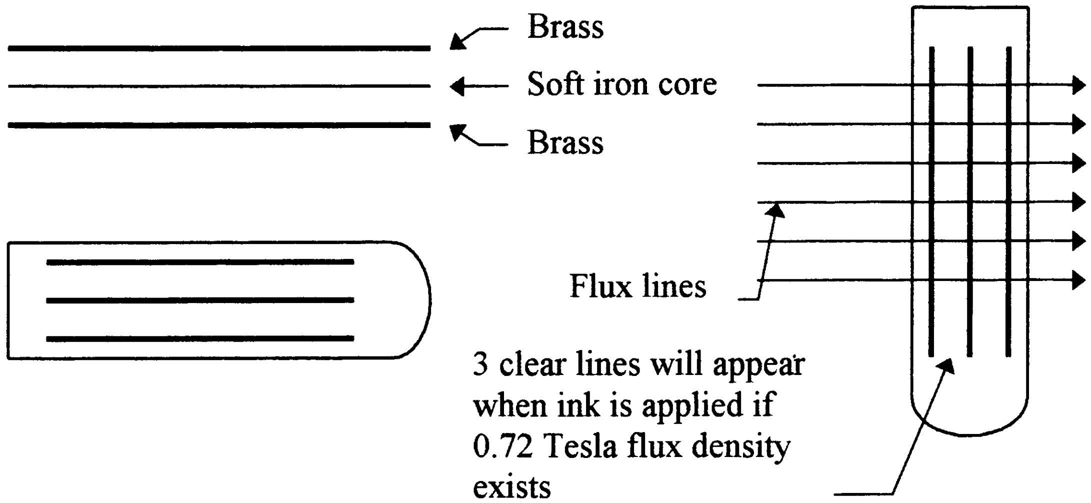


Figure 18.11 The Burmah Castrol Strip

The Use Of The Strip

The strip should be placed on the metal under test with the long axis of the strip running in the same direction as the defects sought. In addition it should preferably be placed on the opposite side of the weld from the magnetising apparatus. Once this has been done then the magnetic field will be applied followed by the detecting media, if the correct flux density for testing exist then three clear lines will appear on the strip. On a tubular weld this should be done at all the cardinal points of the weld at least, if all is well then the inspection can commence.

Gauss Meter

The Gauss meter is an electrical measuring device, this can be used to ensure sufficient flux density in a material in much the same way as the above flux indicators. The main difference in the use of the Gauss meter is that it will give a quantitative measurement and so will tell us not only if there is not enough flux density, but also is there is too much, which would cause saturation of the testpiece.

FIELD STRENGTH (H)

Field strength is the strength of the external magnetising force tending to set up a flux density in a material. If this is to be produced by means of electricity then the unit is the AMPERE TURNS PER METRE. This means that if for instance we need 1000 amperes to magnetise the test piece sufficiently for MPI we can either have one turn carrying 1000 amperes or 1000 turns carrying 1 ampere, the effect will be the same.

PERMEABILITY (μ)

Permeability is the ease with which a material can be magnetised, the flux density, which can be built up in a material, will be related to the Permeability and the applied external field (Field strength)

HYSTERESIS (lagging)

When we want to magnetise a ferromagnetic material, we first have to build up an external magnetising force, this can be done in a number of ways as we will see later. It stands to reason that there will be no flux density (flux lines running in the material) built up in the material until the field strength (external magnetising force) is applied. Consequently, the flux density (B) always lags behind the field strength (H). If we use a permanent magnet or direct current to produce the external magnetising force then the result will look like this:

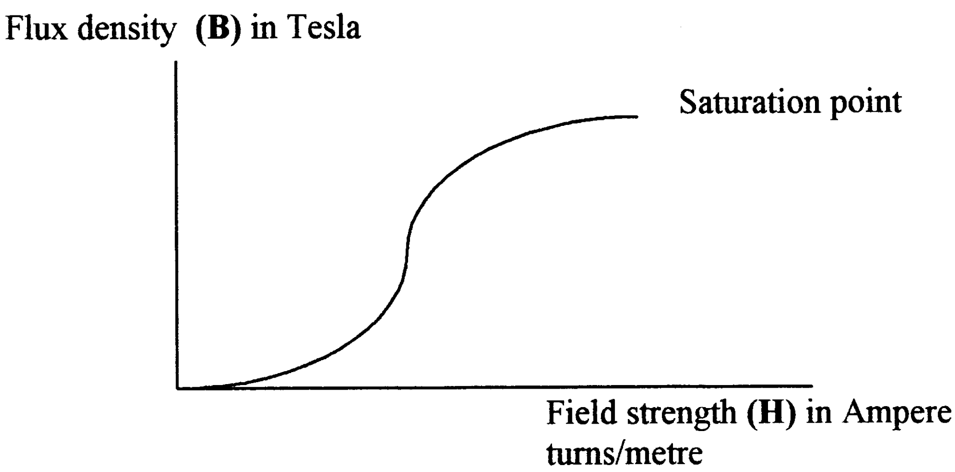


Figure 18.12 Flux Density and Field Strength (B/H curve)

The flux density that will be built up for a given field strength is proportional to the permeability (μ) of the material. Once the material has reached saturation then there will be no increase in flux density regardless of the amount of extra field strength applied. The above shows the initial magnetisation curve for this material, this is referred to as the **Virgin Curve.**

In free space the relationship between flux density (B) and external magnetising force (H) may look like this:

$$B = \mu o H$$

As can be seen below the differing permeability of the materials will allow the flux density to build up at a different rate:

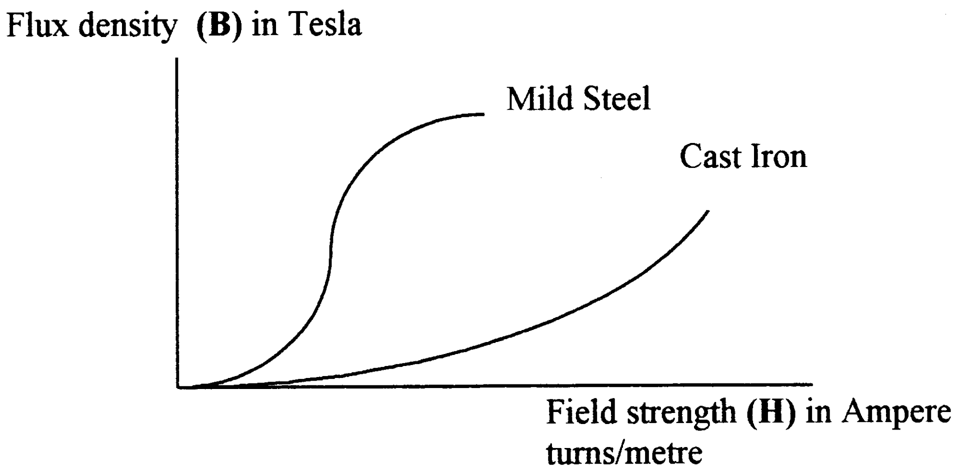


Figure 18.13 Differing Permeability B/H Curves

RETENTIVITY

When the external magnetising force is removed from the above then the material will lose some of its magnetism, the flux density will degrade to the point of Retentivity as shown in figure 18.14:

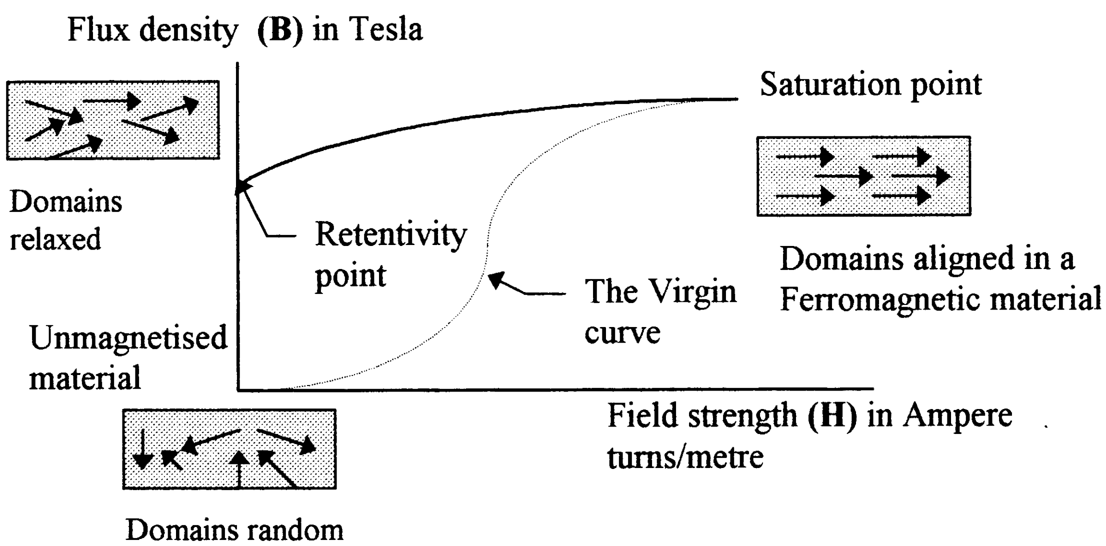
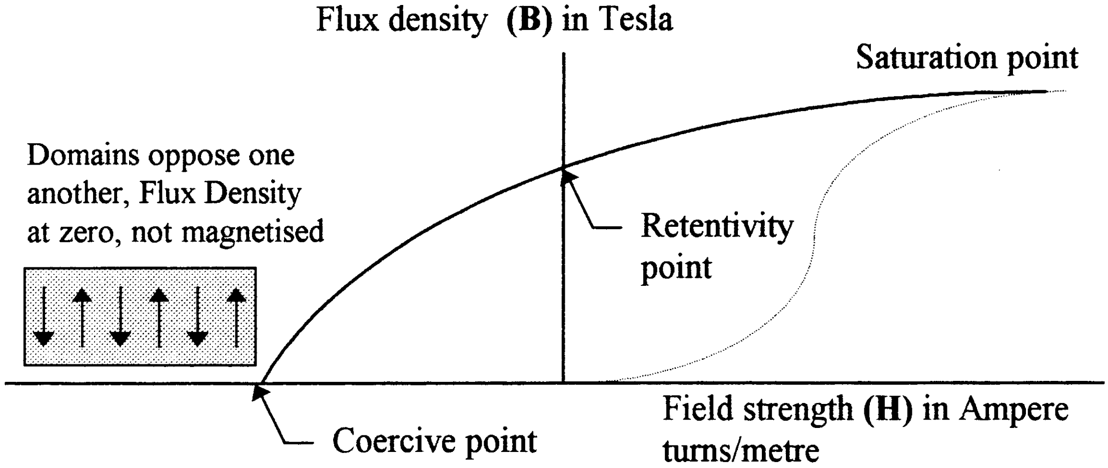


Figure 18.14 Retentivity

COERCIVE FORCE

Once the flux density has degraded to the Retentivity point this will show how much residual magnetism remains in the material, if however we need to remove this magnetism then we will need to use an external magnetising force which is oriented so as to oppose the original external magnetising force, this force is termed the **COERCIVE FORCE**, and can be shown in figure 18.15:



Coercive force = External magnetising force applied in an opposite direction to the original magnetising force, this will remove Flux Density built up in the material

Figure 18.15 Coercive Force

The above figure 18.15 indicates what will happen if we use a direct field to magnetise, if on the other hand we use an alternating field which can be achieved using an alternating electrical current, then the curve will be reversing every time the current reverses, (50 times every second in the UK). Then the following will be true, this is then called the Hysteresis loop:

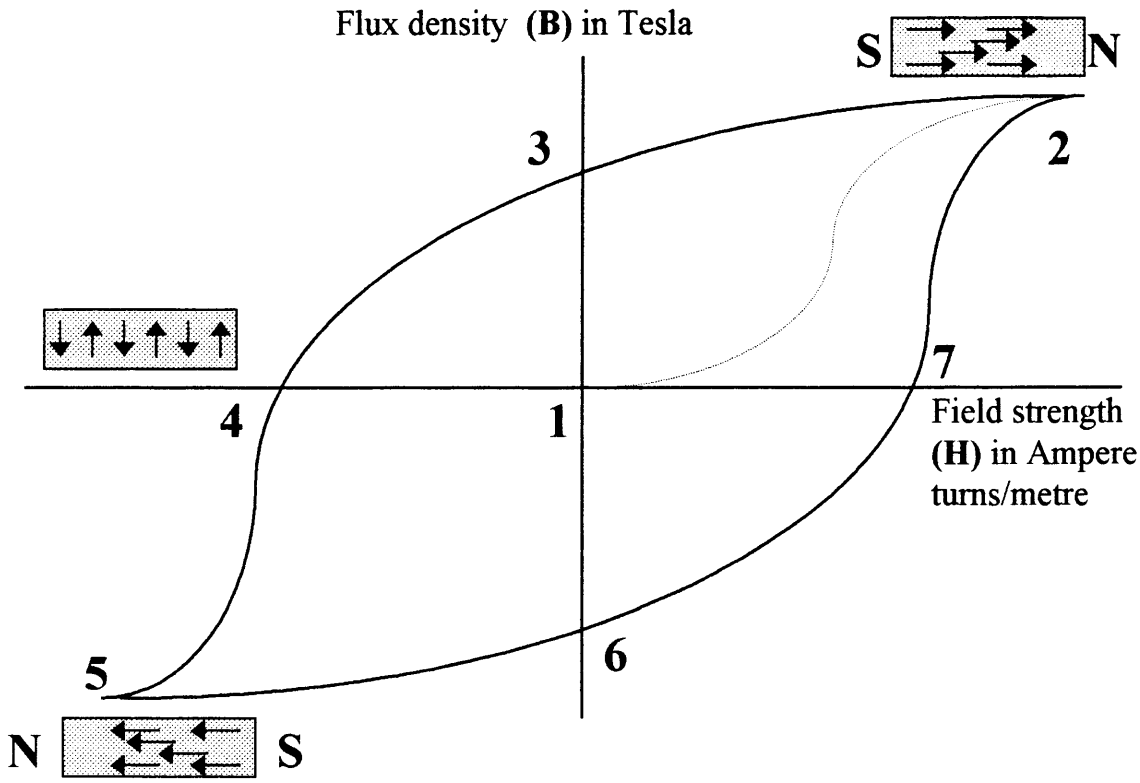


Figure 18.16 Hysteresis loop

THE HYSTERESIS LOOP

1 **Material in the un-magnetised state.**

An external field is then applied and the flux density starts to build.

2 **Maximum flux density achieved in one direction (saturated).**

No matter how much more external field is applied the material can hold no more flux lines and so can be termed saturated.

3 **Retentivity point (shows residual flux density).**

This is the amount of flux left in the material once the external field has been removed.

4 **Coercive point (shows the force needed to reduce flux density in the material to zero).**

A magnetising force applied in the opposite direction to the original field will tend to reduce the flux density in the material to zero.

5 **Saturation point (the poles in the material would now be reversed i.e. what was the north pole will now be the south pole).**

6 **The second point of Retentivity.**

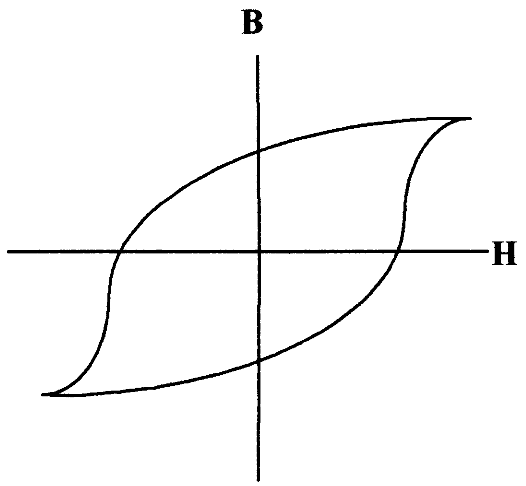
7 **The second point of coercive force.**

1-2 **Virgin curve** (cannot be repeated once the material has been magnetised once).

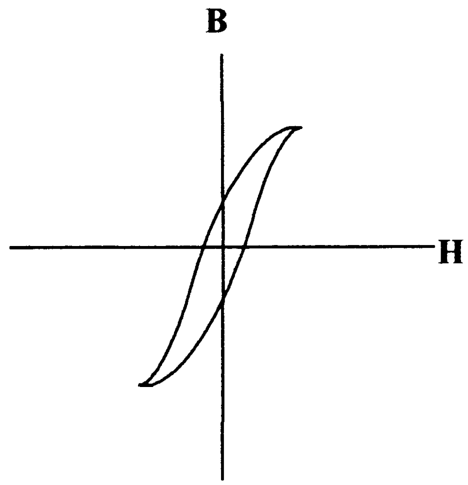
1-3 **Residual magnetism** (a measure of the flux density left in the material after the external field has been removed).

1-4 **Coercive force** (a measure of the amount of external magnetising force of opposite polarity to that which was used for the initial magnetisation of the material needed to reduce the flux density in the material to zero).

The Hysteresis loop can be used to show a number of things:



Wide Loop



Slender Loop

Low Permeability (difficult to magnetise)	**High Permeability (Easily magnetised)**
High Retentivity	Low Retentivity
High Residual Magnetism	Low Residual Magnetism
High Reluctance	Low Reluctance
High Coercive force needed to reduce the flux density to zero	Low Coercive force needed to reduce the flux density to zero

PRODUCTION OF A FIELD (BS 6072)

A magnetic field can be set up in a material in the following ways:

i) Align the test piece with its long axis north south in the earth's magnetic field.

ii) The above can be enhanced if the test piece is first heated above the Curie point (700 - 720 degrees Celsius with steel) and then aligned as above.

iii) Bring the test piece into the field of a permanent magnet or an electro magnet.

iv) Pass an electric current directly through the test piece.

v) Pass an electric current through an insulated conductor immediately adjacent to the test piece.

vi) Place the component inside an insulated current carrying coil.

Of these six ways the only ones that are able to produce a flux density sufficient for the application of MPI (0.72 Tesla) are the last four. So we will be concentrating on these.

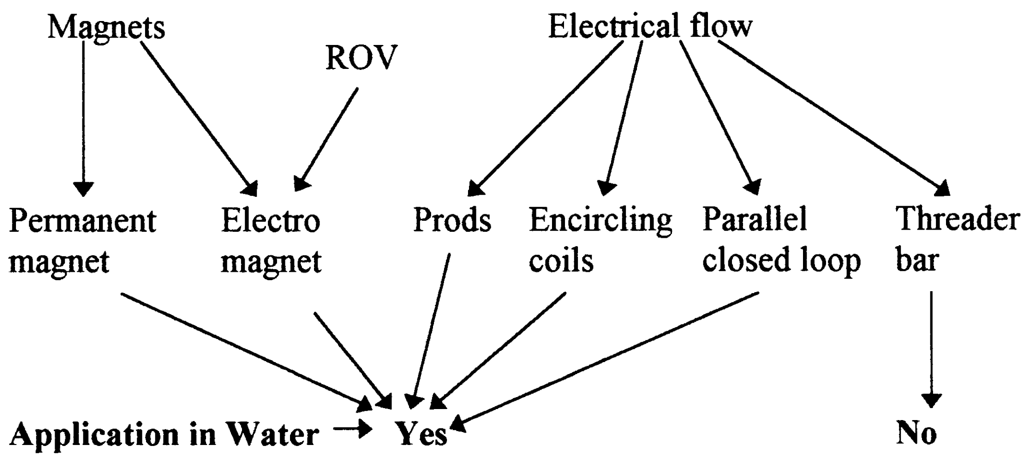


Figure 18.16 Methods of Magnetising

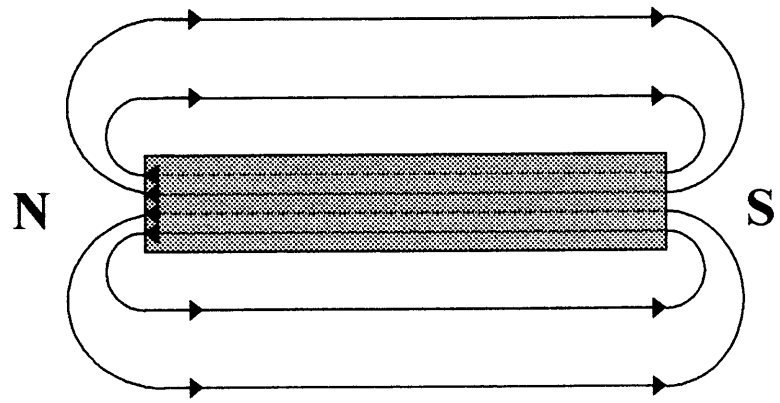
1. PERMANENT MAGNET

The permanent magnet is a hard low permeability high Retentivity material which has a strong residual magnetic field there are several points to note:

i) The magnet will have two poles, one at either end, which we call a north pole and a south pole as per the earth's field.

ii) Magnetic flux lines always run north to south outside of the magnet (south to north inside).

iii) If two magnets are brought close to one another with their like poles facing then they will repel each other. Because of the properties of flux lines it can be seen that if two north poles are brought together then the flux lines will not be able to cross, as they are being held in tension they will act to repel one another thus forcing the magnets apart. Conversely if the north pole of one magnet faces the south pole of the other, then the magnets will try to pull themselves together to form one longer magnet, so it can be said **like poles repel, unlike poles attract**.



Flux lines run north to south external and return south to north internal of the magnet

Figure 18.19 Field of the simple bar magnet

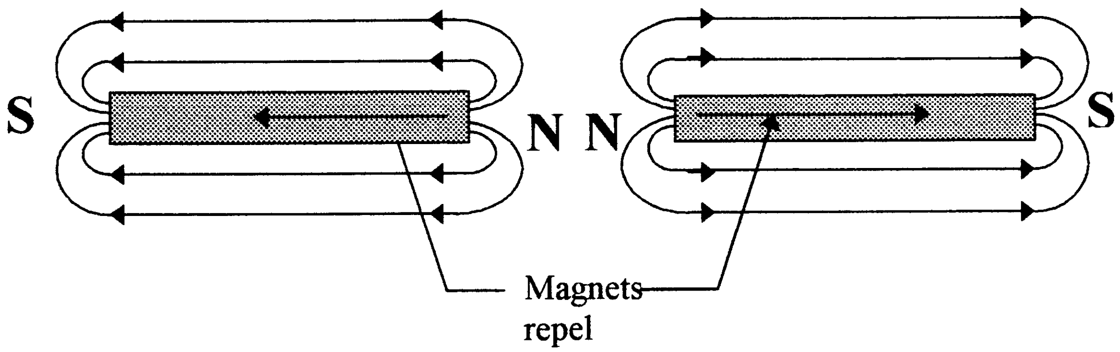


Figure 18.20 Like poles repel

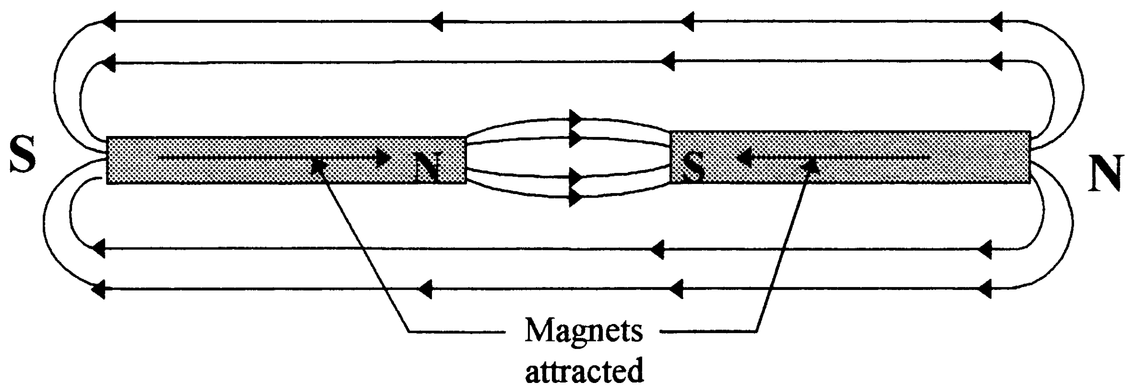


Figure 18.21 Unlike poles attract

The above can be shown by means of a magnetograph, which is a visible representation of a magnetic field, made by putting the magnet below a sheet of paper and sprinkling iron fillings onto the paper. The result will show the orientation of the lines of force or flux lines of the magnet.

Bar magnets whilst being good for some uses are not normally used in MPI The more usual form is for the magnet to be bent to form the shape of a horseshoe, which may have articulated arms to help the transmission of the flux to the test piece and so make use of them. The shape of the field of a horseshoe magnet will be as shown in figure 18.22:

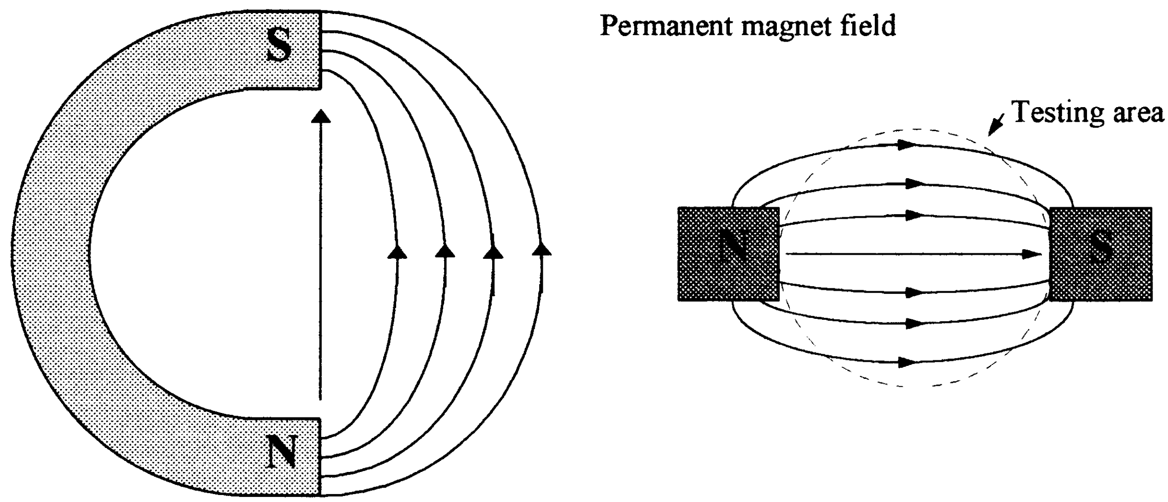


Figure 18.22 Magnetic Field from a Horseshoe Magnet

To help in the transmission of the flux the pole pieces may well be shaped to fit the test piece as shown in figure 18.23:

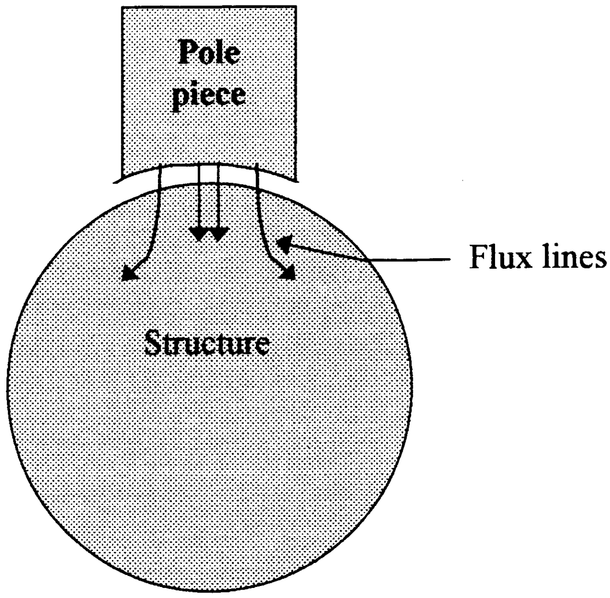


Figure 18.23 Shaped Pole Pieces

THE USE OF PERMANENT MAGNETS IN MPI

The British standard, which relates to magnetising operations is B.S.6072. This states that in order for a permanent magnet to be useable for MPI it **must be able to lift at least 18 kilogram's** with a pole spacing of between 75mm and 150mm. The area, which can then be inspected, should lie between the poles of the magnet. There are advantages and disadvantages to all magnetising apparatus and the following are true for the permanent magnet:

ADVANTAGES

i) They are cheap and readily available.
ii) No power supply is needed.
iii) There are no electrical contact problems, and there will be no burning of the test piece due to arcing.
iv) They will cling to vertical surfaces.
v) They are lightweight.

DISADVANTAGES

i) The magnet will deteriorate with use, every time it is removed from a test piece it will leave a small amount of its finite store of magnetism in the test piece thus depleting it's reserve.
ii) They give a direct and longitudinal field only thus the skin effect cannot be utilised (skin effect will be explained later).

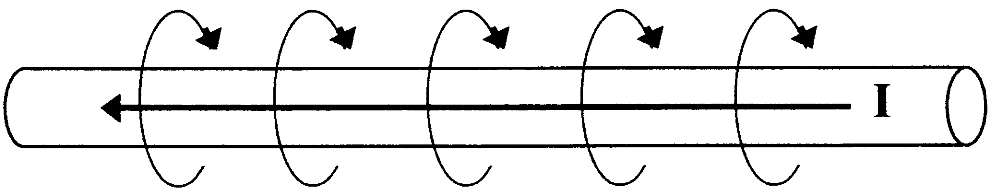
iii) The magnet will have to be pulled from the test piece each time it is to be moved and this can be fatiguing for the operator as the magnet can pull 18 kg it will be quite difficult to remove repeatedly.
iv) There is no control of field strength and so the test piece can become saturated quickly.
v) Magnetic poles will attract the particles and so may mask some defects.
vi) There must be area contact of the poles as this will facilitate good transmission of the flux lines from the magnet to the test piece.

Note that the pole pieces may well be articulated to facilitate good contact of the pole pieces in structures with tight geometry.

ELECTRICITY AND MAGNETISM

The movement of an electrical charge along a conductor will produce a magnetic field around that conductor. The direction that the field will travel can be shown by **THE RIGHT HAND RULE**, this says that if we imagine an electrical current is flowing down our arm and out of the thumb of our right hand then the fingers will show the direction of the resulting magnetic field.

The right hand rule can be applied to a conductor, if we hold the conductor with our right hand with the thumb pointing in the direction of flow then the fingers will be gripped around the conductor in the same direction as the flow of magnetism.



* Note I = Current flow

Figure 18.24 The Right Hand Rule

With this in mind we can look at the different ways in which we can create a field using electricity.

There are certain differences in the field produced by alternating current and direct current. If we use direct current (the current flows in one direction consistently) then the field produced will be similar to the field of a permanent magnet. It will be a "direct field" and this will tend to magnetise the material evenly throughout its whole thickness.

If on the other hand we use an alternating current (a current which is constantly reversing direction 50 or 60 times every second) to magnetise we will end up with an "alternating field".

This will tend to concentrate the magnetism in a layer of the material close to the surface. The thickness of penetration of the magnetism will vary according to the frequency of the applied alternating field, typically when using normal "Mains supply" (50-60 Hz) the layer will be only approximately 10mm thick, this is called the skin effect. Since we are primarily interested in surface breaking defects then this can be an advantage.

THE SKIN EFFECT

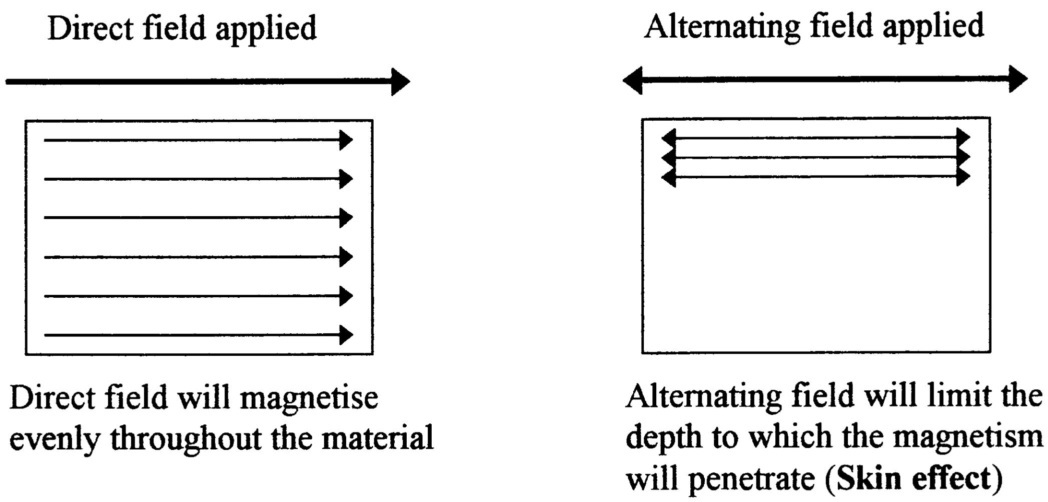
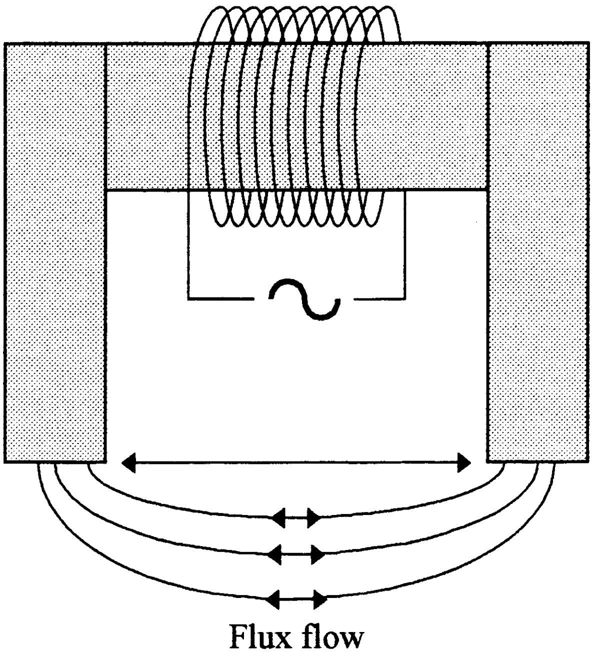


Figure 18.25 The Skin Effect

ELECTROMAGNET OR "YOKE"

An electromagnet is a soft, iron core often laminated to cut down on induction effects, around this there will be wrapped a large number of insulated copper windings. The effect is to make a solenoid, the field, which is produced, will be similar in shape to that produced by a permanent magnet. Electromagnets can however, make use of the "skin effect" if they are used with alternating current and so can be more versatile than a permanent magnet. B.S.6072 says that **an AC electromagnet must be able to lift 4.5 kilogram's** with a pole spacing of up to 300mm. As with the permanent magnets the inspected area should be between the poles.



AC yoke field

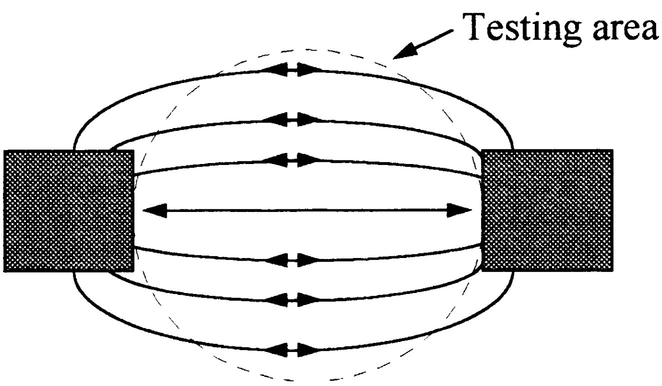
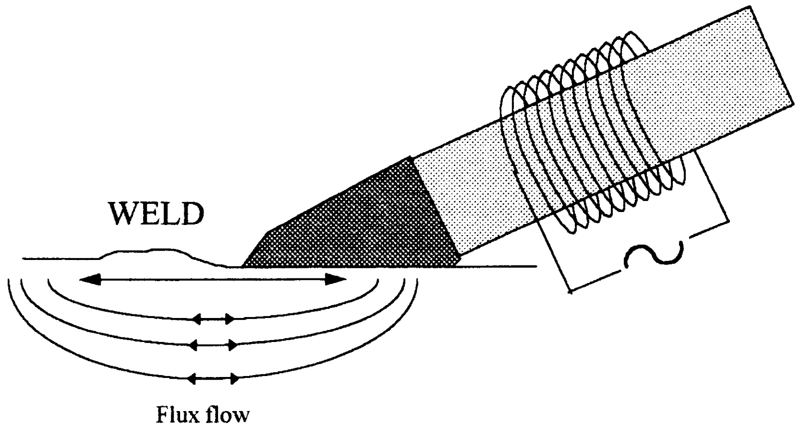


Figure 18.26 Electromagnetic Yoke

Single pole Electromagnetic or "Yoke"



The advantages and disadvantages are as follows:

ADVANTAGES

i) AC or pulsed DC can be used.
ii) We will have control of the field strength and so control the flux density in the material.
iii) The magnet can be switched on and off at will so there is no need to pull it from the test piece.
iv) Can be run directly from the mains power supply (no heavy transformers).
v) Will be no damage caused to the test piece.
vi) They are lightweight.
vii) If we use AC they can be used to demagnetise.

DISADVANTAGES

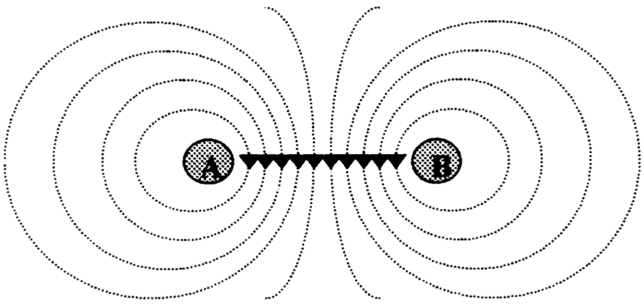
i) There is a need for a power supply.
ii) It is only possible to create a longitudinal field in the test piece.
iii) The magnet will carry mains voltages.
iv) The poles must have good area contact to ensure good transfer of the magnetic flux to the test piece.

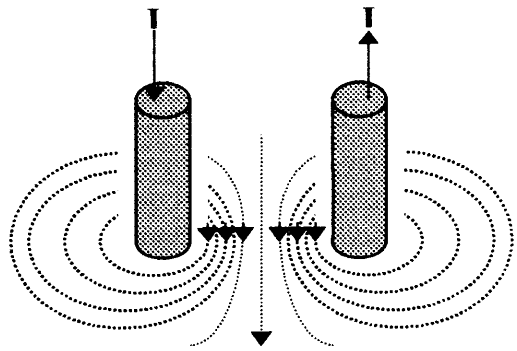
It should be noted that the use of mains voltages is seen as both an advantage and a disadvantage, this will depend on the circumstances at the job site. For example, it is an advantage to not have to carry around a heavy transformer but only if there is not a risk of electrocution (i.e. working outside or in damp conditions).

CURRENT FLOW USING "PRODS"

In the case of current flow using prods we pass an electric current directly through the test piece. This will produce a circular field transverse across the direction of the current flow. It will need a high amperage low voltage supply.

BS 6072 states that for every 1mm of prod separation we will need 4 or 5 Amperes of current (100 to 125 amps per inch).





Current flowing into the plate through prod **A**,
And out through prod **B**

I = Current flow

Field from above

Viewed from above and to the side

Figure 18.27 Field Produced by the use of Prods

Prods are used in certain areas of the North Sea and are stipulated by some procedures such as the D.N.V. inspection procedure.

ADVANTAGES

i) AC or DC can be used.
ii) Low voltages are used (typically 3 volts).
iii) Control of field strength.
iv) There are no poles to attract the particles (the prods may well be made of a diamagnetic material and so cannot be magnetised anyway).

DISADVANTAGES

i) It will be possible to switch on the prods without a field being produced if there is no electrical contact.
ii) Low voltage means a heavy transformer is required.
iii) There is a danger of arcing and so damage to the test piece.
iv) There is a danger of overheating the equipment.
v) If an incompatible material is used for the tips of the prods, there may be some contamination of the test piece. By the inclusion of a part of the prod tip, for example if copper is used (prod tips should be made of lead).

FLEXIBLE LOOPS

These will induce magnetism into the test piece by induction this means that there is no electricity passing through the test piece. The magnetism is generated by placing the test piece adjacent to an insulated current carrying conductor.

This can be done by either using encircling coils or a parallel closed loop conductor (the latter is commonly know as the kettle element). When using flexible loops it may well be necessary to employ some method of fixing them in place for the inspection. Permanent magnets and aluminium spacers will normally be used for this.

ENCIRCLING COILS

If a current carrying conductor is bent into a coil then the resulting flux flow will be longitudinal through the coil, as shown in figure 18.28 below:

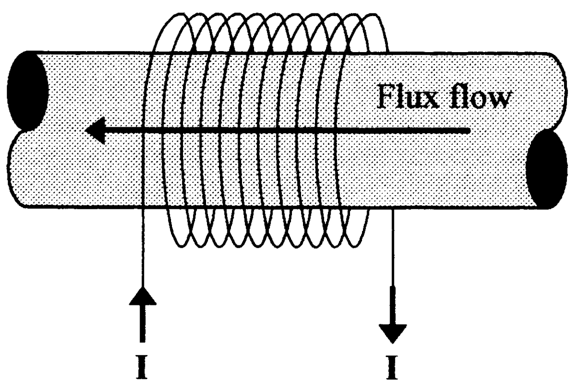


Figure 18.28 Longitudinal Flux Flow Through a Coil

This can perhaps be best explained by showing a section through the coil, illustrating the current flow and the resultant flux flow as shown:

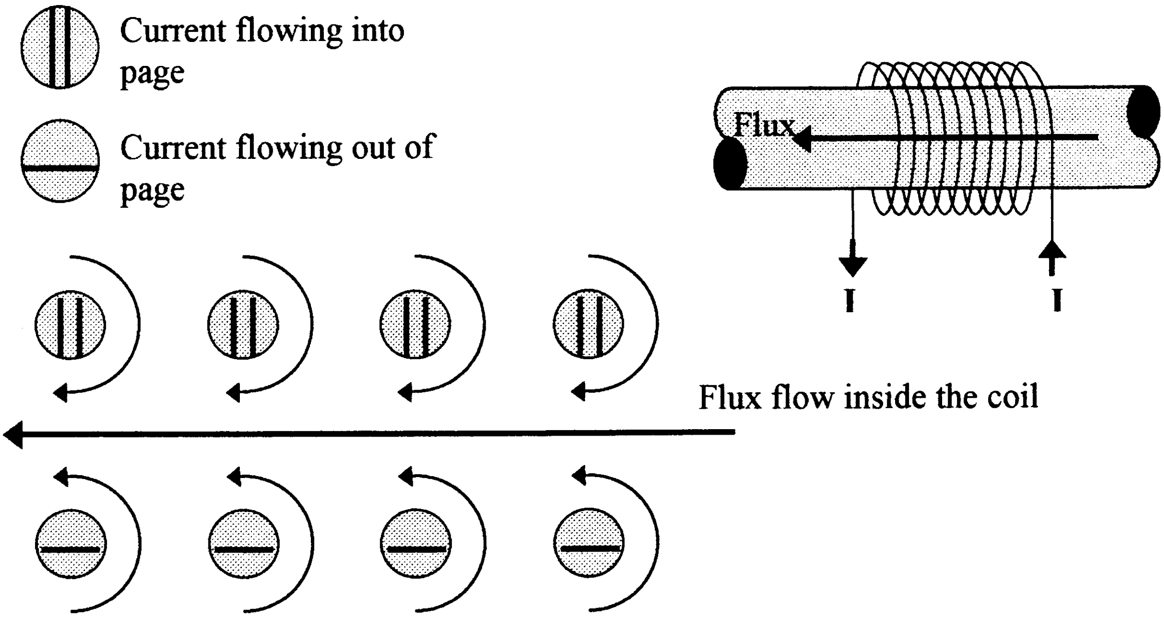


Figure 18.29 Section Through a Current Carrying Coil

This coil can be placed around a testpiece in a number of ways, we will look at two.

1. Evenly Spaced Coil

The coil is wrapped around the test piece in such a way that the weld to be inspected lies within the coil and the individual coils will be equally spaced apart. See figure 18.30 below:

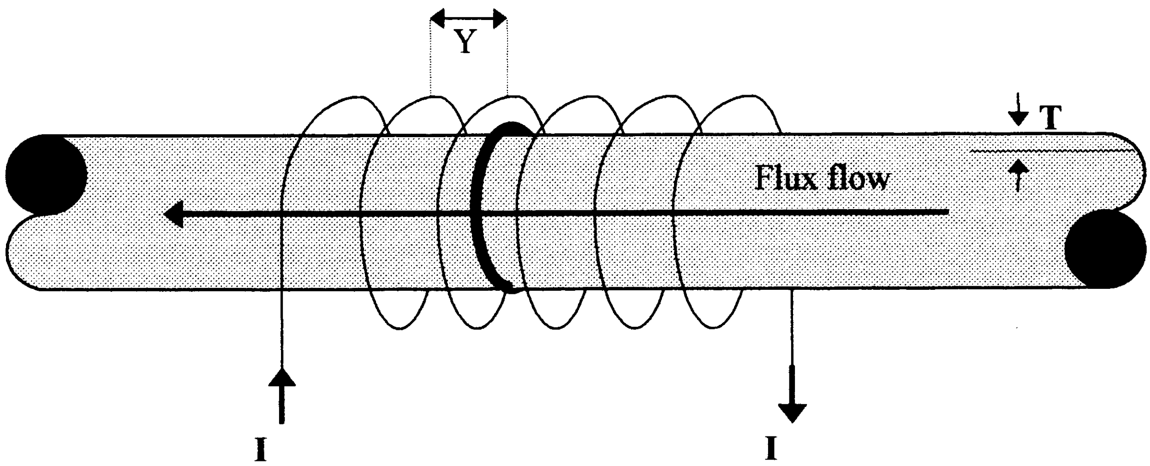


Figure 18.30 Evenly Spaced Coil

The following is a formula for working out the amperage to be employed using this technique:

$$I\,DC = 7.5 \times \left(T + \left(\frac{Y^2}{4T}\right)\right)$$

Where I = current (DC).
T = bracing wall thickness.
Y = coil spacing.
4 = constant.
7.5 = constant.
Y = coil spacing factor

If the skin effect is to be employed we will need to use A.C. current to magnetise and the formula is modified as follows:

$$I = 7.5 \times \left(10 + \left(\frac{Y^2}{40}\right)\right)$$

The only difference is that the 10 has been substituted for the T in the DC. calculation because the magnetism is concentrated near to the skin of the material. This method will find longitudinal defects in the weld metal of a circumferential butt weld.

If the weld to be inspected is at the end of a bracing it may be difficult, if not impossible to have the weld laying inside of the coil, if that is so then the close wrapped coil should be used.

2. Close Wrapped Coil

With this method the weld does not have to be inside the coil but must lie close enough to the coil to ensure the correct flux density to be achieved. Figure 18.31 below shows the way that the coils should be placed:

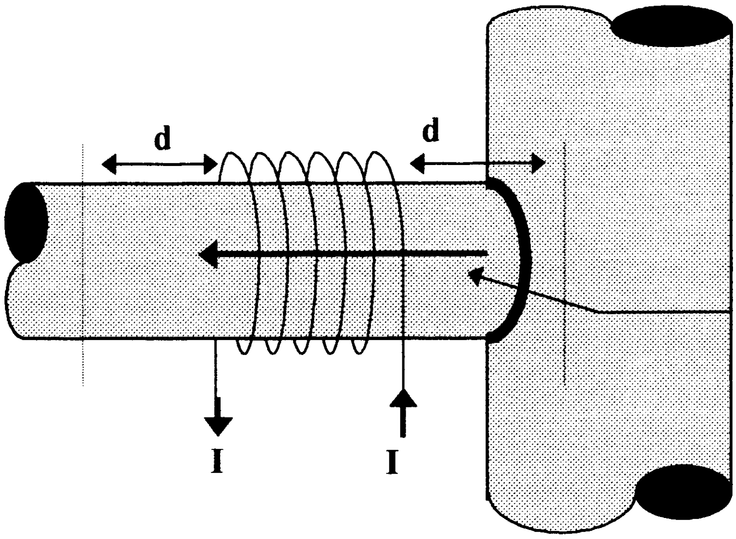


Figure 18.31 Close Wrapped Coil

The formula for the computation of the current to be used is thus:

$$I \text{ peak A.C.} = \frac{16 \times r}{N}$$

Where I	= the peak current A.C. (for peak current see fig 18.45).
r	= the radius of the brace measured in millimetres.
N	= number of coil turns employed.
16	= constant.

This will tell us the amperage to be used, but it will not tell us the distance each side of the coil where the flux density remains high enough for MPI (0.72 Tesla), to calculate the width of inspected area we will need to use the following formula:-

$$d = \frac{N \times I}{30}$$

Where d	= width of the inspected area (at 0.72 Tesla).
N	= number of coil turns employed.
I	= current in peak amperes used.
30	= constant.

Having done all of the above, the set up is ready to be used, and will find longitudinal defects in the weld.

PARALLEL CLOSED LOOP

This method is commonly called the kettle element, the reason for this can be seen quite clearly from figure 18.32. A conductor is placed against the surface of the testpiece in such a way as to ensure that cable runs either side of the weld and parallel to it, in such a way as to guarantee that when current is passed through the loop, the flow of current will be in the same direction along both sides of the weld. A magnetic field will result running transverse across the weld, the direction of the field will be shown by the "Right hand rule". It is employed when testing welds on a large, flat area or on very large, tubular members, which may be impossible to circle with a loop.

Note: When using this method the width between the parallel loops "d" is decided by the operator, it is imperative that the return loops of cable must be at least 10 times "d" distant from the energising loop. This will ensure that the magnetism in the inspection area will not be affected by the return loops.

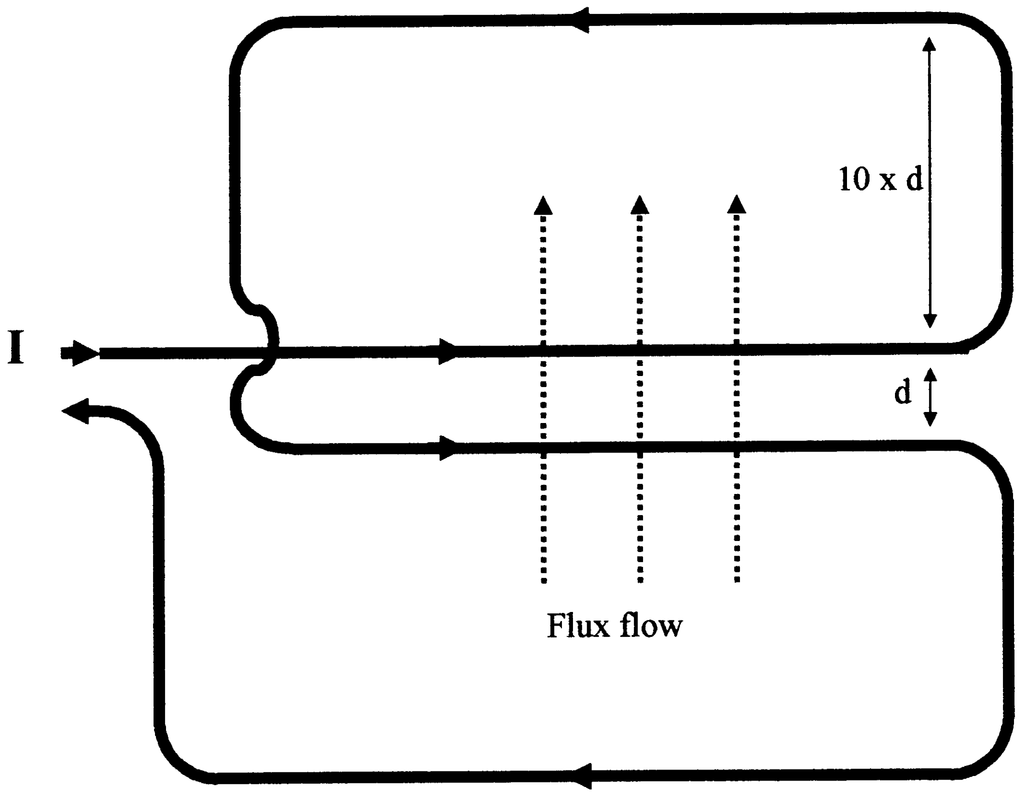


Figure 18.32 Parallel Closed Loop

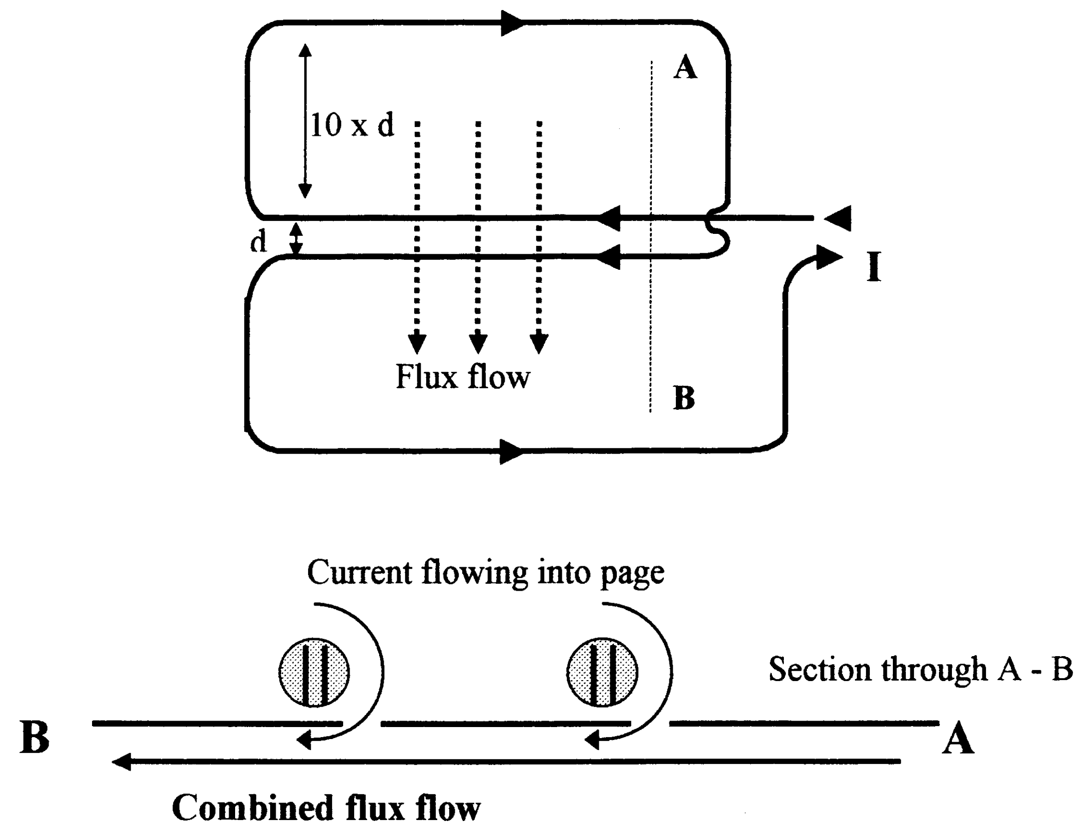


Figure 18.33 The Parallel Closed Loop Showing Current to Magnetic Field Relationship

For this method the current is worked out using the following formula:

$$I \text{ A.C. peak} = 30 \times d$$

It should be noted that this formula is just a transposition of the formula used previously to find the width of inspected area at 0.72 Tesla, when using close wrapped coil, i.e.:

$$d = \frac{N \times I}{30}$$

The following should be noted when using this method:

1. The current must travel in the same direction down both sides of the weld, otherwise the magnetism will be cancelled out.

2. The return loops must be at least ten times the width of the inspected area away or the magnetism will cancel out.

In this example the flux flow will be from top to bottom in the test piece and so we should be able to find longitudinal defects in the weld.

ADVANTAGES

i) The loops can be placed relatively easily.
ii) Large areas can be inspected with one coil placement.
iii) There is the facility to vary the field strength.

DISADVANTAGES

i) There is a relatively weak field produced.
ii) Long cables are required.
iii) Large and heavy step down transformers are needed because of the high current involved.

THE MECHANICS OF MPI

Now we are going to look at how the method works in finding discontinuities. In order for us to understand, we will look more closely at flux leakage around a defect as it is this leakage, which MPI actually locates.

Flux leakage is a point at which flux lines which can normally travel within a material are forced to leave and then re-enter that material as shown in figure 18.34 below:

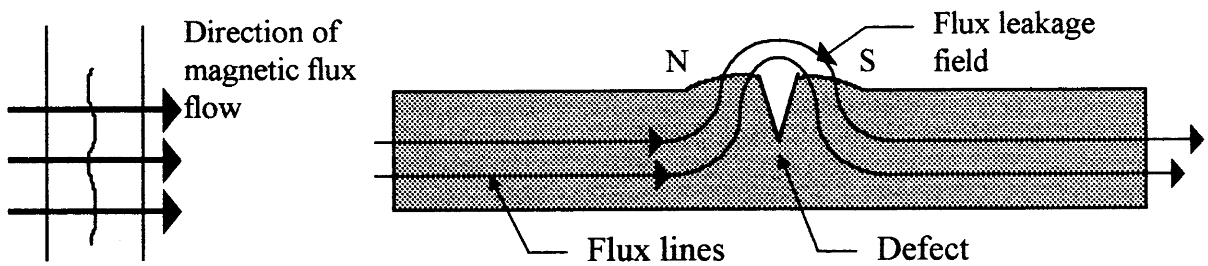


Figure 18.34 Flux Leakage Field Around a Defect

As can be seen in figure 18.34 the flux lines are travelling wholly inside the material until they encounter the defect. Because of the reduction of unit area of the testpiece and the properties of the flux lines they cannot all squeeze underneath (provided that we have sufficient flux density 0.72 Tesla) so they are forced out of the material thus forming a north pole.

When the flux lines have crossed the defect, then there is enough material for them all to run inside again and so they will re-enter, thus forming a south pole. These poles are called consequential poles and it is this area of flux leakage which we are able to detect using MPI The strength of the leakage field will depend to an extent on the type and location of the defect, i.e. a surface breaking defect will give a much stronger leakage than will a sub surface defect.

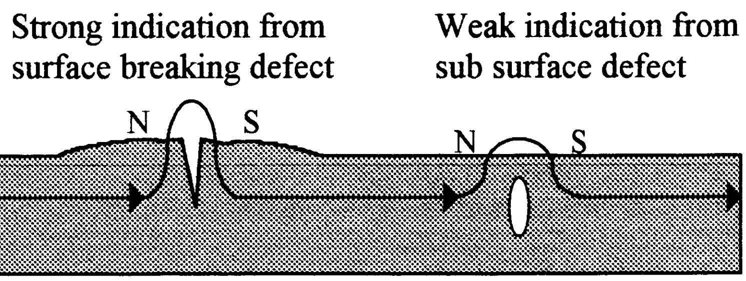


Figure 18.35 Flux Leakage Field Comparison

The above figure 18.35 shows that MPI will give the strongest indications when used on surface breaking defects.

The angle and orientation of the flux relative to the defect is also important. If the flux lines are running parallel to the defect then there will be no flux leakage as the flux lines will be able to flex enough to squeeze past the defect, instead of being forced out of the material and so will be undetectable. If the lines cross the defect at 45° then we will start to see a flux leakage sufficient for our purposes and this will give an indication of the defect, but the best angle for the flux lines to cross is 90° this will give a strong flux leakage and so a good indication of the defect location.

Defect running @:

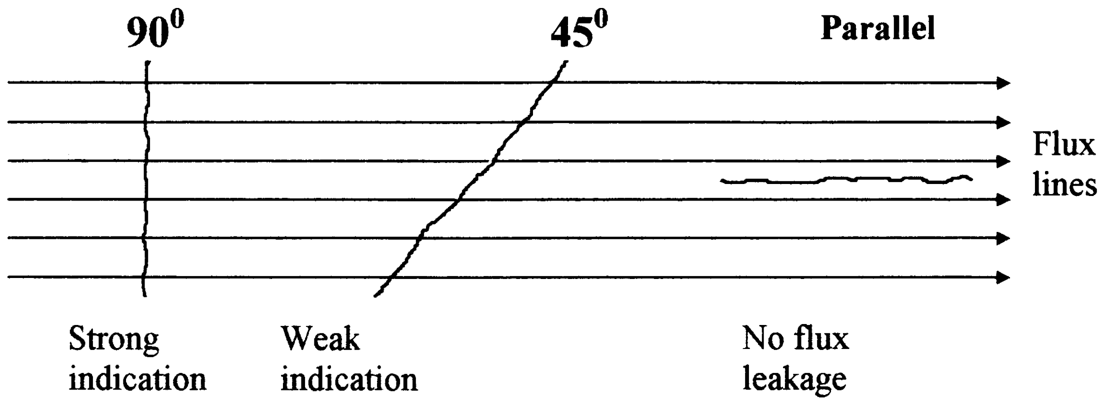


Figure 18.36 Flux Line Orientation Relative to Defects

Because of the above we must always test in two directions perpendicular to one another in order to ensure all of the defects are located.

DETECTING MEDIA (BS 4069)

Having created the right conditions to allow the flux leakage we now have to find some way to make that leakage visible. To achieve this we use either a powder containing fine ferromagnetic particles, or more commonly in our situation a suspension of the ferromagnetic particles. The particles used are fine ferrous oxides, they are used in preference to iron filings as they are much lighter and so will not settle out of the suspension as quickly. When the particles are applied to the surface of a test piece having a defect, which has been magnetised properly, they will be attracted to the area of flux leakage (the consequential poles) in such large quantities that the defect location becomes visible.

When reporting MPI the indications are always quoted as crack like indications **and not cracks** as we cannot actually see the cracks. They are not proven to exist until there is a destructive test done or the component fails.

PROPERTIES OF A GOOD INK

The British standard that relates to inks is B.S.4069 and this specifies that an ink must be non toxic, free of contaminants, not cause discomfort to users and must not corrode the test piece. In addition, the ink should possess the following properties:

i) The ink should contain particles with a fine grain as this reduces the gravitational effects, although it is possible for the grains to be too fine and this will not allow proper dispersion in the ink they will coagulate.

ii) The particles should have an elongated shape as this will aid the polarisation of the particle.

iii) High permeability is essential as the particle must be readily magnetised.

iv) Low Retentivity is also necessary as this will allow the easy removal of particles after the test or between shots.

v) The ink must have good contrast against the background as the defect can only be located if the indication can be easily seen.

Colours of Inks Used Underwater

There are red, black and fluorescent inks used in water, the most common is fluorescent as this is much more sensitive than the others. The fluorescent ink is made by coating the particle with a fluorescent salt which will fluoresce under ultra violet conditions. This will increase the sensitivity dramatically, providing the lighting conditions are correct as the indications become minute sources of visible light.

In order for the ink to perform properly it must contain the correct concentrations so we will look at the procedure for mixing and testing an ink as per BS 4069.

PROCEDURE FOR TESTING OF MPI INK

First check that the British standard number is printed on the container, if it is not there then the ink may not be up to the required standard. The batch number should also be noted. When these have been noted put the correct weight of powder as per the manufacturers instructions into a small container and add a little water. There will also be a need to add a "wetting agent" to enable the powder to mix easily, (the wetting agent is basically a pure soap) however, there should be not more than 10% by weight of wetting agent. Once we have a well mixed slurry we can add the rest of the water in a graduated bucket until the correct concentration has been reached, these days it is not unusual for the ink to be supplied as a slurry thus negating the need for mixing powders and adding wetting agents, these will just need to be diluted with the correct amount of water prior to use. After the ink has been mixed its concentration must be checked by the following procedure:

i) Mix the ink to the manufacturers instructions
ii) Agitate for at least five minutes.
iii) Pour 100ml into a settlement flask.
iv) Allow to settle for 60 minutes.
v) Read off and record the volumes from the bottom of the flask.

The above should be done every time a new batch of ink is mixed.

RECOMMENDED CONCENTRATIONS FOR MAGNETIC PARTICLE INKS

FLUORESCENT INKS

There should be between 0.1% and 0.3% by volume of ferromagnetic particles and no more than 10% by weight of other solids (6 - 24 grammes per litre).

VISIBLE LIGHT INKS

Should have a concentration of between 1.25% and 3.5% by volume of ferromagnetic particles and no more than 10% by weight of other solids.

THE CARRIER FLUID

This can be either water or paraffin, in our case it will normally be water and it should contain no more than 10% by weight of soluble additives such as wetting agents.

LIGHTING OF THE INSPECTION SITE (BS 4489)

In order for the indications to show up well the lighting of the inspection site is of course important. The British Standard for lighting is BS 4489 the levels given are as follows:

1. INSPECTION USING VISIBLE LIGHT INKS

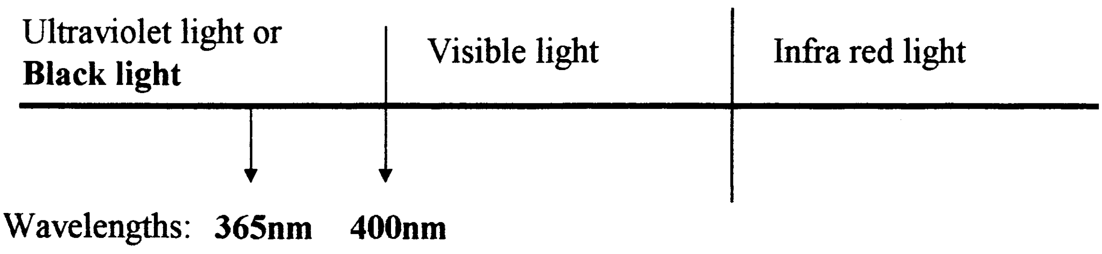
The level should be at least 500 lux of white light, this level should be attained using a diffused light source, (not a spot light) if possible. To give some idea of what this light level is, an 80-watt fluorescent tube at 1m distance gives 500 lux.

2. INSPECTION USING FLUORESCENT INKS

The level of ultra violet light (black light) should be at least 800 $\mu W/cm^2$ (micro Watts per square centimetre). In addition the inspection site must be dark, otherwise there will not be sufficient contrast, so the ambient light at the job site should not exceed 10 lux.

ULTRA VIOLET LIGHT

Part of the electromagnetic spectrum is shown below. It can be seen that the visible light is made up of wavelengths, which lie between ultra violet and infrared. For MPI we are interested in ultra violet light.



Note * 1nm (nanometre) = 10^{-9} metre.

Figure 18.37 The Electro Magnetic Spectrum

Ultra violet light is dangerous, it can cause cancers and cataracts amongst other things. The safest wavelength is UV/A, which has a wavelength of 365 nano metres this is the one that we use in the inspection. All of the other more harmful wavelengths are filtered out using a filter on the front of the ultra violet lamp called a **Woods Filter**. Even so, it is not advisable to look into the black light or shine it in another person's eyes, as this can be very unpleasant and indeed can cause damage.

The ultra violet light is normally produced by means of a mercury vapour discharge bulb, which means that an arc is caused to jump between two terminals through a mercury vapour. The result is ultra violet light and visible light, the bulb will not always produce the ultra violet light as it tends to have a limited life.

This makes the testing of the black light essential in order to ensure the production of ultra violet is of sufficient intensity. Looking into the lamp is both dangerous and ineffective as the purple glow does not mean that there is any ultra violet being produced and so we must use the following procedure to prove the production of ultra violet.

PROCEDURE FOR THE TESTING OF THE ULTRA VIOLET LAMP

i) Switch on and allow the lamp to warm up for 15 minutes. The lamp must not be left switched on for more than 5 minutes in air as the heat it generates will cause damage to the seals. Ensure the lamp is cooled during the 15 minute warm up and then allow to cool prior to immersion afterwards.

ii) Shine the light into a photometer (black light meter) from the viewing distance, taken as 400mm.

iii) Read the meter and record the result, should be at least 800 microwatts ($\mu W/cm^2$) per square centimetre ($1000\mu W/cm^2$ to BS EN ISO).

The above can be checked by the use of a Photometer (figure 18.38). This should be done at least once a month or more often if there is any doubt as to the lamps Ultra violet light output.

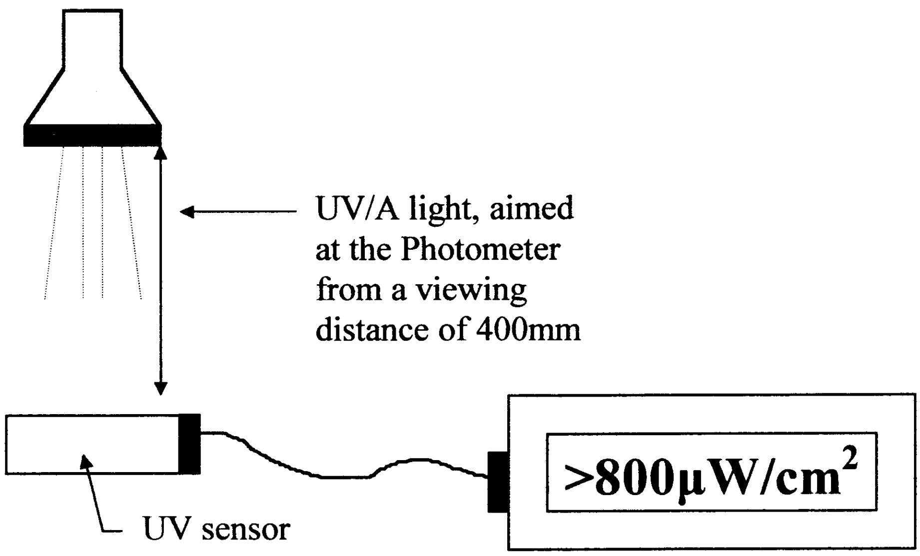


Figure 18.38 The photometer

CLEANING STANDARDS RELATING TO MPI

In order for the magnetic particle inspection to be carried out properly the weld must be cleaned to SA 2½ or 3 to at least 75mm either side of the weld. In addition sufficient gross removal must be achieved to allow intimate contact of the magnetising apparatus.

SENSITIVITY OF THE MAGNETIC PARTICLE INSPECTION

The sensitivity of a magnetic particle inspection is primarily dependant on; operator ability, equipment used and environmental conditions.

The operator can only achieve good results through good training and experience but the other factors can be explained as follows and will affect either the contrast (the ability of the particles to make the indication visible due to a colour difference between the indication and the background) or the definition (the sharpness of the indication) of the test, firstly the contrast:

1. Contrast

Contrast will be affected by the following:

i) Surface conditions of the test piece i.e. rough or smooth and also the state of cleaning.

ii) Conditions of the detecting media (solid content and colour).

iii) Magnetic field strength must be sufficient to enable the flux density to reach at least 0.72 Tesla.

iv) Lighting of the inspection site must be adequate to enable good visual contrast between indications and the background.

2. Definition

Definition will be affected by the following:

i) Conditions of the ink again can affect the definition this is the reason for such a small particle in the ink to give a very fine line to the indication.

ii) Geometry of the workpiece will affect the test by producing false indications, which can mask relevant indications and so reduce the definition.

iii) Direction and efficiency of the flux flow through the test piece and with current flow the electrical contact will be important.

SENSITIVITY OF THE MAGNETIC PARTICLE INSPECTION

Contrast

1. **Surface conditions**
2. **Conditions of the ink**
3. **Magnetic field strength**
4. **Lighting of the inspection site**

Definition

5. **Condition of the ink**
6. **Geometry of the testpiece**
7. **Magnetic field efficiency**

Figure 18.39 Sensitivity of a Magnetic Particle Test

DEMAGNETISING

Demagnetising is done to remove any residual fields in a material this may be necessary for the following reasons:

i) Prior to magnetic particle testing a residual field may upset the required flux flow and cause vector fields. Vector field is a magnetic field, which is the result of two magnetic fields running in different directions it will produce a field at an angle to the original fields.

ii) Post inspection - residual fields may upset navigational equipment etc.

iii) Prior to a weldment technique being applied.

iv) Prior to any other process which can be affected by magnetism.

To illustrate the process of demagnetising we can use the Hysteresis loop. With the loop we can see the coercive point, which is the point at which the flux density in the material is reduced to zero. The force needed to achieve this, (coercive force), which is the external magnetising force produced in the opposite direction to the original magnetising force.

In order for the material to be properly demagnetised we must randomise the domains, this will involve repeated changes of direction of the external field. So when demagnetising we will change the field polarity and apply sufficient force to exceed the coercive force then reverse the polarity and do the same again **(CONSTANTLY REVERSING AND REDUCING THE EXTERNAL FIELD)**. Each time this is done the Hysteresis loop will be smaller as shown in the diagram, and eventually the material will be demagnetised and the flux density will be zero.

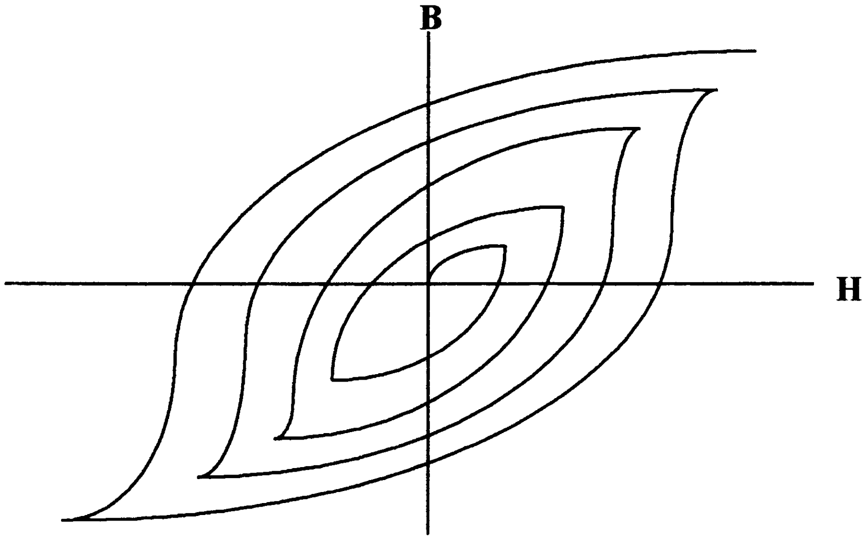


Figure 18.40 The Hysteresis Loop and Demagnetising

Ideally the demagnetising should be carried out east- west but as this may involve moving the component it will not normally be considered in our field. The following are the methods of demagnetising:

1. Alternating Current Aperture Coil

The coil will be made up of a large number of insulated copper windings, which when energised will create a magnetic field strong enough to take control of any residual field present in the component. As the current used is alternating current then all that must be done is to reduce the current slowly, thus reducing the Hysteresis loop until the flux density is zero. This is the method most widely used offshore as the energising coils can be left in- situ and used to demagnetise at the completion of the task by simply increasing the current to take control, and then reducing the current to zero.

Alternatively, once the coil has been energised the component can be removed from the coil thus reducing the flux density in the material.

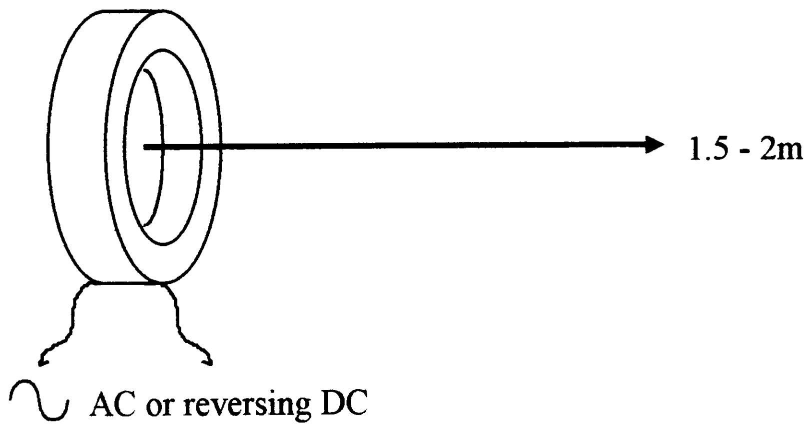


Figure 18.41 Alternating Current Aperture Coil

2. Aperture Coil with Reversing Direct Current

Essentially, this is the same as method 1, except that the current does not change direction automatically. First we apply sufficient direct current to produce a field in the material which is stronger than the residual field then switch off the power, reverse the terminals and reduce the current before applying the current again. This must be done until the current is at zero. Care must be taken not to reduce the current by steps, which do not allow sufficient coercive force to be built up as this will result in a residual field being left in the material. This method will of course be more time consuming than the alternating current aperture coil, but if the original magnetising force was generated by the use of direct current or a permanent magnet then direct field must be used to remove it, because of the skin effect.

3. A.C. Electromagnetic Yokes

If alternating current has been used to magnetise then we can employ an electromagnet using alternating current to remove the residual field. This is done by stroking the magnet over the surface of the test piece and removing in a circular movement several times, making sure that the return path is well removed from the test piece (see figure 18.42 below).

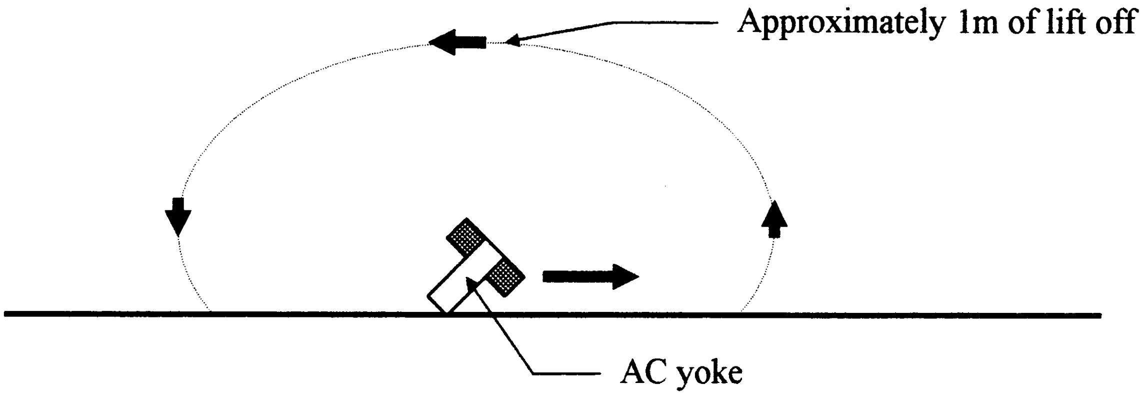


Figure 18.42 A.C. Electromagnetic Yokes

4. Heating Above the Curie Point (700-720°C)

This method will not normally be used in our field but it should be noted that if we heat a metal to its curie point (700-720°C in steel) the domains will be randomised and so the residual field will be destroyed.

ASSESSMENT OF RESIDUAL MAGNETISM

Residual magnetism is assessed after demagnetising using a **FIELD STRENGTH INDICATOR.** This is a very sensitive meter, which detects the presence of residual external magnetic fields around a testpiece.

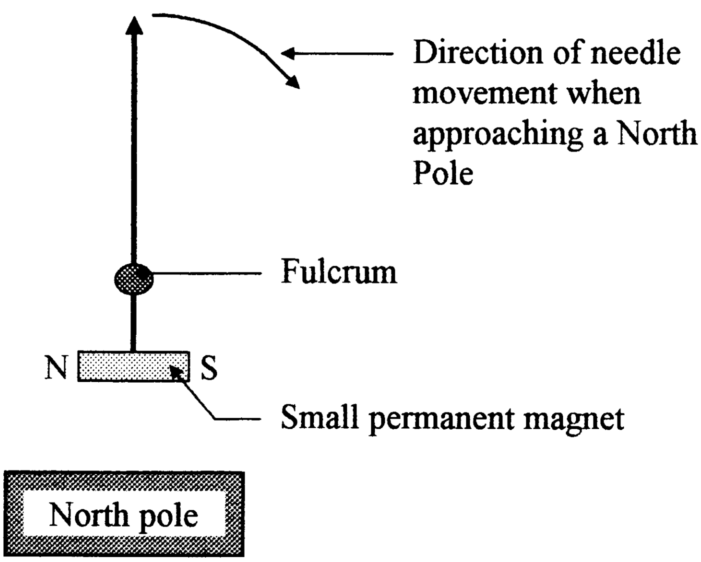


Figure 18.43 Field strength indicator

ELECTRICITY AND AMMETERS

Electricity can be measured in two ways, the first is the measure of potential, measured in **VOLTS**, and this is the ability to do work. The second way is to measure the flow of electricity and this is measured in **AMPERES.** It is amperes that interest us when using Magnetic Particle Inspection, as the flow of electricity is what produces the magnetic field. An AMMETER is used to measure this flow. If we use direct current the electricity is always flowing in the same direction so the ammeter will measure the correct value, which is the peak current as shown in figure 18.44:

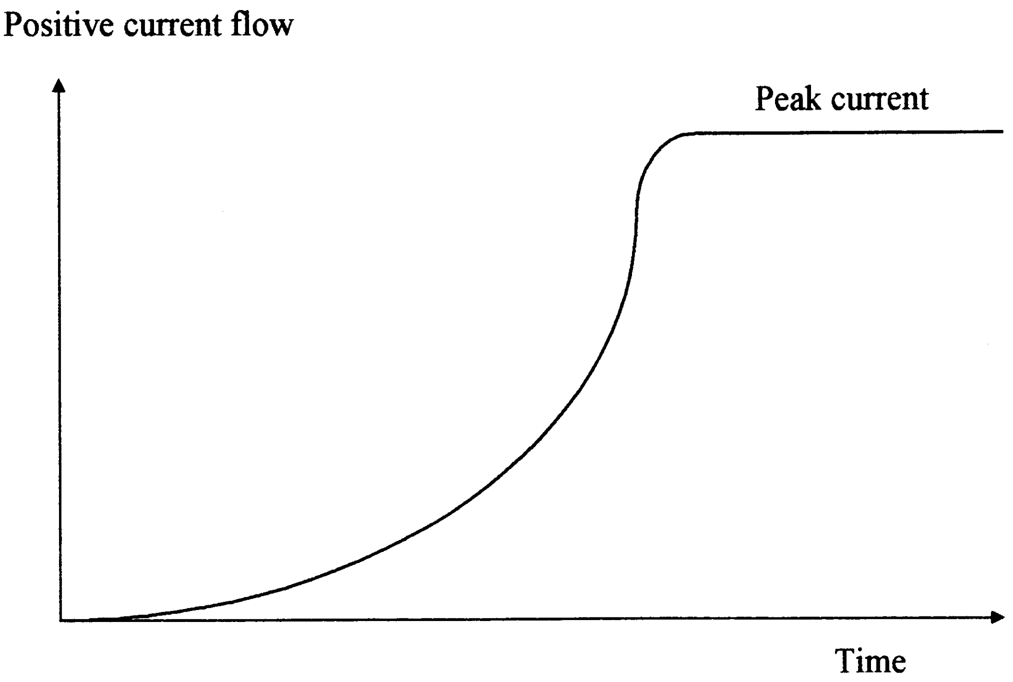


Figure 18.44 Direct Current

Alternating current is somewhat different in that, for half the time the current is flowing in one direction and for the rest of the time it will flow in the opposite direction. This presents a problem with measurement because an ammeter cannot measure negative values and has to show a positive current flow. What an ammeter actually shows is the ROOT MEAN SQUARE or RMS value. This will show a lower value than the peak current. The method for working out the RMS is as follows, alternating current can be represented as in figure 18.45 below:

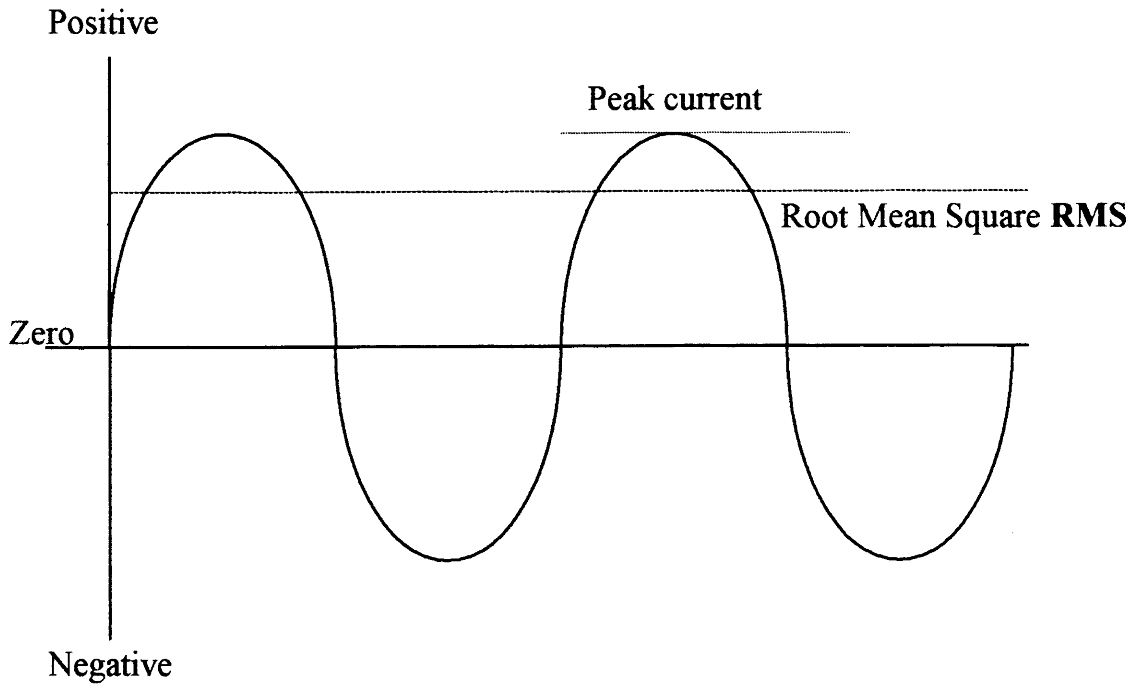


Figure 18.45 Alternating Current

To find the root mean square value (RMS) from the peak value we must divide the peak current by 1.414, which is a constant. In order to find the peak current from an ammeter reading we must multiply the meter reading by 1.414, so if the meter reads 900 amperes (RMS value) the peak current will actually be 900 multiplied by 1.414 which is 1272.6 amperes peak current.

DIRECT CURRENT FROM ALTERNATING CURRENT

It is possible to produce direct current from an alternating source by the use of a rectifier, this is a series of electrical non-return valves called diodes, and these allow electricity to travel along a path in only one direction. When they are arranged properly we can either cut out the lower part of the sine wave from the alternating current, so producing half wave rectified AC. Or we can turn the lower peak around so that it will appear above the line and this is termed full wave rectified A.C. or pulsed DC as shown in figure 18.46 below.

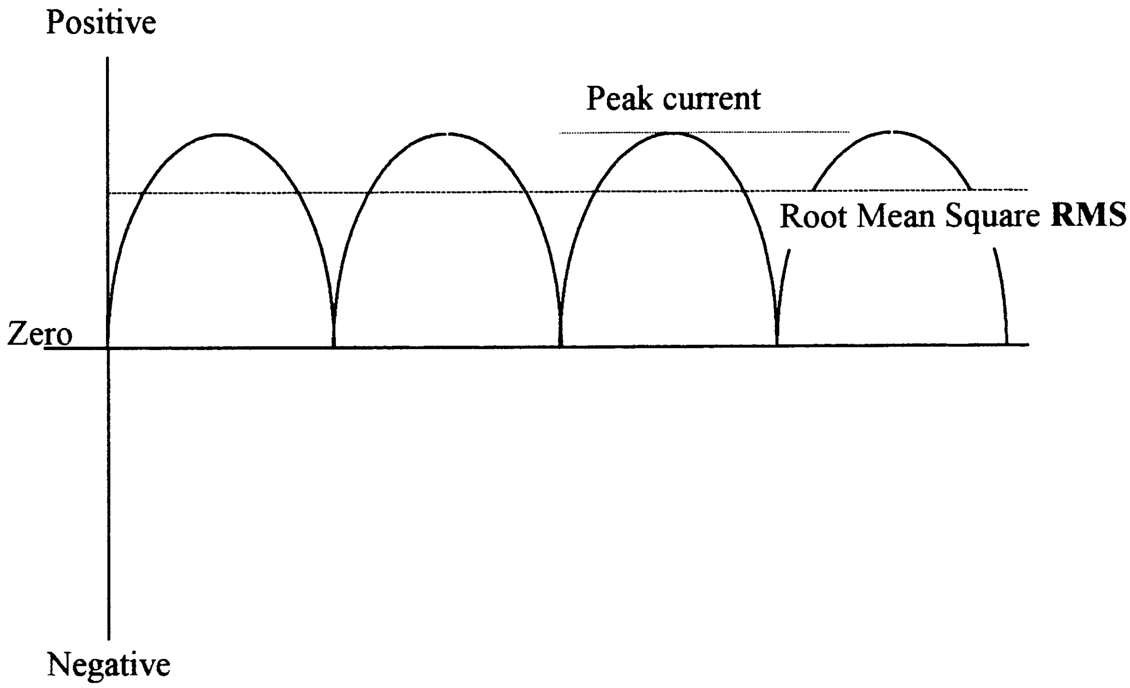


Figure 18.46 Rectified Current

PROCEDURE FOR MAGNETIC PARTICLE INSPECTION

An MPI procedure is designed to enable the inspection to be carried out in the correct manner using the correct and proper techniques. The following is an outline procedure for use with fluorescent inks, which could be adapted for most sub sea inspections:

1 Surface Checks

- i) Obtain the correct and appropriate permits to work. Test all circuit breakers or Residual Current Devices (RCD's) for correct operation.
- ii) Check all electrical cables for kinks and breaks in the insulation.
- iii) Check rigging and buoyancy arrangements.
- iv) Ensure the ultra violet light is functioning properly to BS 4489, ensure the woods filter is in good condition and undamaged.
- v) Ensure the detecting media is mixed to BS 4069 (carry out the settlement test), and that the ink delivery system is functioning properly, depress the trigger for 15 seconds to flush out all air from the system.
- vi) Work out the expected current required for the inspection with the chosen method.
- vii) Function test the magnetising apparatus ensuring correct current supply and adequate amperage.
- viii) Check there is an undamaged flux indicator attached to the ultra violet lamp.
- ix) Check all ancillary equipment (Tapes, hammer, punch, grinder etc)

x) Ensure personnel are properly qualified and competent
xi) Carry out proper briefing for the diver and deck crew
xii) Ensure recording method is in place prior to the diver entering the water
xiii) Obtain correct permits to work

2. Establish down lines and working lines at the correct location.

3. Clean the inspection area to SA 2½ at least 75mm either side of the weld. Ensure that sufficient gross cleaning is also carried out to allow intimate contact of the magnetising apparatus.

4. Establish a datum and mark up the weld using a tape measure, clock positions and member idents.

5. Carry out a close visual inspection of the weld looking for defects and sharp changes of contour, which could cause irrelevant indications during the MPI.

6. Rig the transformer in a safe place close to the inspection site.

7. Switch on the ultra violet lamp and allow 15 minutes for warming up.

8. Ensure ambient light is less than 10 Lux.

9. Rig up the magnetising apparatus on the weld.

10. Demagnetise if required.

11. Ensure the ink is being agitated constantly.

12. Place the flux indicator flat on the heat affected zone close to the weld in the correct orientation for the defects sought. If coils are used it should be placed on the far side of the weld from the coil.

13. Switch on the magnetising current, and report the current used.

14. Apply the detecting media to the flux indicator.

15. Inspect the flux indicator for the proper indications to ensure 0.72 Tesla flux density. This should be done at the cardinal points of the weld i.e. 12 o'clock, 3 o'clock, 6 o'clock and 9 o'clock, possibly more often on a large weld.

16. Providing that the flux density is sufficient then the inspection of the weld can commence.

17. Ensure the data recorder is ready to accept information.

18. Apply the magnetising amperage.

19. Apply the ink to the weld surface and heat affected zone and inspect under U/V light.

20. If an indication is found, turn off the magnetising apparatus (Possibly demagnetise) clean off particles and repeat steps 18 and 19

21. If the indication is still evident record and report the following:

    i) Location (distance from datum in millimetres)
    ii) Length
    iii) Orientation and position relative to the weld (HAZ, weld cap etc)
    iv) Continuous or intermittent
    v) Branching or not (note location and orientation of branches)
    vi) Weak or strong indications

22. Carry out remedial grinding as required by the client.

23. Carry out retest after grinding to assess the condition of the defect, mark ends of the indications if required.

24. Once the weld has been fully inspected demagnetise if required.

25. Remove all equipment and return to surface.

26. Wash all equipment with fresh water and flush the ink delivery system with fresh water.

27. Report all findings correctly and concisely to the client and cancel the permit to work.

MAGNETIC PARTICLE INSPECTION INTERPRETATION AND REPORTING

When using MPI there are three types of indication, which can occur they are as follows:

1. **RELEVANT INDICATIONS** - Produced by defects.

2. **NON RELEVANT INDICATIONS** - produced by magnetism holding the particles at points other than defects, there are a number of places that this can occur as shown below:

    i) Sharp changes of geometric contour, such as occur at the toes of welds and uneven weld caps:

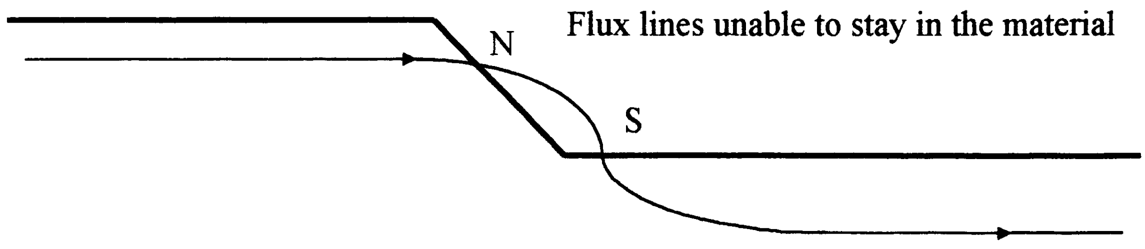


Figure 18.47 Sharp Geometric Changes

ii) Tool and Hammer Marks:

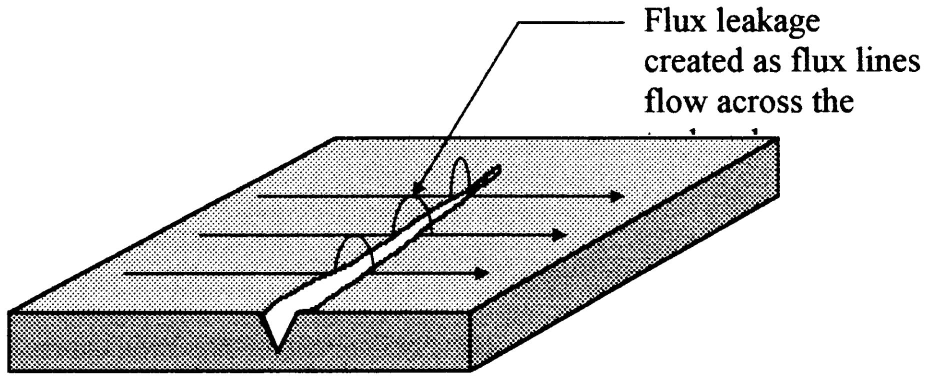


Figure 18.48 Tool and Hammer Marks

iii) Brazed Joints:

Brazed joints will cause a flux leakage around them owing to the change in permeability at the joint.

iv) Permeability Differences:

The permeability of a material can be altered by heat treatment, this means that over a weld zone there may well be three slightly different permeabilities. The parent plate will have one permeability, the heat-affected zone will be another and the weld metal itself will be a third. This can leave a line of particles at each boundary.

v) Magnetic Writing:

This is brought about by two metals of differing permeability rubbing together, when particles are applied to the surface they will be held at the point of contact between the two materials. This will mean that if, say a shackle has been dragged over a member the particles will show a line indicating where the shackle made contact.

3. **FALSE INDICATIONS** - The particles are held on the testpiece by some means other than magnetism, such as gravity or by marine growth etc.

REPORTING OF INDICATIONS

Indications should be reported as follows:

i) The distance from the datum mark to the start of the indication measured in millimetres.

ii) Length of the indication.

iii) Orientation and position of the indication relative to the axis of the weld.

iv) State whether it is a strong or a weak indication.

v) State if it is continuous or intermittent.

vi) State if it has branches or not. If it has then the location and orientation of the branches should be reported together with their length.

vii) Position of the indication i.e., HAZ, toe, centre line etc.

viii) INDICATIONS should be reported using correct terminology as they appear i.e. Undercut, Porosity, Cracks. But it should be noted that the indications are just that i.e. a suspected crack will be reported as a **CRACKLIKE INDICATION**.

If the indications are very small and so are difficult to see, then it is possible to use a magnifying glass to inspect them.

As with all other methods the report is the final end product of the Magnetic Particle Inspection, figure 18.49 is an example of an MPI report sheet:

Client:				**MPI report sheet:**	
Location:		**Node reference:**		**Depth:**	
Dive number:		**Date:**		**Sheet of**	
Description of workpiece					
Equipment:	**Used:**	**Make & serial No's:**	**Ink:**	**% by vol:**	
Permanent magnet:			**Make:**		
Coil:			**Water based:**		
Parallel loop:			**Fluorescent:**		
U/V lamp:			**Black:**		
Ink dispenser:			**Current used: Amps**		
Other:			**AC: DC: Turns:**		
Cleaning:					
HP water:	**HP grit:**	**LP grit:**	**Hyd wire brush**	**Hand:**	
Viewing conditions: Ambient light Lux UV/A µW/CM²			**Surface finish:**		
General report:	Flux Indicator: 3o'c	6o'c	9o'c	12o'c	
Test restrictions:			**Diver:**		
Client:			**Inspection engineer**		

Figure 18.49 MPI Report Sheet

The above report may well be sufficient for the client but the following are a number of ways in which the inspection findings can be recorded:

1. **Ultra Violet Photography**

   Photography of the indication under ultra violet light, either by means of an ultra violet lamp and long exposure or by ultra violet filters on a strobe light.

2. **Capture of the Particles in a Cast**

   The casts or mouldings such as "Microset" would be applied while the power is still on and any particles would be captured in the cast. When set, the cast can be removed and will contain the particles, which can then be viewed at a later date.

3. **Foil Packets ("Magfoil" trade name)**

   The packets are individually numbered and bar coded, there will be an internal barrier that is used to separate the carefully controlled amounts of magnetic particles, powders and fluid mixtures. Each foil carries a triangular shaped wire indicator, which is used in the process of recording field strength and direction.

   Operation of the foils:

   Pressing the foil will break the internal barrier, the fluids can then be mixed, and the foil should then be placed onto the testpiece area.

   Once the contents of the foil have been mixed (45 seconds) the substance in the foil will be a dark grey colour. It will remain liquid for approximately 100 seconds, during which time the foil will be applied to the test surface and the magnetising force should be applied. After approximately 5 minutes the foil will have set allowing removal from the test piece, the defect indication will show as a white zone in the foil. By measuring the length of the white zone the length of the crack can be determined. Measurement of the width will give an approximation of the width of the defect, and both of these indications is said to give an impression of the defect depth.

4. **CCTV**

   Some video cameras can capture the visible light from fluorescent particles so producing a record of the inspection.

5. **Rubberised Tape Transfer**

This method is not widely used in our field for obvious reasons, if however the inspection is carried out in a dry environment (such as a welding habitat) then an adhesive tape can be applied to the indication once it has been dried off. When the tape is applied the particles will become adhered to the tape and thus removed with it to be viewed at a later date.

CHAPTER 19

Ultrasonic Inspection Using A'scan

Sound

A series of mechanical vibrations, which result from the back and forth particle motion in the material. It can travel through solids, liquids and gases although it will travel at different velocities depending on the density of the material.

Cycle

The movement of a particle from rest to its maximum deflection in one direction, and then back through its mid point and out to the maximum deflection, finally returning to the start point (see figure 19.1).

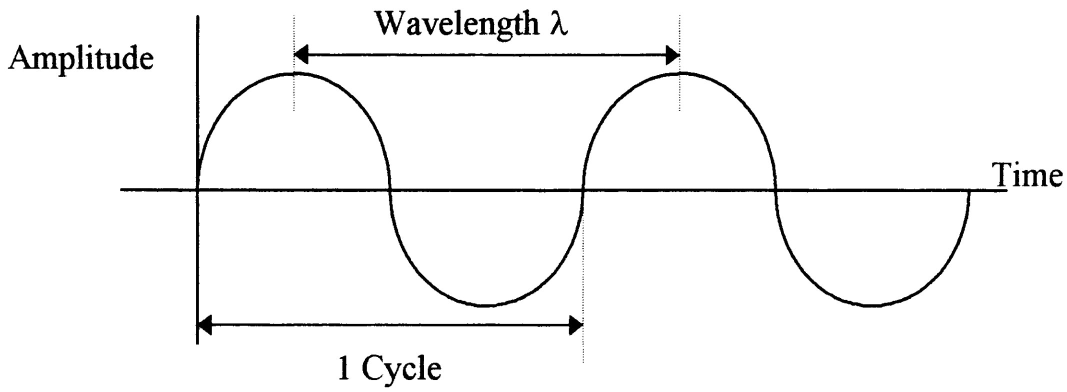


Figure 19.1 The cycle

Frequency

This is the number of complete particle vibrations in a given time (cycles occurring per second), usually expressed as HERTZ, one Hertz is one cycle per second.

$$\text{Frequency } (f) = \frac{\text{Number of cycles}}{\text{Time for that number of cycles}}$$

1 CYCLE PER SECOND = 1 HERTZ (1 Hz).

1,000 CYCLES PER SECOND = 1 KILOHERTZ (1 KHz).

1,000,000 CYCLES PER SECOND = 1 MEGAHERTZ (1 MHz).

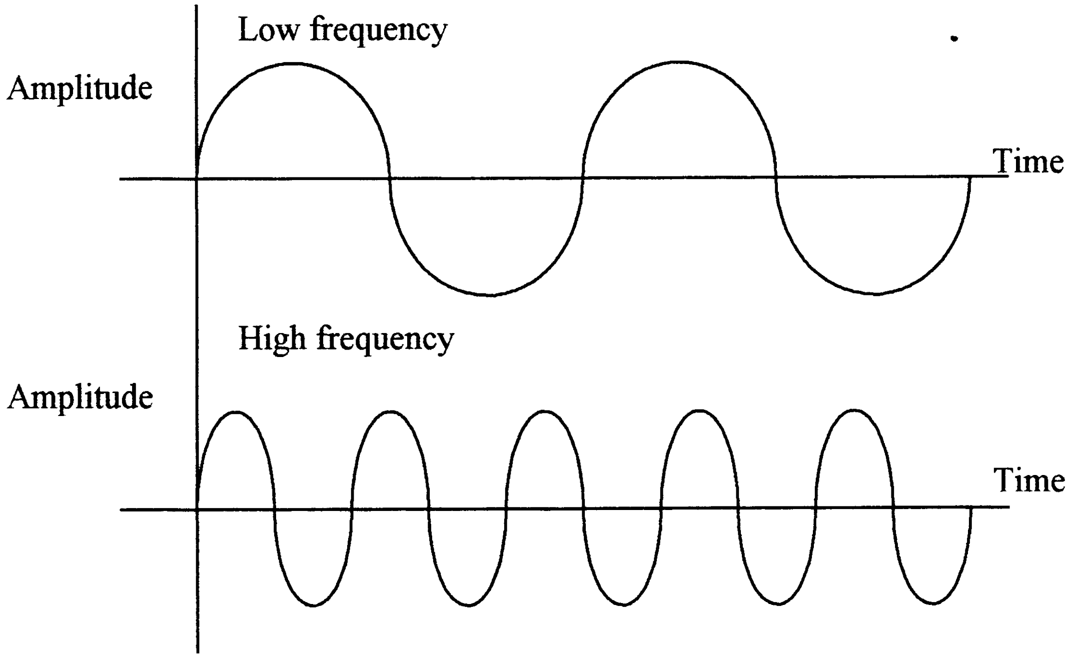


Figure 19.2 Frequency

Sound can be divided into three categories as follows:

1. Infra sound - 0 to 16 hertz (below audible range).

2. Sonic sound - 16 hertz to 20,000 hertz (audible sound).

3. Ultrasound - 20,000 hertz and above (above audible range).

We use ultrasound because high frequency sound will have superior penetrating power, also ultrasonic sound being inaudible, allows us to use very high power levels, which would cause damage to our ears if the audible range were to be used. The maximum allowable sound level allowable for continuous exposure is 90 decibels (db), exposures to sound above 120-db will cause damage to our ears.

The normal frequency used for the testing of steel is between :

1 MHz and 6 MHz.

Period

The time taken for one complete particle vibration (one cycle). Symbol used for period is T.

$$T = \frac{1}{f\,(Hz)}$$

Velocity (speed of the wave)

The distance travelled in a unit of time, i.e. miles per hour, kilometres per hour or in our case metres per second (m/sec).

Some useful velocities from our point of view are:

Air = 330 m/sec (@ 1 bar).

Water = 1480 m/sec.

Perspex = 2730 m/sec (compression wave).

Steel = 5960 m/sec (compression wave).

Steel = 3245 m/sec (shear wave).

Wavelength (λ Lambda)

The distance travelled by one cycle of energy. In different substances the sound will travel at different velocities due to the differing densities and hardness of the material. **The smallest detectable defect will be one half of one wavelength.**

The formula for working out the wavelength of an ultrasonic beam is as follows:-

$$\text{WAVELENGTH } (\lambda) = \frac{\text{VELOCITY OF SOUND IN THE MATERIAL}}{\text{FREQUENCY OF THE ULTRASOUND}}$$

OR

$$\lambda = \frac{V}{f}$$

So if we have a 2.5 MHz probe working in steel (velocity of 5960 metres per second).

Note : When working out this formulae all of the values have to be in base units, this means that the velocity will need to be in millimetres so we need to multiply the 5960 by 1000, and the frequency will need to be in cycles per second or Hertz, this is because the wavelength worked out will be in millimetres.

$$\lambda = \frac{5{,}960{,}000}{2{,}500{,}000}$$

$$\underline{\lambda = 2.384 \text{ mm}}$$

As a compression wave passes from one material to another the velocity will also change:

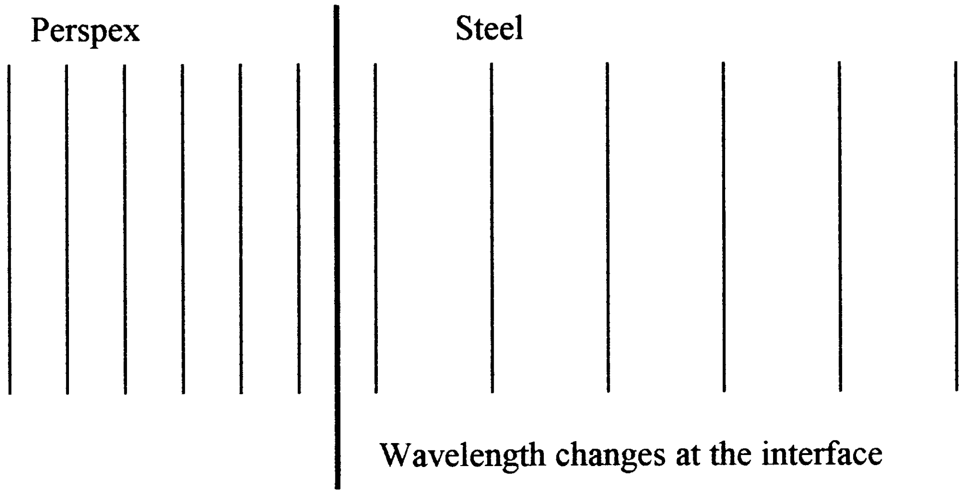


Figure 19.3 Velocity Change at an Interface

We can see that as the sound travels from the Perspex to the steel the velocity changes from 2730 m/sec to 5960 m/sec thus the wavelength will also change and with it the sensitivity of the test.

PULSE REPETITION FREQUENCY

This should not be confused with the frequency of the probe, which will remain constant. The pulse repetition frequency (P.R.F.) is controlled by the coarse range control of the A'scan flaw detector, and in short it ensures that there is no interference of the received sound by the transmitted sound. This is achieved by the sound being sent into the material in short bursts, so that the end result is a number of small "packages" of sound all travelling in the material one behind the other, much as carriages on a railway track indeed this is called a <u>wave train</u>.

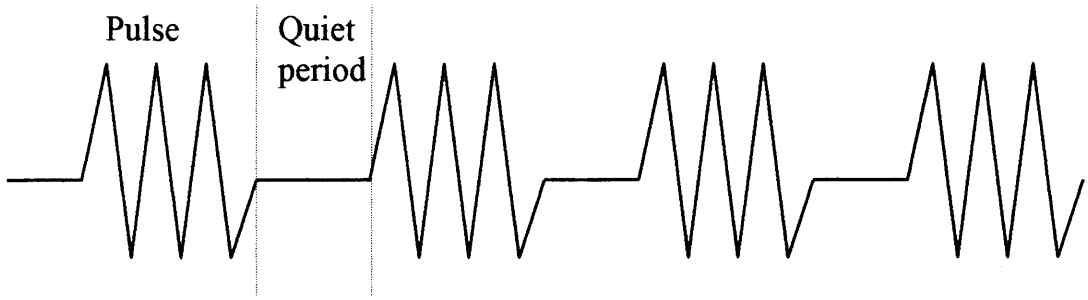


Figure 19.4 Pulse Repetition Frequency (Wave Train)

PULSE WIDTH

The pulse width is considered to be measured from the point at which the crystal is vibrating at its maximum amplitude to the point where it reduces to ten percent of the maximum. This variation is controlled by the amount of mechanical damping applied to the probe, different probes will "ring" (The time taken for the crystal to stop vibrating after the electricity has been switched off) for differing lengths of time. There are short pulse, medium pulse and long pulse probes as shown below:

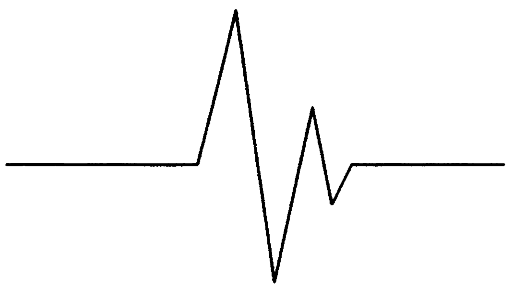


Figure 19.5 Short Pulse (rings for only one to two cycles)

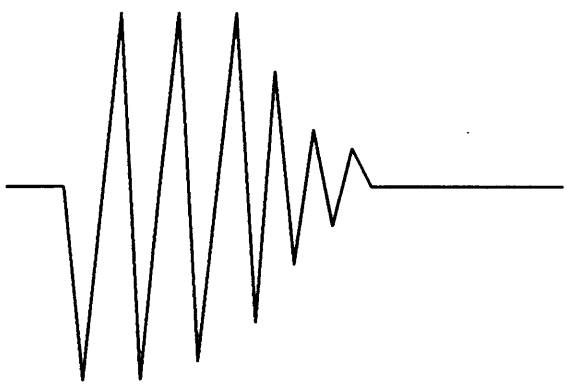


Figure 19.6 Medium pulse (rings for between five and ten cycles)

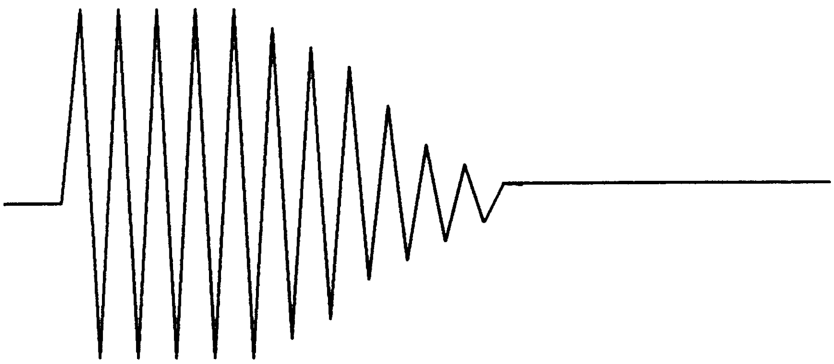


Figure 19.7 Long pulse, rings for longer than ten cycles.

Sound obeys the laws of light, which are:

REFLECTION

The angle of incidence is equal to the angle of reflection
(I = R) with no loss of intensity.

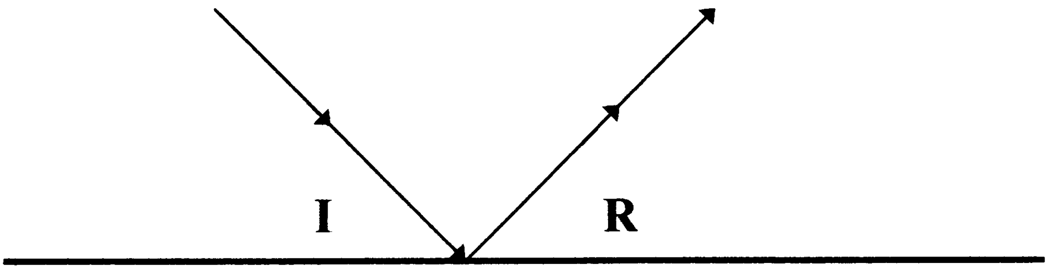


Figure 19.8 Reflection

REFRACTION

As a sound beam crosses the interface (boundary between the two materials), from one medium to another it will either slow down or speed up resulting in a change of direction.

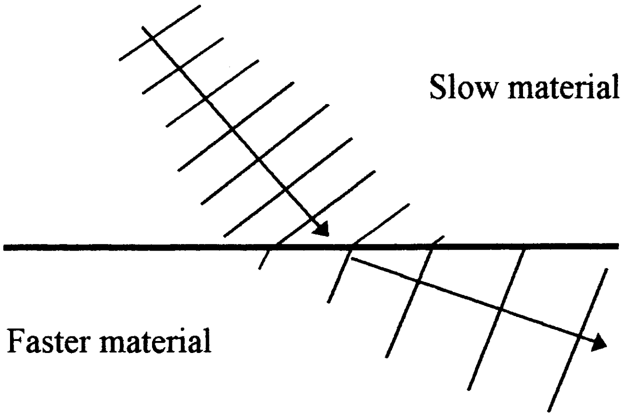


Figure 19.9 Refraction

ATTENUATION

The loss of sound energy due to its passage through a material, this will occur primarily because of scatter and absorption.

i) Scatter

This is the sound being reflected away or prevented from returning to the probe, this can occur due to the following:

a) Incorrect coupling material between transducer and material.
b) Rough surface of the material under test.
c) Grain boundaries causing scatter.
d) Non-metallic inclusions causing scatter.

ii) Absorption

Energy can neither be created nor destroyed all we can do is change it from one type to another. As the sound travels through the material it will have to move the particles as has been said previously. This movement will take a certain amount of energy from the beam and change it to firstly kinetic energy (movement), some of the energy will be dissipated in the form of heat energy.

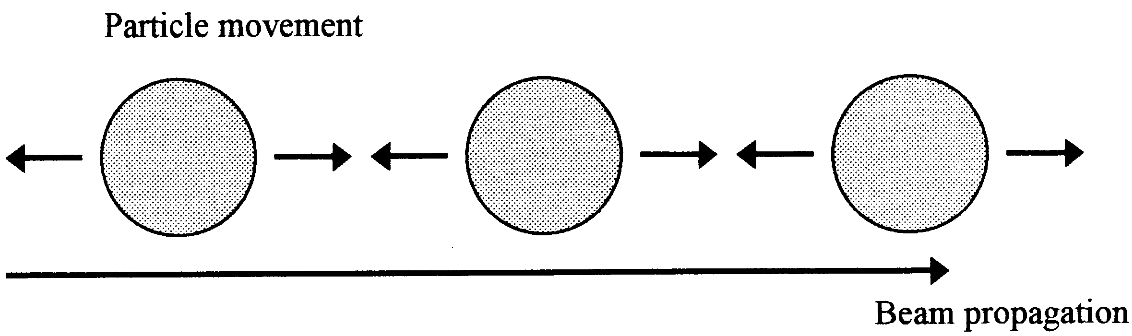


Figure 19.10 Absorption

Both of the above are commonly termed ATTENUATION, the resistance of a material to sound travelling through it. Different materials will attenuate the ultrasonic beam at different rates, this is called the **ACOUSTIC IMPEDANCE OF THE MATERIAL.** It is primarily dependant on the density of the material and the velocity of the sound wave.

OTHER LOSSES

Due to the shape of the ultrasonic beam being a diverging cone there will be some losses owing to sound not returning to the probe.

INTERFACE BEHAVIOUR (Acoustic mismatch)

Between Perspex and steel at least 87% of energy will be reflected directly back and so will not penetrate, thus it will be lost. The net result being that only approximately 1 to 1.5% of transmitted energy returns as a signal on the cathode ray tube (C.R.T.).

COUPLANT

Between Perspex and air there is 100% reflection, the result being that if there is air between the probe and the steel under test then there will be no sound transmitted into the testpiece. We must as a consequence ensure that all of the air is excluded, this is achieved by the use of a liquid placed between the probe and testpiece commonly termed the "couplant", this can be grease, oil or in our case water. This couplant will bridge the gap by reducing the variation of velocities through which the sound has to travel. The best couplant would have a velocity between that of the probe and the steel, however this would be a solid and so is of no use to us.

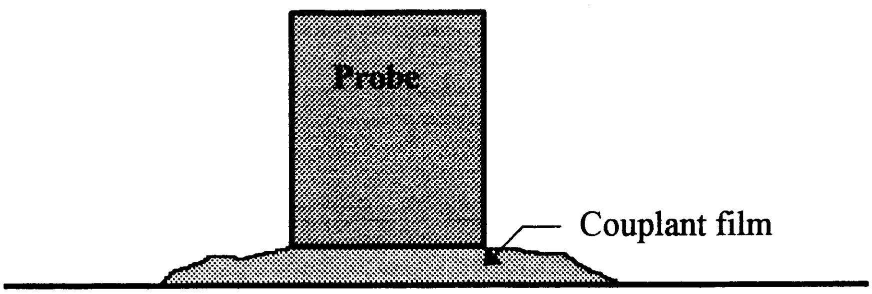


Figure 19.11 Couplant

THE PRODUCTION OF ULTRASOUND

In order to produce sound travelling in a material we will have to cause the particles in that material to vibrate, the simplest way in which this can be done is to strike the material with a hammer. If the hammer used is a "ball peen" hammer then the source of sound will be a point source. The sound will propagate through the material in all directions rather like the ripples on the surface of a pond after a rock has been thrown in.

This kind of beam propagation will be of no practical use for inspection, what is needed is for the sound to be produced in a beam that can be focused and directed in the material. This is achieved by the use of a probe incorporating a vibrating crystal, not being a point source the crystal will produce a beam of energy in the material. This beam will still diverge but only slightly and so can be used to locate areas of discontinuity in a material.

A machine, which can change one form of energy to another, is called a transducer, in our case we will be using a material, which possesses the **PIEZO ELECTRIC EFFECT.**

THE PIEZO ELECTRIC EFFECT

A material, which possesses this characteristic, will when subjected to a mechanical vibration produce an electrical potential and vice versa.

In the case of ultrasonic probes the crystal will have silvered faces to allow the electrical potential to be applied and also for the returning electrical potential to be detected by the machine:

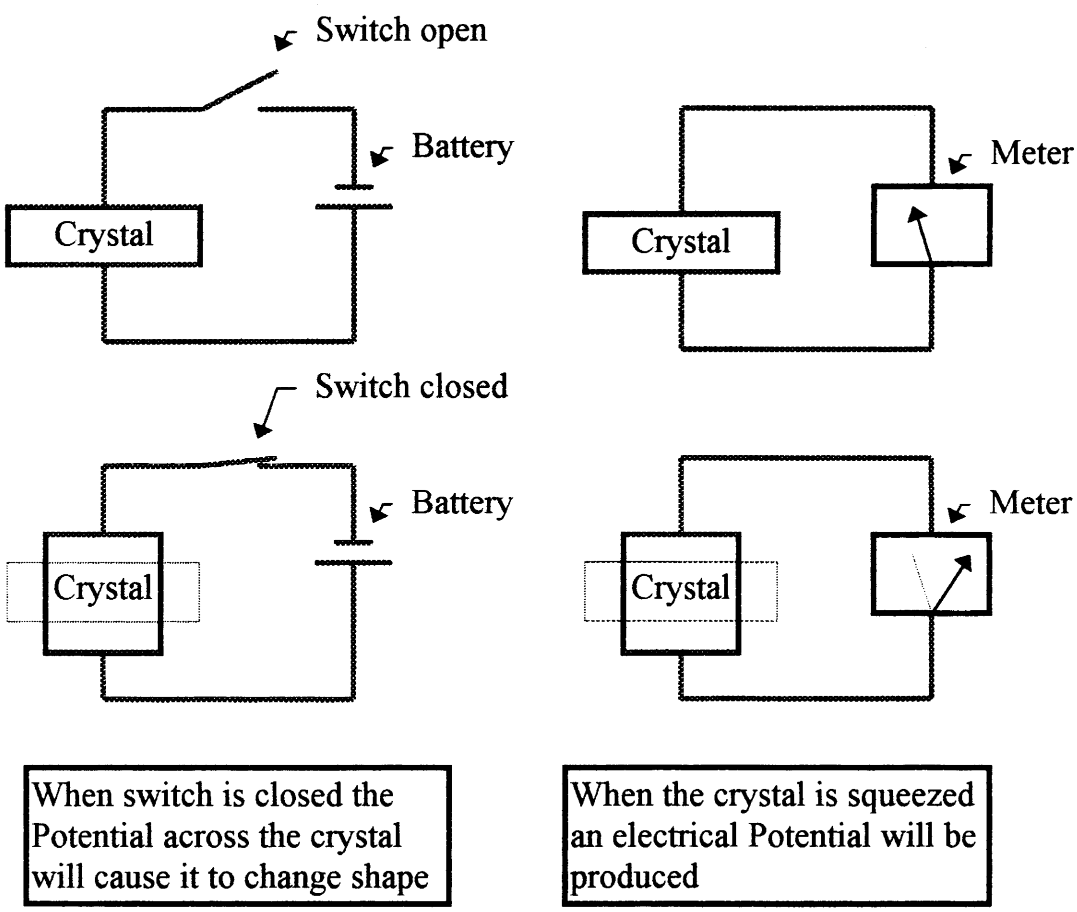


Figure 19.12 The Piezo Electric Effect

The type and cut of the crystal used will dictate the frequency of the beam, i.e.: the thinner the crystal the higher the frequency produced will tend to be.

There are several of materials possessing this property, some are as follows:

a) Quartz - These are either natural or artificially grown crystals.

b) Lithium sulphate - Crystals grown artificially.

c) Polarised ceramics - There are several commonly in use today they are:

Barium titanate
Lead metaniobate
Lead zirconate
Lead zirconate titanate (PZT)

Properties of Transducers

i) Quartz

Advantages

a) Uniform characteristics, they are electrically and mechanically stable and can be sharply tuned.
b) Resists ageing.
c) High resistance to wear.
d) Quartz is insoluble in water.

Limitations

a) Quartz is the least efficient generator of ultrasound.
b) Requires high voltage to drive low frequencies.

ii) Lithium Sulphate

Advantages

a) Operates well on low voltage.
b) Most efficient receiver of ultrasound.
c) Low electrical impedance.
d) Will not age.
e) Gives good resolution and is easily damped to give control of the pulse width.

Limitations

a) Low mechanical strength.
b) Crystal will decompose at 160° Celsius.
c) The crystal is water-soluble.

iii) Polarised Ceramics

Advantages

a) A very efficient generator of sound.
b) Will operate on low voltages.
c) Can be used on high temperatures.

Because of the above the <u>most widely used crystals will be either Lithium sulphate or Polarised ceramics</u>.

PROBE CONSTRUCTION

Ultrasonic probes are designed to produce the correct waveform for the test to be carried out. In the probe the crystal will have silvered faces to enable an electrical potential to be applied across it.

Single Crystal Probes

The simplest form of probe is the single crystal probe. In this probe the same crystal will be used to transmit the signal and receive it, the probe will produce a pulse of ultrasound and will then wait, "listening" in a quiet period for the returning sound. A single crystal probe will have a thin membrane covering the crystal and no "Perspex shoe" to protect it. Behind the crystal will be the acoustic damping designed to absorb the sound emerging from the back of the crystal which otherwise could cause interference to the test.

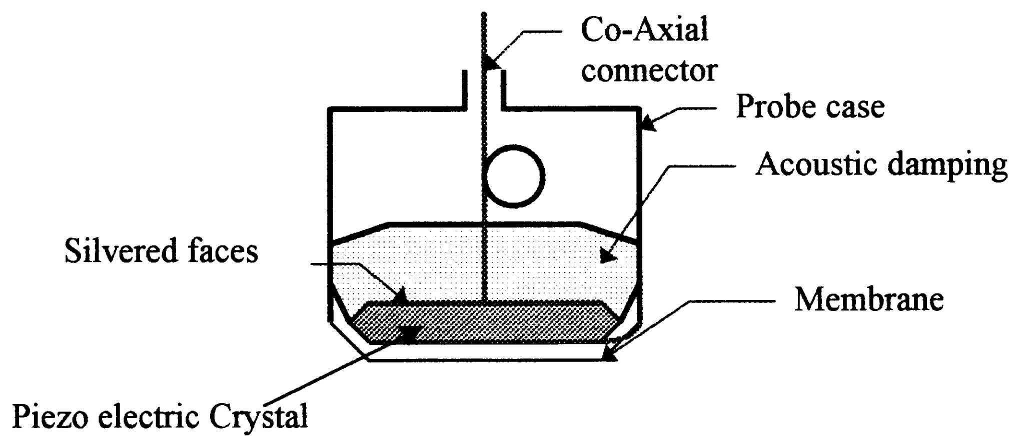


Figure 19.13 Single Crystal Probe

Advantages

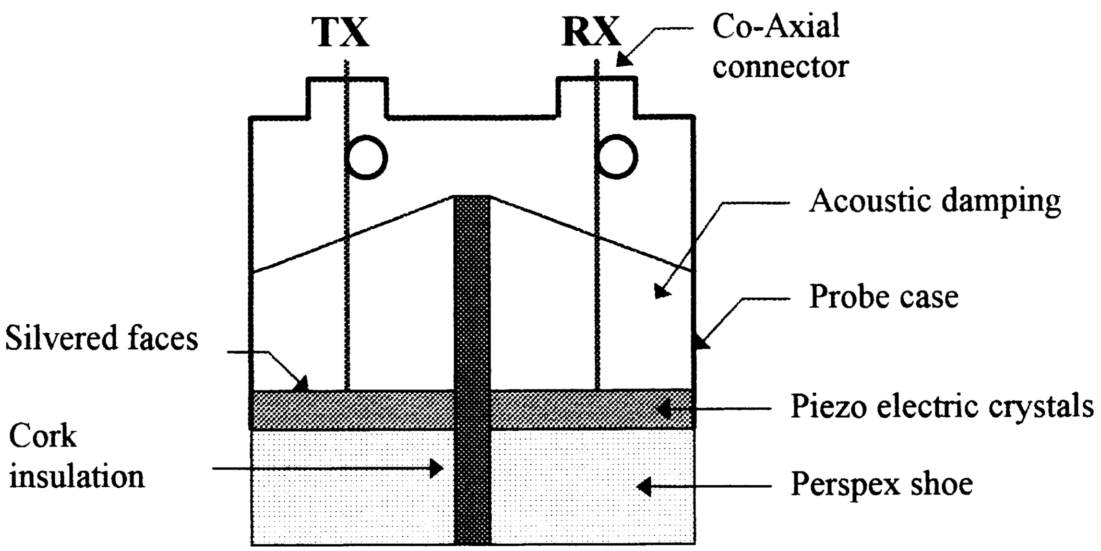
a) Good power delivery.
b) Better for thick plate (greater than 40mm).

Limitations

a) Poor near surface resolution.
b) Cannot measure thin plate accurately.

Twin Crystal Probes

The twin crystal probe is basically the same as the single crystal probe. The difference lies in the fact that whereas the same crystal was used for both transmit and receive in the single crystal probe, the twin crystal arrangement will make use of two crystals, one for transmission and another for reception. The twin crystal probe is in essence two single crystal probes working in conjunction with one another but not connected electrically or acoustically, they will be separated by a cork insulator, which is designed to stop any "crosstalk" between the two crystals.



Note, Tx means transmit crystal
Rx means receive crystal

Figure 19.14 Twin Crystal Probe

Advantages

a) Good near surface resolution.
b) Initial pulse will be contained in the shoe and so will not appear on the timebase.
c) Able to focus at any depth.
d) Able to measure thin plate.

Limitations

a) Thicker shoe reduces intensity.
b) Limited range.

Typically used on plate thinner than approximately 40mm thick.

Compression Wave Probes

These probes will send the sound into the testpiece perpendicular to the surface, there will be no refraction at the interface, and only compression waves will result in the material. These probes are called zero degree or normal probes and may look as illustrated in figure numbers 19.13 or 19.14.

Shear Wave Probes

All probes will produce compression waves at the crystal and consequentially in the Perspex shoe. If the requirement is for a shear wave in the testpiece then this can be arranged by angling the Perspex shoe to make a wedge. Then according to Snell's Law, the resulting sound wave striking the testpiece at an angle will produce a shear wave in the material.

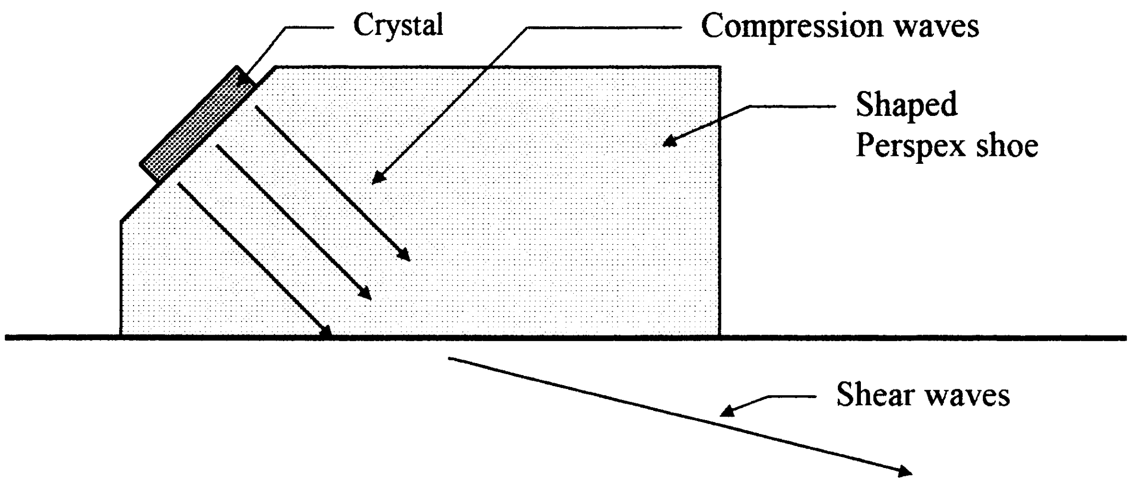


Figure 19.15 Shear Wave Probe

WAVE FORMS

There are four modes of propagation and waveform in ultrasound these are:

1. LONGITUDINAL OR COMPRESSION WAVES

With the beam in compression the particle vibration will be along the same path as the propagation of the wave.

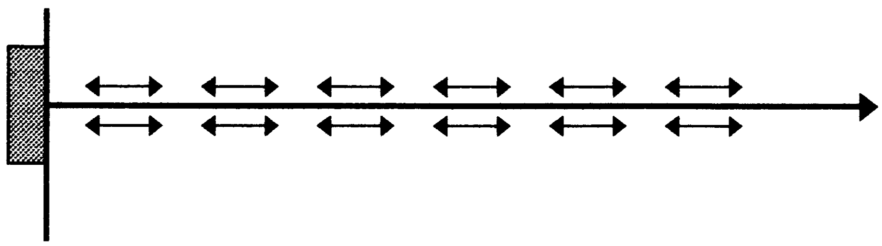


Figure 19.16 Compression wave

2. TRANSVERSE OR SHEAR WAVES

Shear waves can only exist in solids. Particle vibration is at 90° to the direction of propagation of the wave. The velocity of the wave in the material will be approximately half that of a compression wave in the same material. The result is that the wavelength will also be almost half that of a compression wave in the same material, with a corresponding increase in sensitivity.

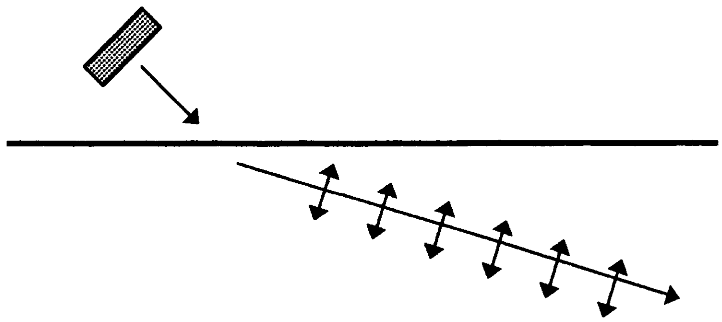


Figure 19.17 Shear Wave

3. SURFACE OR RAYLEIGH WAVES

Particle vibration is elliptical with the long axis perpendicular to the surface of the testpiece. The wave will not penetrate further than one wavelength. Waves on the sea are an example of this type of waveform.

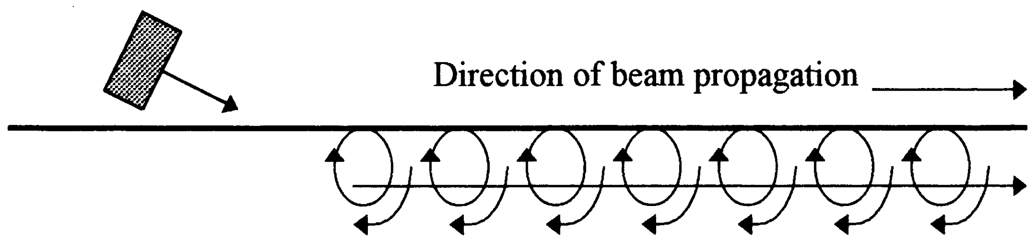


Figure 19.18 Rayleigh Wave

4. LAMB OR PLATE WAVES

The whole of the plate is flexed, used for the testing of flat plate looking for laminations.

MODE CONVERSION

As sound travels from one medium to another some may be reflected and the rest will be refracted, this is called mode conversion as more than one form of wave may result. If the sound strikes the material at 90° to the surface or normal to the testpiece then the resulting sound wave produced in the material will be a compression wave. When the angle of incidence of the wave is varied then it will be possible to produce a shear wave in the material. Beyond a certain point only shear waves will result in the material and if the incident angle is to great then these to will not penetrate leaving surface waves only.

The incident angles involved are as follows:

a) 0° to 15° - Useful compression waves will result in the testpiece.

b) 15° to 27.8° - Both compression and shear waves will result in the material. Because of the differing velocities of the two waveforms there is no useful response in this area from the point of a'scan testing (**27.8°** is known as the **First critical angle**).

c) 27.8° to 57.2° - Useful shear waves exist in the material (**57.2°** is known as the **Second critical angle**).

d) 57.2° plus - Surface waves only exist on the material.

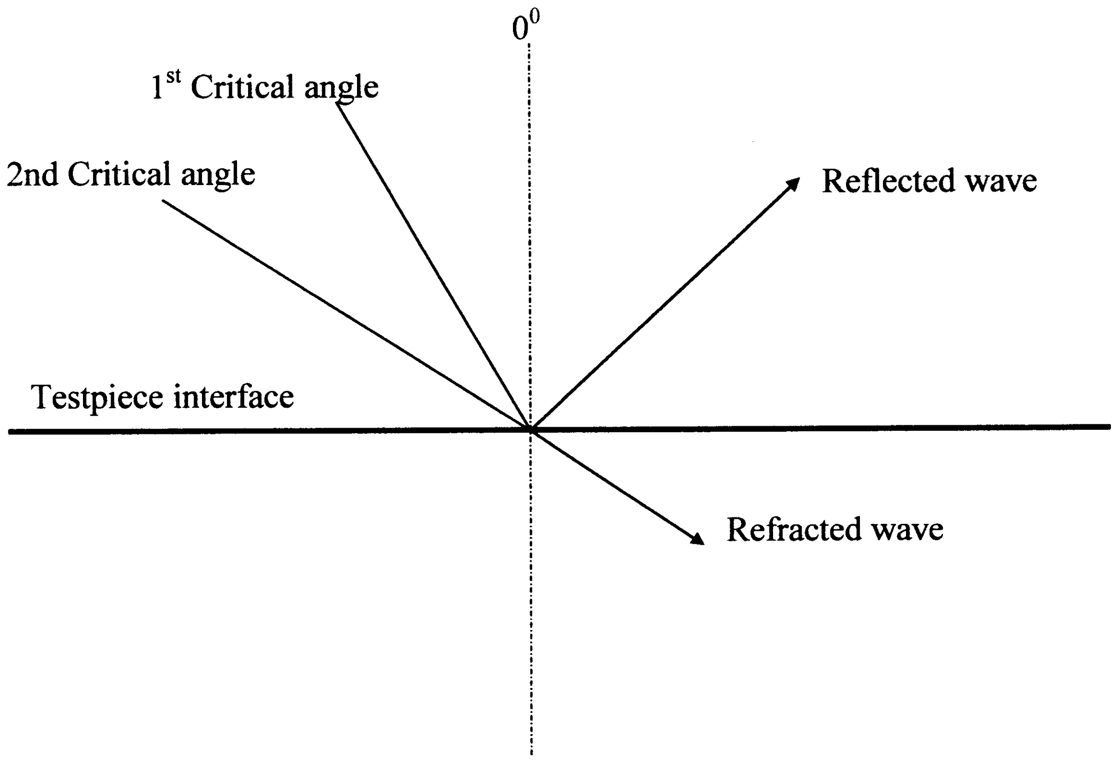


Figure 19.19 Mode Conversion

The relationship between angles of incidence and refracted angles can be shown by Snell's Law.

SNELL'S LAW OF ANGULAR RELATIONSHIPS

Snell's Law can be used to calculate the angular change of a beam at an interface, it can be expressed as follows:

$$\frac{\text{Sine of angle A}}{\text{Sine of angle B}} = \frac{\text{Velocity in material A}}{\text{Velocity in material B}}$$

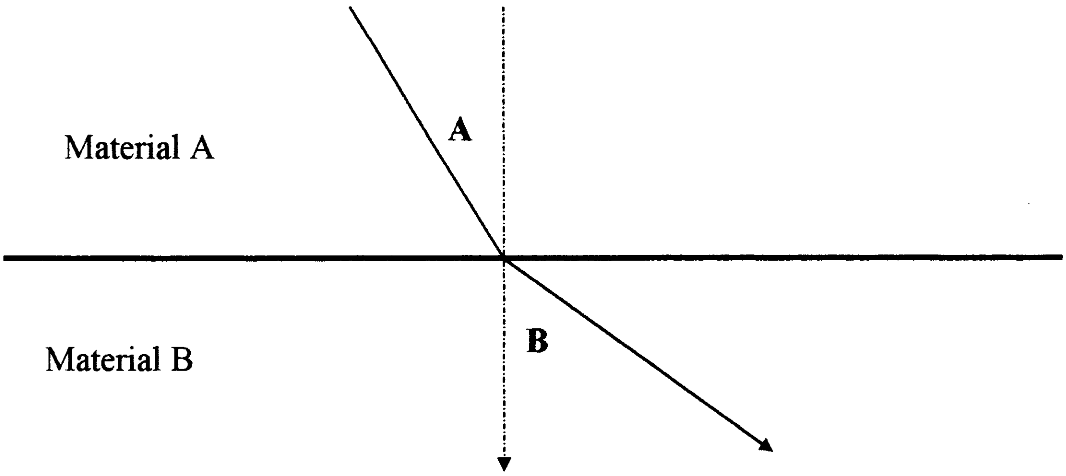


Figure 19.20 Snell's Law

This will normally be used for the selection of probes to be used for weld testing. In this case the weld preparation angle would be known as would the thickness of the parent plate. Using trigonometry it is relatively simple to find the angle B (the angle in the steel), having done this we would have to find the necessary incident angle (angle A in the probe).

Example:

What incident angle would be needed to produce a shear wave at an angle of 40° in the steel (note the wave will be a shear wave and so the velocity is 3245 m/sec)?

The formula needed will be:

$$\frac{\text{Sine of angle A}}{\text{Sine of angle B}} = \frac{\text{Velocity in material A (Perspex compression)}}{\text{Velocity in material B (steel in shear)}}$$

We will be looking for the angle A as this is the incident angle so the transposed formula will be as follows:

$$\text{Sine of angle A} = \frac{\text{Velocity in material A} \times \text{Sine of angle B}}{\text{Velocity in material B}}$$

Now put the figures in:

$$\text{Sine of angle A} = \frac{2730 \times \text{Sine } 40°(0.6428)}{3245}$$ (look up 40° in the natural sines)

$$\text{Sine of angle A} = \frac{1754.844}{3245}$$

Sine of angle A = 0.5408 (look up 0.5408 in the natural sines)

<u>The answer is the Angle A = 32.74°</u>

CRITICAL ANGLES

It should be obvious that at a certain incident angle the compression wave will be refracted to 90° and so will cease to run in the material, leaving shear waves only running in the testpiece. The angle at which this occurs is termed the **<u>first critical angle</u> (27.8°)**.

In the same way at a certain incident angle the shear waves will also be refracted to 90° and so will become surface waves. The angle at which this occurs is **57.2°** this is called the **<u>second critical angle</u>.**

THE FLAW DETECTOR

There are 4 types of ultrasonic presentation the Flaw Detector will show:

1. A'scan - Shows real time depth of the defect, or distance down beam path.
2. B'scan - Holds the reflector and shows a cross sectional view.
3. C'scan - Illustrates using a plan view and traces the defects.
4. P'scan - Adds all of the above together and gives a three dimensional computer impression.

We will be dealing principally with the A'scan presentation, which shows the real time of flight of the ultrasonic pulse, from the time of transmission to reception in precisely the same way that the digital thickness meter does. Except that in the case of an A'scan there is no digital readout, instead the information is displayed on a cathode ray tube capable of displaying more than one indication at any one time. This is presented on the CRT as a peak on the horizontal or X - axis, the longer the lapsed time between transmission and reception the further the peak will appear to the right of the screen.

The vertical or Y - axis will represent signal amplitude or the power of the returning signal, i.e. the more power received the higher will be the resulting peak.

The horizontal or X - axis will represent the distance down beam path, possibly this will be the time taken for the sound to travel to a reflector and return to the probe.

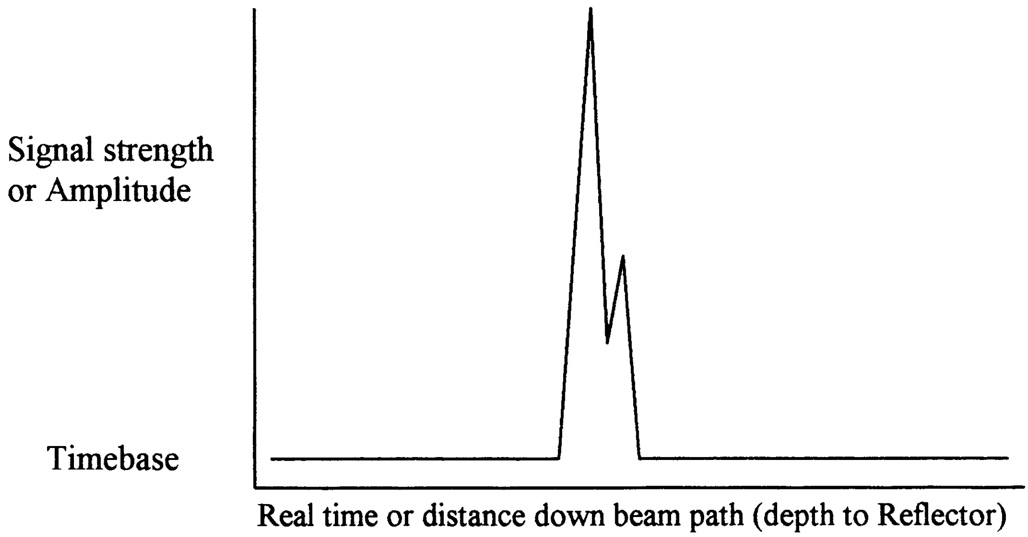


Figure 19.21 The A'scan Display

We can use this type of presentation with suitable probes for the following tasks:

a) Lamination scanning of plate.
b) Lamination scanning prior to weld inspection.
c) Inspection of fusion faces of welds.
d) Thickness measurement ensuring no false response.
e) Flooded Member Detection (FMD).

CONTROLS OF THE A'SCAN FLAW DETECTOR

Different makes of flaw detector will have their controls in a variety of locations but as a rule they will all have the same controls. This means that as long as the operator can locate the individual controls then there should be no problem in his using the instrument, a brief description of the controls is as follows:

1. Reject or Suppression

This control is used to suppress incoming signals and so clean up the baseline on the cathode ray tube (CRT). This at first sight looks like a good idea but what is in fact happening is the baseline is being raised up the Y - axis having the effect of making the flaw detector less sensitive. This control should be in the off position for our purposes, (not all sub- sea sets have this control).

2. Range Controls

These will normally be split into:

i) Coarse range

This alters the pulse repetition frequency (PRF), in order to ensure the incoming signal is not affected by the transmission of a pulse, the coarse range control should be set roughly to the thickness of metal under test.

ii) Fine range

This alters the spread of the peaks on the screen so that the operator can spread them further apart or bring them closer together in order to calibrate the set. This control ensures that the graduations on the X - axis can be made to represent almost any value the operator chooses.

3. Pulse Delay Control

This control will move the whole display sideways across the X - axis without changing the spread of the peaks. It is used in conjunction with the fine range control for calibration of the set.

4. Gain controls

There will likely be either two or three of these depending on the type of set being used. They control the input gain and so the peak height on the cathode ray tube.

i) Fine gain: Controls the input gain by 0 to 2 db.
ii) Medium gain: Controls the input gain in steps of 2 db.
iii) Coarse gain: Controls the input gain in steps of 20-db.

Using the three gain controls (some sets will not have the fine gain) it is possible to place the top of the peak at any point on the screen, imperative in the accurate location and sizing of defects.

Other points of interest:

Battery Indicator

There will be some indicator as to the condition of the battery as the set will not perform properly if the battery is not adequately charged.

Probe Select Switch

This must be set to the correct position in order for the set to interpret the information from the probe, the set will behave differently according to whether a single or twin crystal probe has been used, this control may also be the on/off control.

Probe Connections

There will be two of these and they will normally be marked TX for transmit crystal and RX for receive crystal, if using a single crystal probe it must be connected to the TX connection.

Charging Connection

This will be a connection, which should be blanked while the set is in use. It is important that the correct charging procedure is used at all times as Hydrogen gas can be discharged from the batteries under charging conditions. For this reason there may be a connection to ventilate the housing during charging.

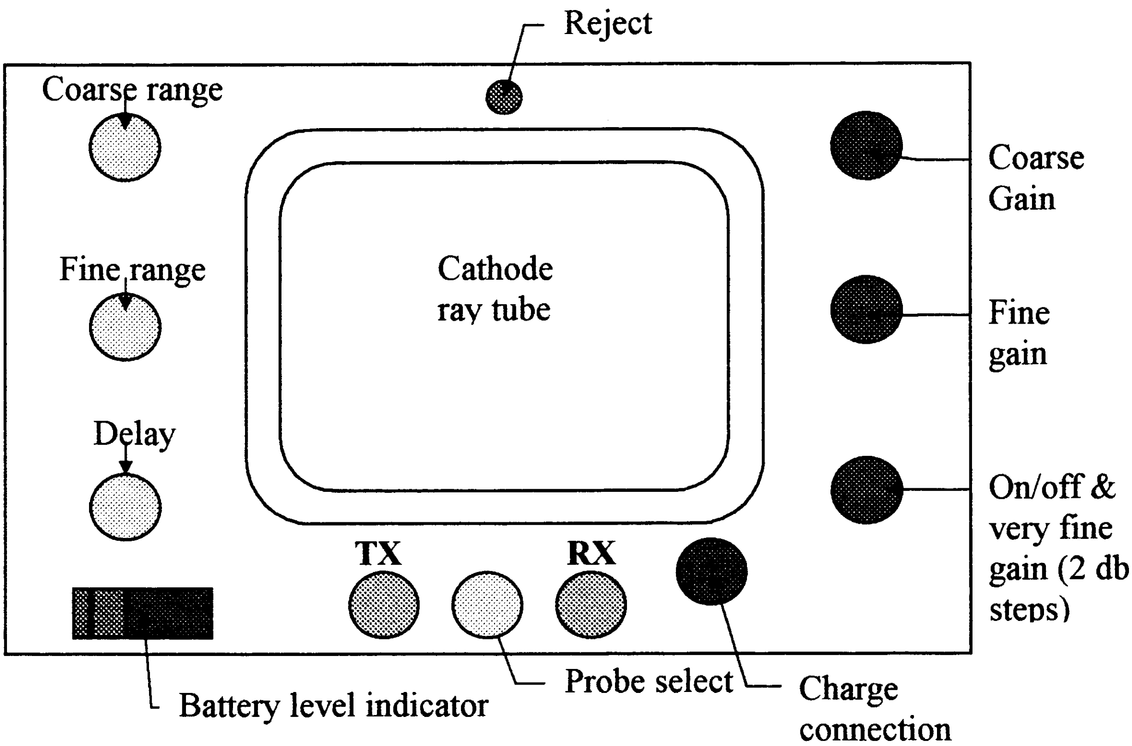


Figure 19.22 Baugh And Wheedon PA 1011

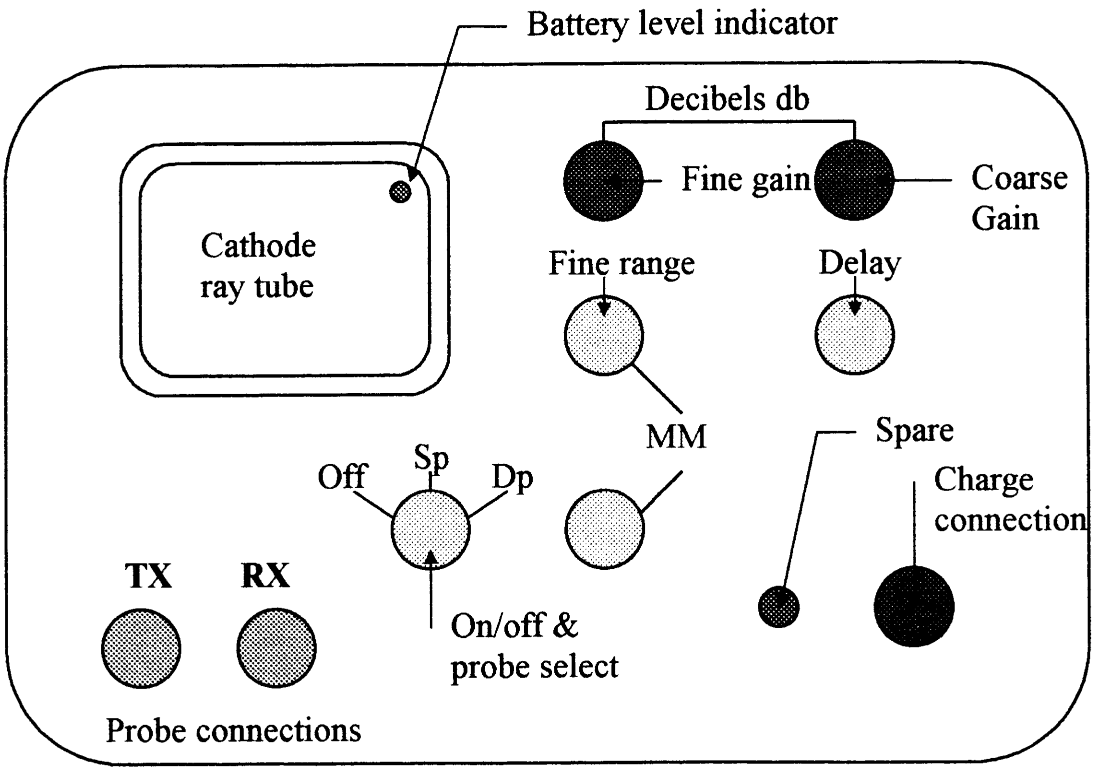


Figure 19.23 Wells Krautkramer USK7 (Subsea) Offshore

CALIBRATION

Both the X-axis timebase and Y-axis gain of an A'scan flaw detector are purely arbitrary and as such there is a need to calibrate for the task. The X-axis or horizontal (timebase) will need to be calibrated for linearity and range of the test. The Y-axis or vertical will need to be calibrated to give information relating to the defect size. In order for us to accomplish this we will need to have a block from which we can set the flaw detector, these can be classified as the following:

1. Calibration Blocks

These are blocks of known dimensions, made of a similar material as that to be tested, with a specific heat treatment and machined to high tolerances. It will allow for the calibration of the timebase and the amplifier, note the correct calibration block must be chosen for the inspection undertaken.

There are three widely used calibration blocks, they are:

i) The International Institute of Welding (IIW) "V1" Block or BS2704 1978. Calibration blocks for use in Ultrasonic Flaw Detection 'A2'

This block is machined from steel and has a block of Perspex (Polymethacralyte) inset. The main dimensions of the block are shown on the diagram below, the Perspex insert has been machined to give an indication equivalent to 50mm of steel but is only 23mm thick this is achieved because of the differing velocities.

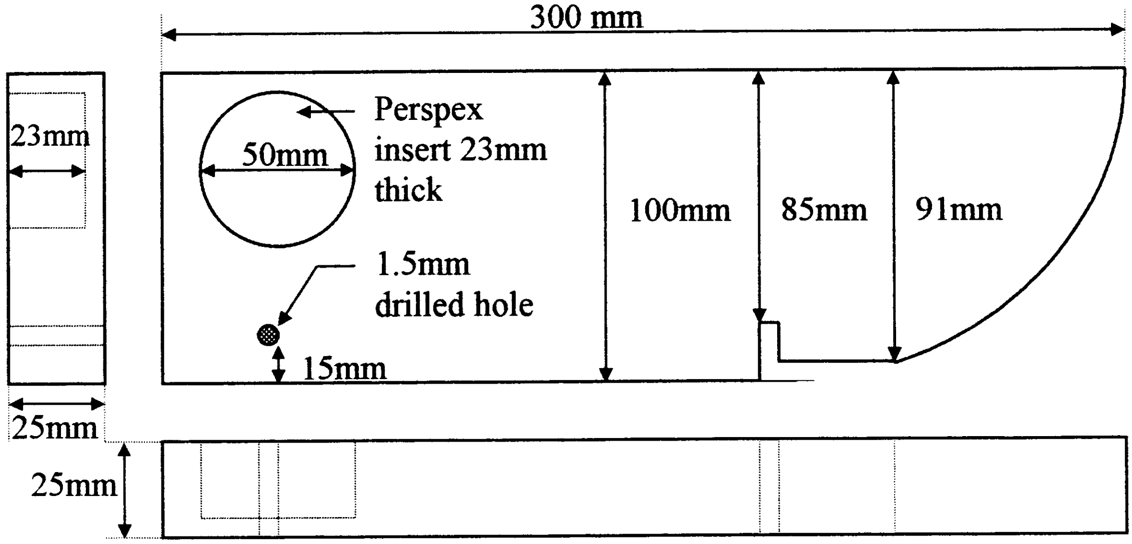


Figure 19.24 The IIW V1 Block

ii) The International Institute of Welding "V2" Block or BS2704 1978 Calibration Blocks for us in Ultrasonic Flaw Detection 'A4'

This block is much smaller and less versatile, it will commonly be used for on site calibration.

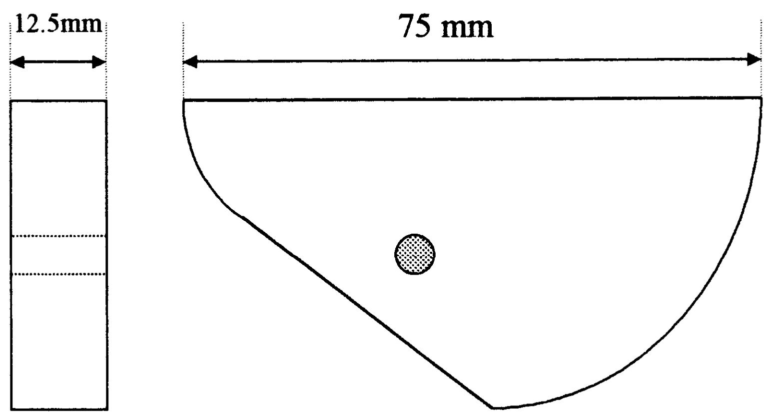
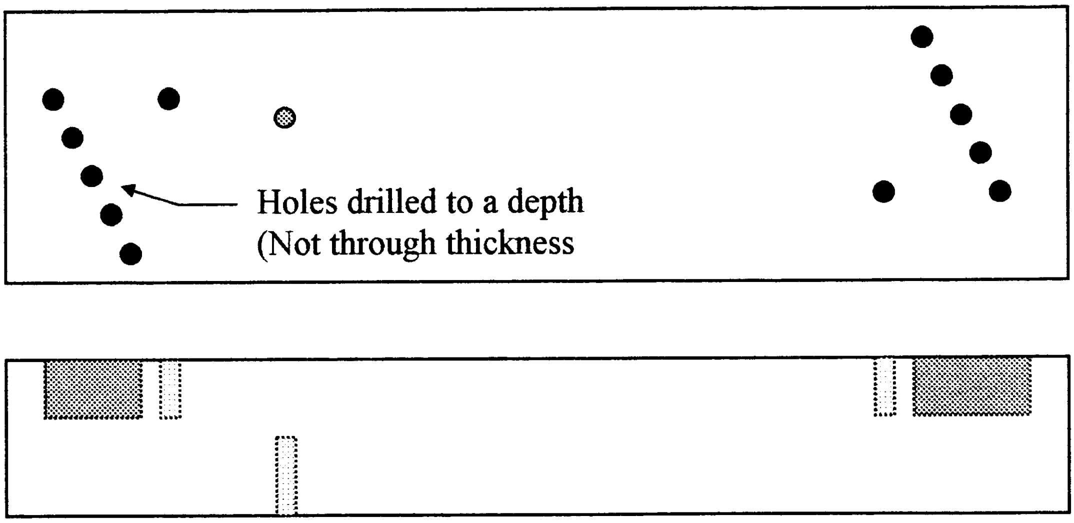


Figure 19.25 The IIW V2 Block

iii) International Institute of Welding Beam Profile Block

- This will be used for assessing the variation of intensities of the ultrasonic beam at various beam lengths.



Note no dimensions are shown on the above sketch, this is because this is only meant to give some idea as to the form a beam profile block may take.

Figure 19.26 The IIW beam Profile Block

iv) Step Wedges

These will be used for the calibration of the sets on site and will be less versatile than the above.

2. Reference blocks

These blocks are made from the same material and incorporating the same geometric form as the sample to be tested and will be used for the operator to gain experience of the task to be undertaken.

CALIBRATION PROCEDURES

Both the Timebase and Amplifier must be linear in order to ensure the accurate location and sizing of defects. The calibration procedure used will be dependant on the task, and should be done both prior to the inspection, and after completion of the inspection, in order to prove the machine. The following is a typical calibration procedure for a "V1" block calibrating the timebase to 100mm of steel using a twin compression probe:

1. Select suitable probes, connect to the correct terminals i.e. single probe (TX) or twin probe to both, once this is done set the probe select switch on the unit, either SP/DP.

2. Switch on the unit and allow to warm up for approximately fifteen minutes.

3. After the warm up period check the battery condition.

4. Calibrate the timebase as follows:

   i) Ensure the reject is switched off.

   ii) Set the coarse range control to suit the block - this will set the pulse repetition frequency and ensure the fine range and delay controls are in the centre of their travel, making calibration possible.

   iii) Set the coarse and fine gain to 20 decibels.

   iv) Using the delay control locate the initial pulse and place on the left hand side of the screen.

   v) Apply couplant to the 25mm side of the "V1" block.

   vi) Apply the probe to the 25mm side of the calibration block.

   vii) Find the first back wall echo (1st BWE) using the delay control, and bring it to full screen height by adjusting the gain controls.

   viii) Using the fine range bring in three more back wall echoes.

   ix) Using the fine range and delay controls adjust so that the left hand side of the 4 peaks cut the timebase at the 2.5 for the 1st BWE, 5 for the 2nd BWE, 7.5 for the 3rd BWE and 10 for the 4th BWE. (Note the "0" position is the surface of the testpiece), if this cannot be done then the timebase may not be linear and the set cannot be used.

   x) There will now be no initial pulse on the screen as the calibration procedure will have pushed this off to the left hand side.

The timebase is now linear and calibrated for 100mm of steel, if we now put the probe on a piece of steel 40mm thick a peak will come up at 4 on the timebase scale.

5. To check the calibration place the probe on the edge of the block at the thickest point (100mm), a peak should come up at the 10 on the timebase scale.

6. Place the probe on the Perspex insert, a peak should appear at the 5 on the timebase scale.

7. Resolution check:

   Set the probe opposite the notch on the "V1" block, maximise the signal using the gain control, three peaks should appear - one at the 8.5 (85mm) one at 9.1 (91mm) and one at 10 (100mm) on the timebase scale, this proves that the set can differentiate between small defects at extreme range and thus has good resolution.

8. Amplifier linearity check:

   i) Set the probe opposite the 1.5 mm diameter drilled hole in the "V1" block.
   ii) Attenuate the 1st BWE to 80% full screen height (FSH).
   iii) Increase gain by 2 db, the peak should now be at full screen height.
   iv) Attenuate the signal using the fine gain control by 6-db, the signal should now be at 50% full screen height.

   If all of this checks out then the amplifier is working as it should and the set is calibrated for 100mm of steel and is ready for use.

SENSITIVITY OF THE A'SCAN TEST

Sensitivity is the ability to find the smallest reflector sought at the maximum range of the test. It will be dependant on the following four factors:

1. **Frequency of the probe.**
2. **Material properties (grain structure etc).**
3. **Probe and flaw detector combination.**
4. **Flaw detector response (backwall to interference ratio)**.

We can check the sensitivity of the test by using a block with drilled holes at increasing distances from the probe surface. As the holes are encountered the amplitude is increased to keep the signal height constant.

Setting a sensitivity level is essential to provide reproducible results from the same inspection carried out by different operators using different probe set combinations. They must all see the same flaw giving the same signal height and therefore have the same data on which to base their accept/reject decisions.

There are several systems for setting sensitivity. Different methods are used in different places. The IOW block is used in SANDT. On the North Sea contracts the 'Distance Amplitude Correction Curve (DAC) Method or 'ASME' Curves are used.

The DAC method is recommended in BS3923 and in Germany the 'Distance Grain Size' (DGS) system is usually applied, especially when evaluating small reflectors.

THE ULTRASONIC BEAM

In the case of a simple round single crystal probe the ultrasonic beam will have three definite zones.

THE ZONES OF THE ULTRASONIC BEAM

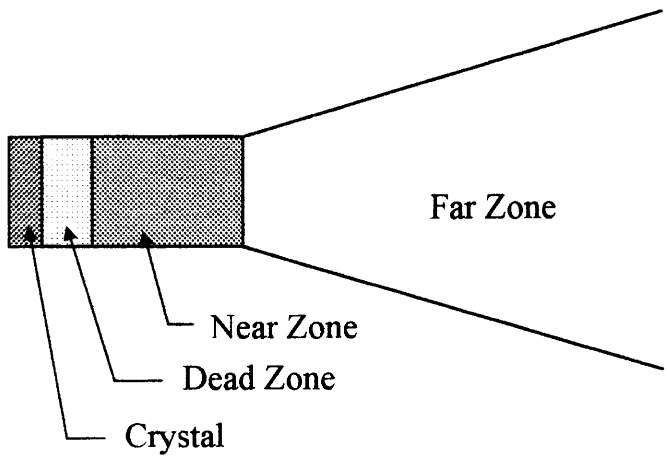


Figure 19.27 The Zones of the Ultrasonic Beam

1. **THE DEAD ZONE**

   In this area there is no useful response and so no reflectors can be assessed. It is due to poor damping of the crystal, which results in waves from the back of the crystal interfering with the incoming waves. High frequency probes have smaller dead zones. In the twin crystal probe the dead zone is contained inside of the Perspex shoe and so will not affect the test.

2. **NEAR FIELD OR ZONE**

   This is an area of fluctuating intensities and as such a defect of a certain size at a given distance from the probe may push up a higher peak than a defect of the same size closer to the probe. Because of this testing in this area is limited to:

   a) Thickness measurement ensuring no false response.
   b) Detection of most defects.
   c) Sizing of large defects.

To calculate the length of the near zone in a 0° compression probe we use the following formula:

$$\text{Near zone} = \frac{D^2}{4 \times \lambda}$$

where:
D = diameter of the crystal
λ= wavelength of the beam

Example:

We have a compression probe with a 10mm crystal and a frequency of 2.5 MHz working in steel what is the length of the near zone.

First we must calculate the wavelength of the beam:

$$\lambda = \frac{\text{Velocity}}{\text{Frequency}}$$

$$\lambda = \frac{5{,}960{,}000}{2{,}500{,}000}$$

$\therefore \lambda$ (wavelength) = 2.384mm

We now put this into our near zone calculation:

$$\text{Near zone} = \frac{10^2}{4 \times 2.384}$$

$$\text{Near zone} = \frac{100}{9.536}$$

$\therefore$ the Near Zone is 10.48mm

This gives us the total distance from the crystal to the end of the near zone or the start of the far zone (the same point). If the probe in question were a shear wave probe then the different velocity in the Perspex would have to take into account.

3. FAR FIELD OR ZONE

In this area the beam has settled down and will now be diverging at a predictable rate, it experiences an exponential decay. Signal height will decrease with distance from the probe according to the inverse square law. This means if a reflector is at one distance and the peak is measured, if we then come across a defect of the same surface area but twice as far away then the peak height will be quarter of the original height. This is by far the most predictable area for the detection and measurement of defects.

BEAM DIVERGENCE IN THE FAR ZONE

We will wherever possible use the far zone for the purposes of ultrasonic testing. For this we will need to be able to show where the edge of the beam is in relation to the beam axis. It is in practice useful to be able to plot the edge where the intensity of the beam has fallen to one half (the 6-db edge), the point where the intensity is at one tenth (the 20-db edge), and the extreme edge of the beam. In order to calculate this we need to determine the angle of beam divergence, for this we use the following formula:

Beam divergence:

$$\text{Sine } \theta = \frac{K \times \lambda}{D}$$

where:
K = constant
λ = wavelength
D = diameter of the crystal

As we are able to use the same formula to calculate the three different angles relating to the 6-db, 20-db and the extreme edge, the constant will change depending on the edge being calculated.

K = 0.56 for the 6-db edge calculation
K = 1.06 for the 20-db edge calculation
K = 1.22 for the extreme edge calculation

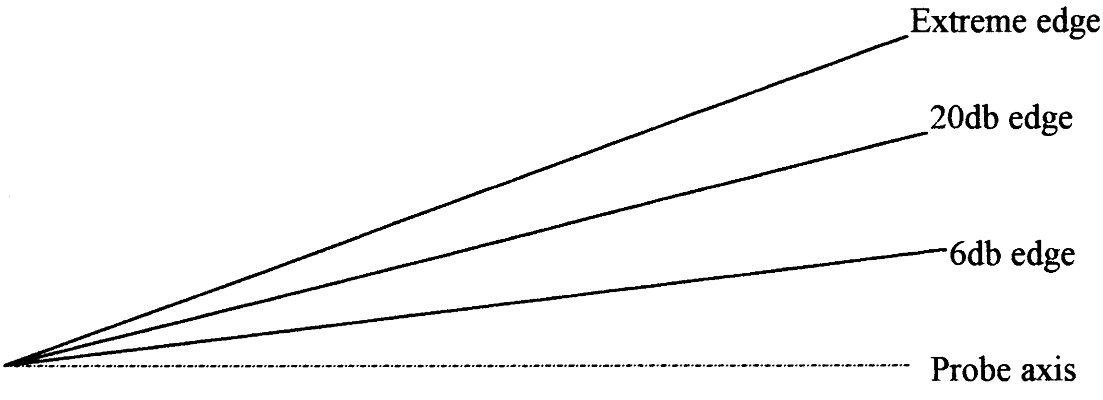


Figure 19.28 Beam Divergence in the Far Zone

So using the previous example we have a 10mm crystal diameter with a frequency of 2.5 MHz compression probe working in steel (λ 2.384), and we are looking for the angle to the 6-db edge.

CHAPTER 20

Grinding Of Defects And Profiling Of Welds

Welds are by definition not as smooth as the parent plates they join together. There will be ripples and sharp contours especially at the toes of the weld, these geometric imperfections can and will cause stress concentration points.

In order to make the welds perform better the weld can be profiled or "dressed". This means that the rough surface will be removed, resulting in the weld having a smooth face and contour right across the weld zone, this ensures that the stress carried by the weld is uniform across its whole surface, so increasing the capabilities and possibly the fatigue life of the weld. The diver may well come across welds which have been profiled at the fabrication stage of the structures life, these will normally be highly stressed welds.

During the in-service life of the structure various weld inspections will be carried out, the result of which will be the location of sundry defects such as undercut and longitudinal imperfections. Both of these will be likely locations for fatigue defects to initiate, so on site profiling may be called for.

Magnetic Particle Inspection will highlight indications which then will normally be ground out over their full length in order to either remove them or to prove the indication as a defect, The grinding will normally be done to a maximum depth specified by the client and in depth increments also specified by the client (normally in half millimetre steps). If the indication has been ground, then either it will be removed, in which case the area can be profiled and left, or the indication will still be evident at the maximum depth of allowed grinding. In this case the decision as to action will be taken ashore by the clients Engineering Department.

Normally after grinding has been carried out, a photographic record will be required, as well as accurate measurements. The depth of the grind will be measured by the use of a pit gauge. This will be done by first taking a reading on an un-ground area, and then moving onto the ground area taking another reading. The difference will give the depth of the grind out. In addition a cast may be taken for inspection by the clients engineering department ashore.

Grinding can be extremely difficult and so it is advised that the task be practised on the surface prior to the dive to ensure the divers know the parameters and are happy with the equipment.

Grinding Equipment

These can be either pneumatic or hydraulic grinders, and are sometimes called "peanut grinders".

The cutting burrs will normally be Tungsten Carbide burrs. There are a large number of profiles available to choose from according to the task and geometry of the weld to be ground, normally profiling will require round burrs whereas grinding to a depth will require flame type conical burrs.

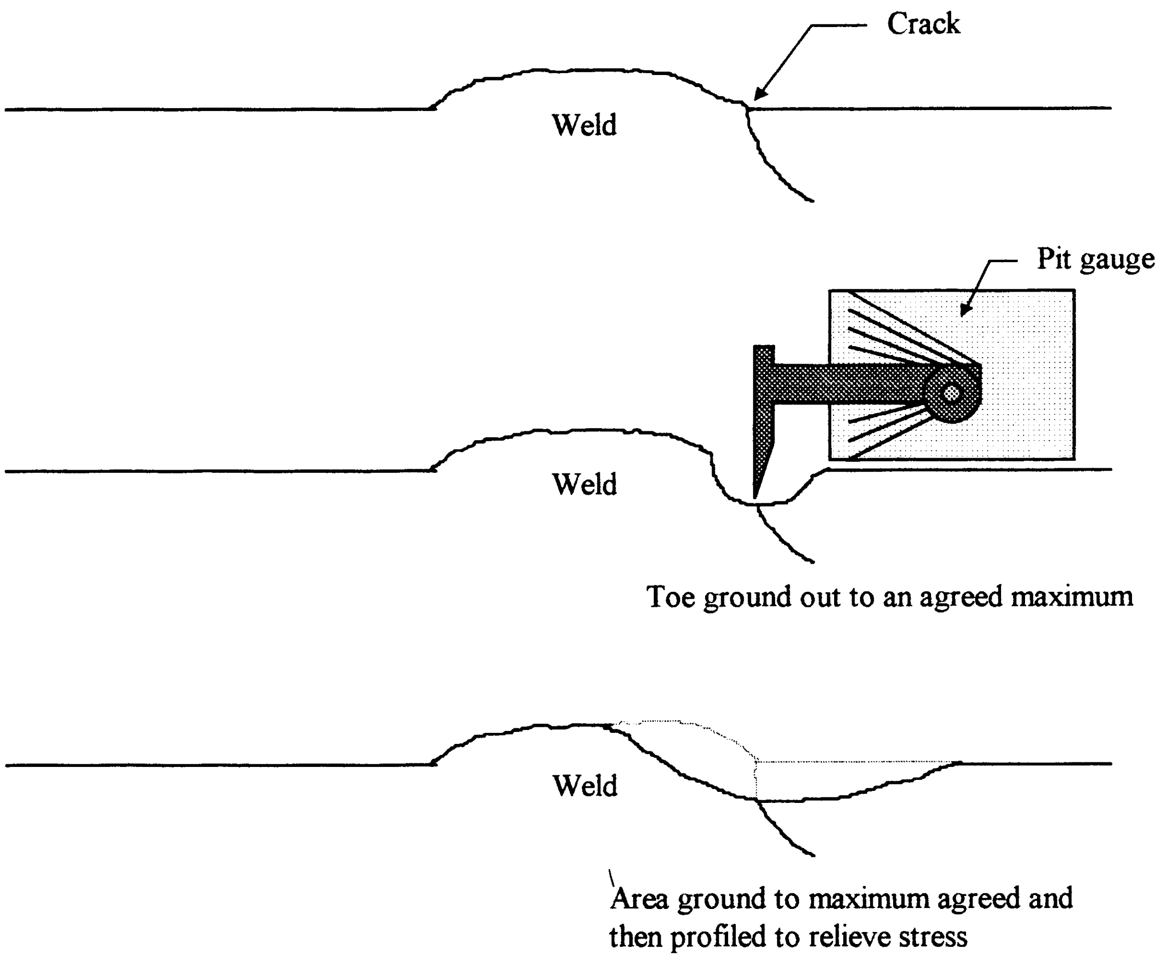


Figure 20.1 Crack Grinding and Pit Gauge Use.

CHAPTER 21

Radiography

Radiography is a method of non-destructive testing which relies on the fact that radiation will penetrate through certain materials. The radiation that does penetrate will be used to expose a photographic film placed on the opposite side of the testpiece. Radiography is now used extensively for the inspection of welds after fabrication, repair or renewal; it is **best employed looking for volumetric defects** in welds. These will mostly occur when the weld is molten; it is not normally used when looking for "in service" fatigue defects.

Advantages	Disadvantages
Permanent record is produced	Safety hazards are high
Can be viewed by many	Storage and transport is expensive
It is a proven method	Needs Government approval
Necessary cleaning standard is low (SA1)	Must use badged personnel
	Costs are extremely high
	Access to both sides of the weld is necessary
	Interpretation can be difficult

RADIATION

There are two types of radiation used for radiography; they are X-rays and Gamma (γ) radiation. Both of these produce very high frequency, short wavelength electromagnetic radiation (which will lie between ultraviolet and cosmic radiation). They both obey the laws of light but only very slightly so they cannot be focused with a lens.

Both X and Gamma radiation are harmful to personnel and steps will have to be taken to ensure that no person receives any dose higher than is absolutely necessary.

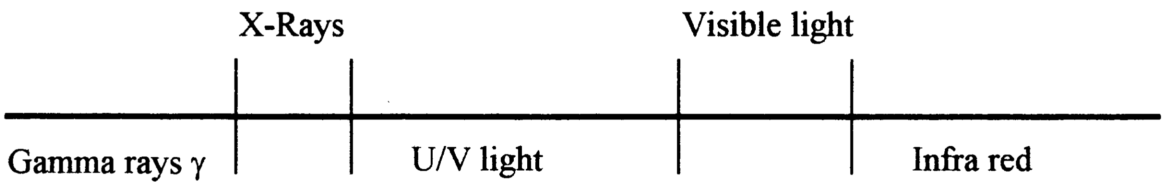


Figure 21.1 The Electromagnetic Spectrum

X-RAYS

X-rays are produced when electrons, travelling at high speed collide with solid matter. In the usual type of X-Ray tube, an incandescent filament supplies the electrons and thus forms the cathode or negative element of the tube. A high voltage applied to the tube drives the electrons to the anode or target. The sudden stopping of these rapidly moving electrons in the target results in the generation of X-Rays (Photons). See Figure 21.2 So in order to generate X-Rays, three criteria must exist: 1. A plentiful supply of free electrons 2. A means of accelerating them at a high velocity 3. A target of dense material.

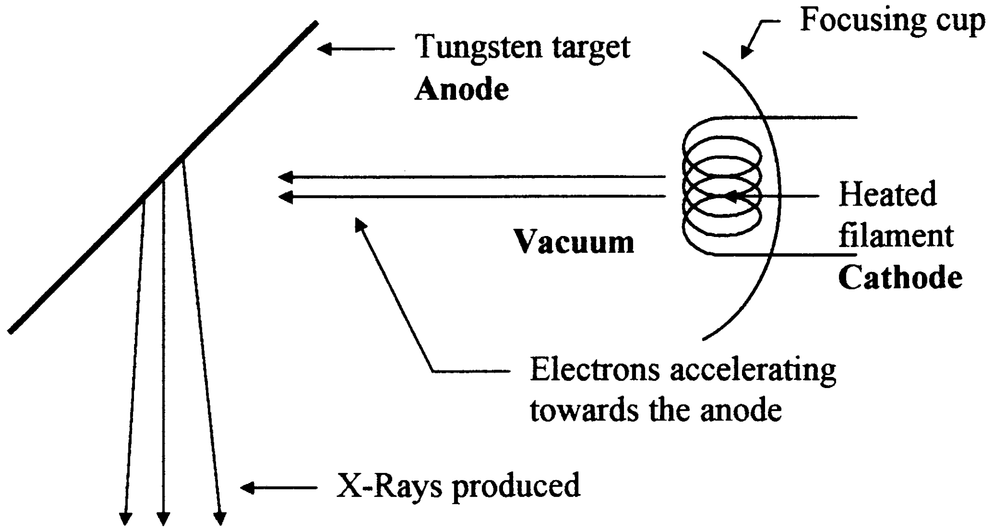


Figure 21.2 Schematic Diagram of an X-Ray Tube

X-ray equipment requires a very high electrical potential with all of the safety hazards accompanying this sub-sea. It is quite bulky and for this reason is not widely used offshore underwater, although the navy do use it in their mine clearance duties.

GAMMA RAYS (γ)

Gamma γ radioactivity can be defined as the spontaneous disintegration of the nuclei of an unstable element as it seeks to become stable. The SI unit for one disintegration is the Becquerel (Bq), this unit however is too small to be used in industrial radiography so we use the Curie (Ci), 1Ci = 37 GBq (Giga Becquerels), 3.7×10^{10}.

Any element whose atomic number is greater than 82 will probably have a nucleus that will disintegrate because of its instability. Artificial isotopes are produced by bombarding certain elements with neutrons changing the atomic structure of the element by capture of the neutrons. The most common substance (termed the source) used offshore is **Iridium 192** (480 Curies), although Cobalt 60 is also quite common, especially when inspecting the newer structures which being more absorbent require a more powerful source.

Iridium 192 can penetrate approximately 3½ inches of steel, but is not normally used on steel thicker than 2 inches. If the steel were thicker than 2 inches then another technique of NDT would normally be used, such as ultrasonic inspection.

The source would be contained in a radiation-shielded housing (depleted Uranium), which will only be opened for the time necessary to complete the radiographic exposure. There are several different types of housing in common use, some involve the diver winding out the source from a safe distance using a worm driven remote device. Most often the source would be exposed by the surface crew after the diver has retired to a safe distance (this distance should not be less than 8m, however the maximum dose normally allowed would be 7.5 micro Sieverts per hour [7.5μS/hr] and the diver should wear a warning device which will inform him of any high levels of radiation before it becomes dangerous), using an air activated housing. Typically this will need to be supplied with 3½ bar over ambient pressure to open exposing the source. Note: the source would normally be checked by ROV or a fixed CCTV to see that it is safe prior to the diver being allowed back to the area.

Radioactive sources:

Natural	- Radium (Ra)	
Artificial	- Iridium 192 (Ir)	12.5mm - 62.5mm
	- Cobalt 60 (Co)	50mm - 150mm
	- Thulium 170 (Tm)	2.5mm - 12.5mm
	- Caesium 137 (Cs)	50mm - 100mm
	- Yterbium 167 (Yb)	1.2mm - 15mm

SAFETY

At all times it is imperative that there be an exclusion zone of at least 8 metres around any exposed radioactive source.

The single most important factor when dealing with radiation is the safety aspect, if used incorrectly the radiation will cause great problems for the personnel involved, therefore the use of radiation is strictly regulated.

In order to use radiography the operating company must have Home Office Approval, and all personnel using the technique must be registered under the Radiological Protection Act. This states that all personnel must have an up to date radiation exposure record, to make this possible all persons must wear exposure film badges or carry dosimeters, which must be checked regularly. While radiography is in process there must be an area properly designated into which no person can stray by mistake.

When the technique is used in water the area can be much smaller than in air, as five inches of water will have the same absorption as one inch of steel. Also the inverse square law applies, this means that if the distance is doubled the intensity of the radiation will be divided by four, treble the distance and the intensity will be one ninth of the original.

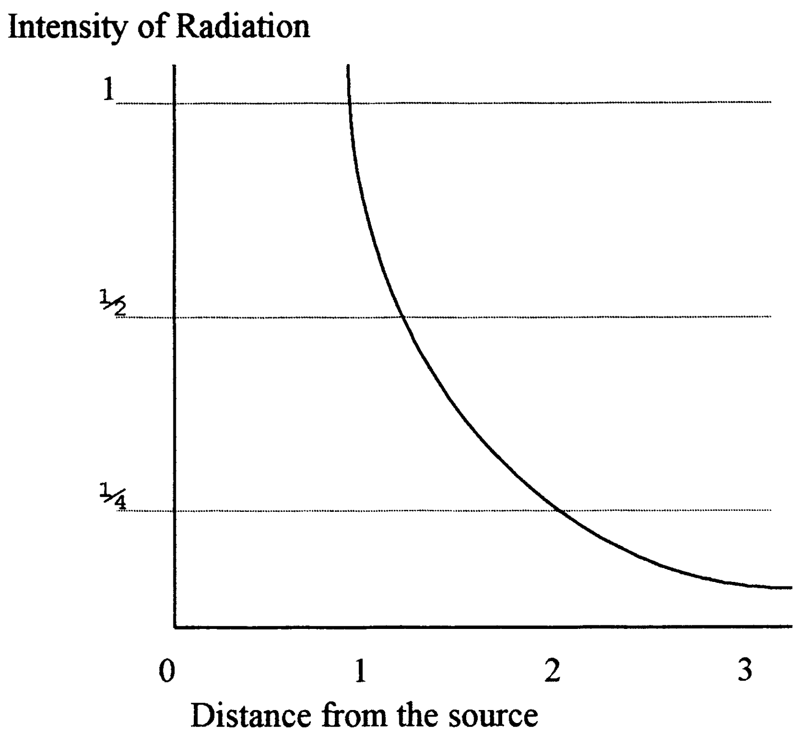


Figure 21.3 Intensity of exposure against Distance from Radiation source.

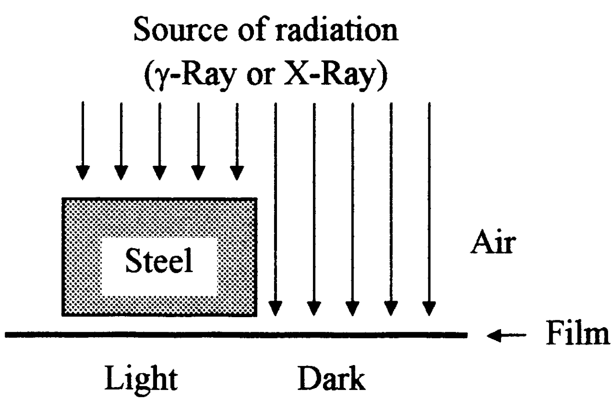
No persons under the age of eighteen years may use radiography; in addition no person not on the radiological protection list may use radiography.

RADIOGRAPHY AS AN NDT TECHNIQUE

The way in which radiation is used as an assessment of the integrity of a component is to place a Gamma of X-ray source on one side of the component and a recording film on the other side. The recording film is similar to monochrome photographic film in that the sensitive part of the emulsion consists of silver halide crystals. The difference is that whereas with a photographic film the emulsion was on one side only, and the film was exposed by visible light, a radiographic film will be coated on both sides of the film base. This gives a much higher density to the exposed radiograph, and of course the film will be exposed by the radiation, so the film is kept in lightproof containers while it is being exposed.

When a radiographic film is exposed to radiation it will change according to the intensity of the radiation hitting it, the more intense the radiation the darker the film after processing.

Radiation is absorbed at different rates as it travels through materials depending on a variety of factors. The main factor as far as we are concerned is the density of the material as can be seen from the figure 21.4:



As can be seen the radiation has to travel through a much denser medium in the case of the steel and so has what is termed a longer **Beam Path Length**, this means that less radiation will reach the film beneath the steel and the result is a lighter area on the film which is beneath the steel once that film is developed.

Figure 21.4 Path Length Shown Through and around Steel

As can be seen from figure 21.4 above the image produced can be termed a shadowgraph, and assessment can be made of the integrity of the component as we can see from the example below:

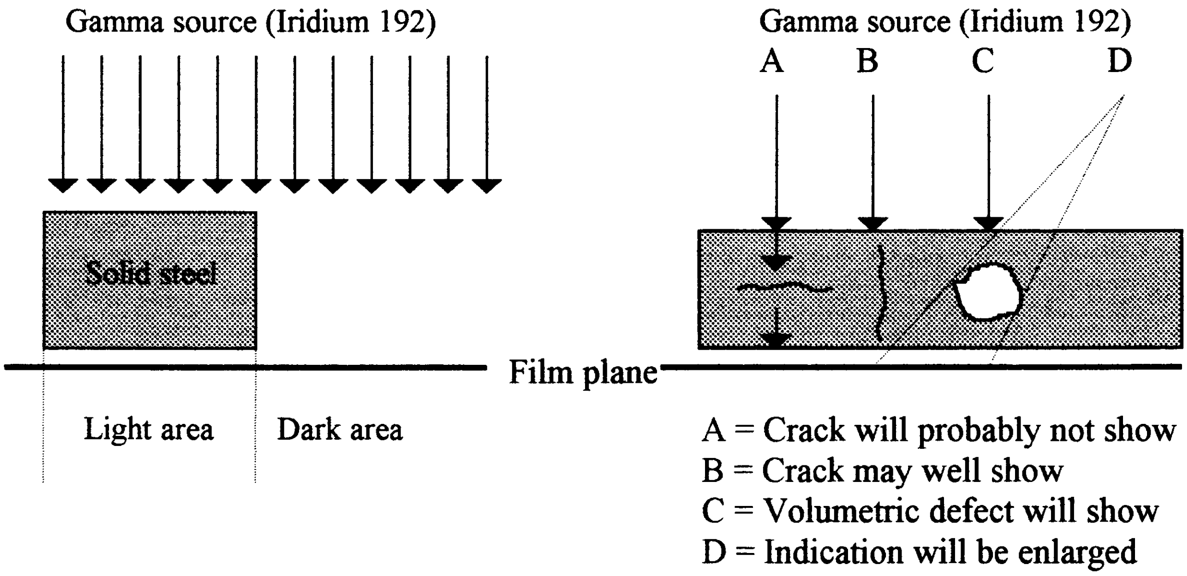


Figure 21.5 Assessment of Defects With Radiography

The above figure 21.5 shows that the difference in path length through the horizontal crack and the full thickness of the material is minimal, so this will probably not show on a radiograph. In the case of the vertical crack, the difference in path length through the material over that through the crack is quite marked, so the defect may well show up. Although the cracks mentioned might be found, planar defects will not always show, and so, this method is unreliable for their detection, unless the exact orientation is known allowing the source/film positions to be adjusted accordingly.

Radiography is much more **dependable** for the detection of **volumetric defects** such as inclusions, porosity and lack of penetration etc. The reason is that the path length through the defect is always quite different from the path length through the material around the defect. However as can be seen from the above diagram the location and size of the defect can sometimes be difficult to assess; as the geometrical relationship of source, film and defect changes. This must be taken into account when interpreting the radiograph.

APPLICATION OF RADIOGRAPHY UNDERWATER

There are two main techniques used in water, they are:

1. Panoramic Technique

The panoramic technique is used to radiograph a circumferential weld in a tubular such as a pipeline or structural member. The source is placed at the centre of the pipe and the film is placed in a continuous band around the outside. Using this technique it is possible to take a radiograph of the whole weld in one shot.

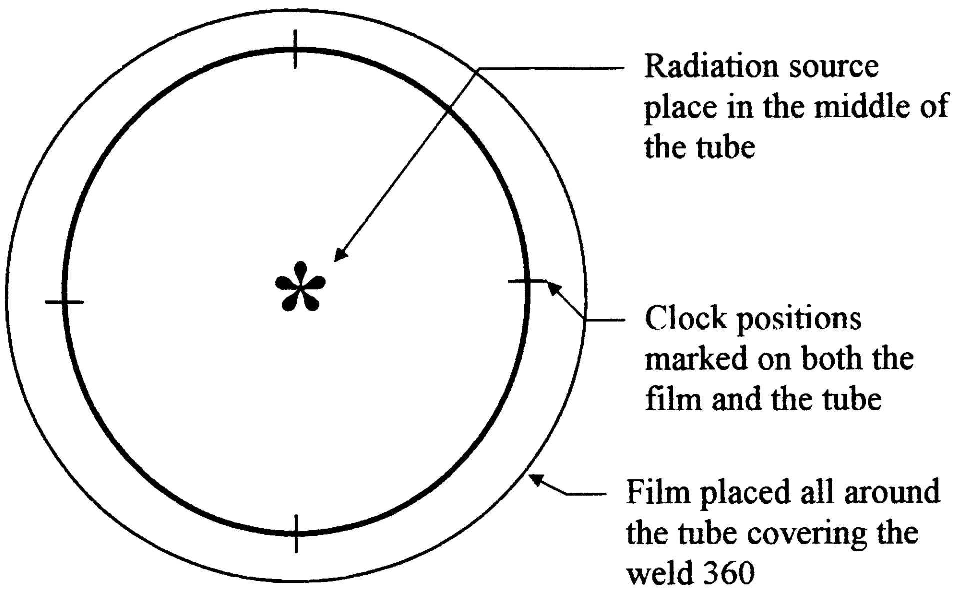


Figure 21.6 The Panoramic Technique

2. Double Wall Single Image Technique (DWSI)

This technique is used where it is impossible for the source to be placed at the centre of the pipe or tubular, as is the case in the majority of tubular members on offshore structures. The double wall single image technique involves the placing of the source outside the member on one side, the film being placed directly opposite the source on the other side of the member, thus the film is exposed through both walls of the steel member. Only the wall in close contact with the film will be recorded in focus on the film. With this method at least three shots would be needed in order to ensure complete coverage of the weld.

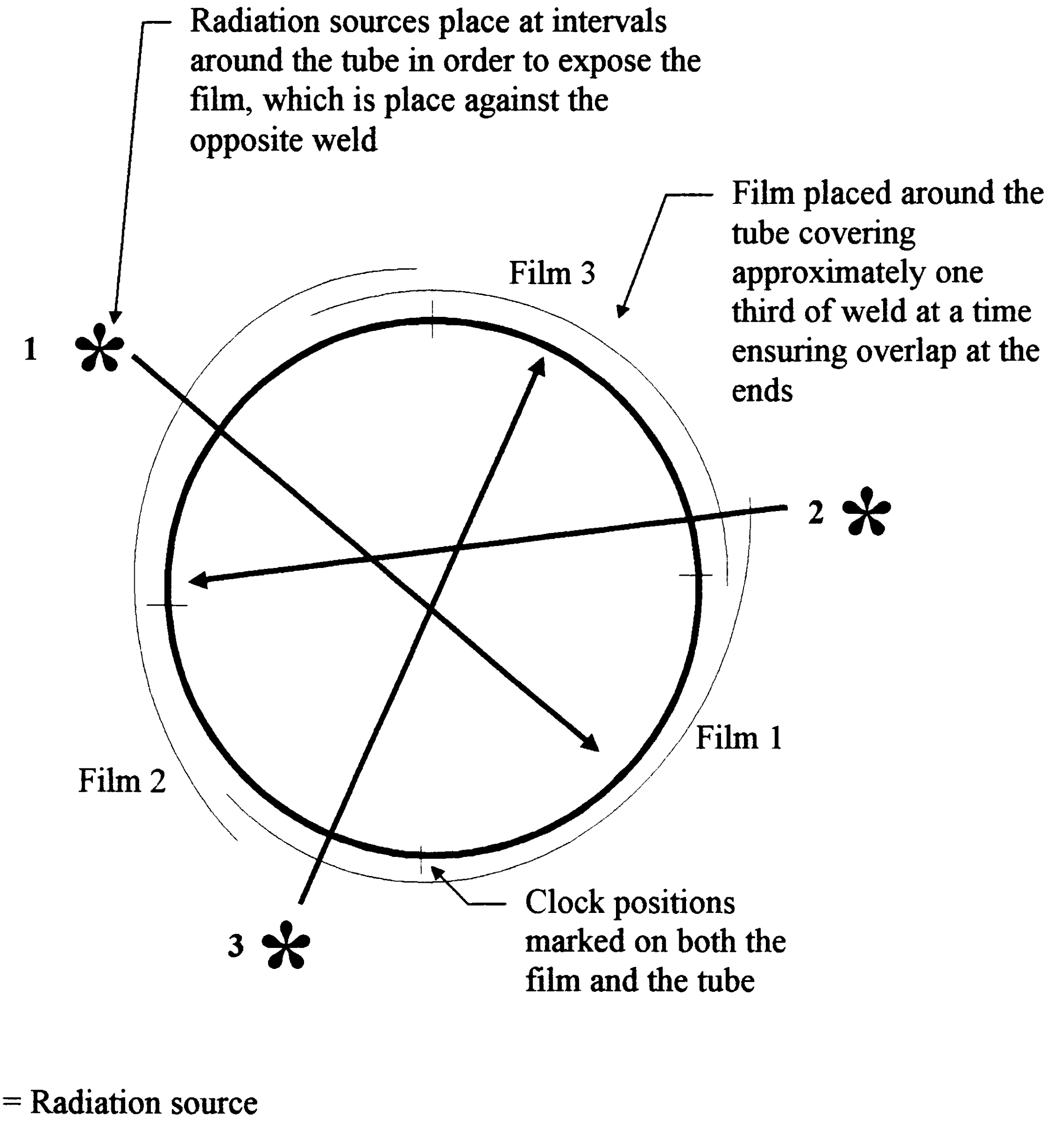


Figure 21.7 Double Wall Single Image Technique.

IMAGE QUALITY INDICATORS (I.Q.I.)

The quality of radiograph is obviously of great importance, as this will indicate the type and size of defects detectable. The image quality indicator is designed in such a way as to allow the operator to assess the sensitivity, so giving an idea as to what he will be able to appraise. The indicator consists of a series of ferrous or copper wires of varying diameters ranging from large diameter at one end of the I.Q.I. to thin at the other end. This is placed on the film side where access to the source side cannot be gained, when the radiograph is processed the operator will look to see how many of the wires are visible, from this he can tell the quality of the image. In addition the shot will be identified by the use of lead figures and numbers, showing the identity of the weld, whether it is a butt or a fillet weld, who the operator is and the date etc.

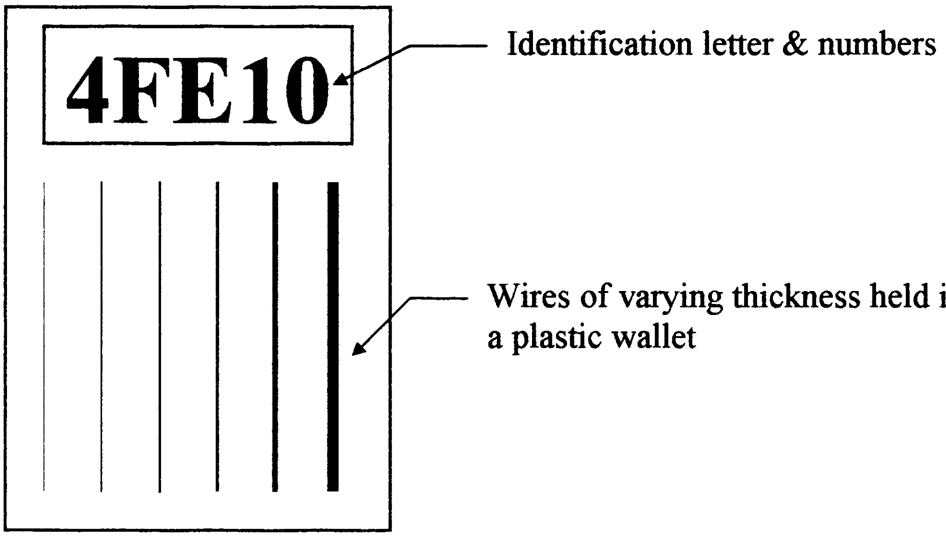


Figure 21.8 The Image Quality Indicator

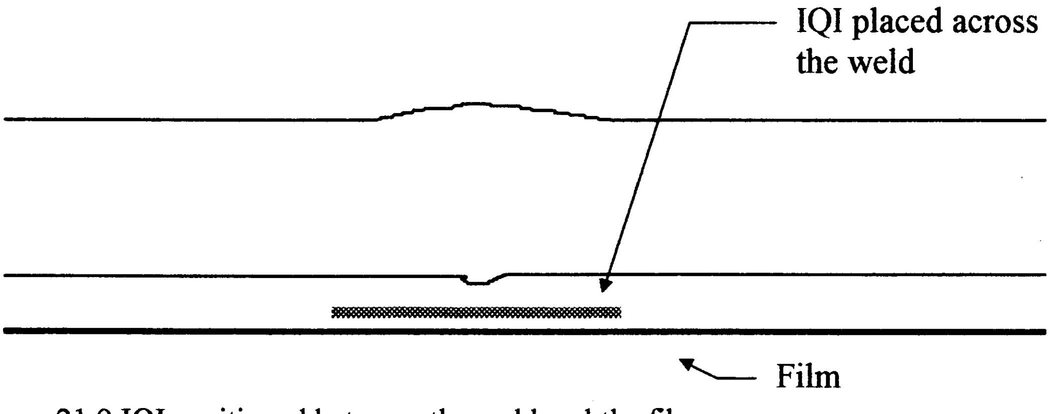


Figure 21.9 IQI positioned between the weld and the film

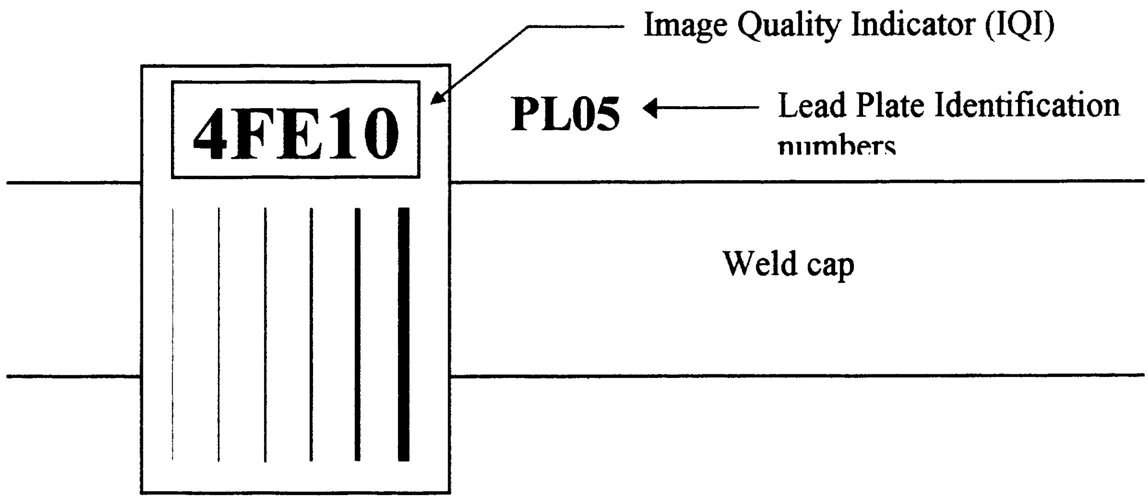


Figure 21.10 Positioning of the Image Quality Indicator IQI.

CHAPTER 22

Flooded Member Detection (FMD)

Flooded member detection can be achieved in three ways:

1. **Ultrasonic F.M.D.**
2. **Gamma Radiography (gauging).**
3. **Thermal F.M.D.**

The most widely used is the ultrasonic method.

With offshore structures being designed to a very high specification it is clearly going to be a disadvantage if a member that is supposed to be dry suddenly floods. This can affect the performance of the structure in a number of ways. There will be a change in the overall loadings i.e. there will be added weight as the buoyancy of the member is lost and so on.

ULTRASONIC F.M.D.

In the case of ultrasonic flooded member detection a low frequency ultrasound is used typically 0.5 MHz (500KHz). The probe is held at a fixed standoff from the member under test, on a frame. It is very important that the probe is held square to the member in order to receive the reflected sound.

If the member is air filled then the ultrasound will not penetrate to the back wall of the member and so the only signal, which the operator will see on the cathode ray tube, will be from the front wall of the member. If the member is flooded, then the ultrasound will penetrate to the back wall and so will be reflected back to the probe, there will then be a smaller peak on the C.R.T where the front wall indication was and there will be an additional peak which corresponds to the position of the back wall (see diagram).

Ultrasonic FMD should be carried out at the six o'clock on a horizontal member, so that even a partially filled member could be detected. **The necessary cleaning standard will be SA2.**

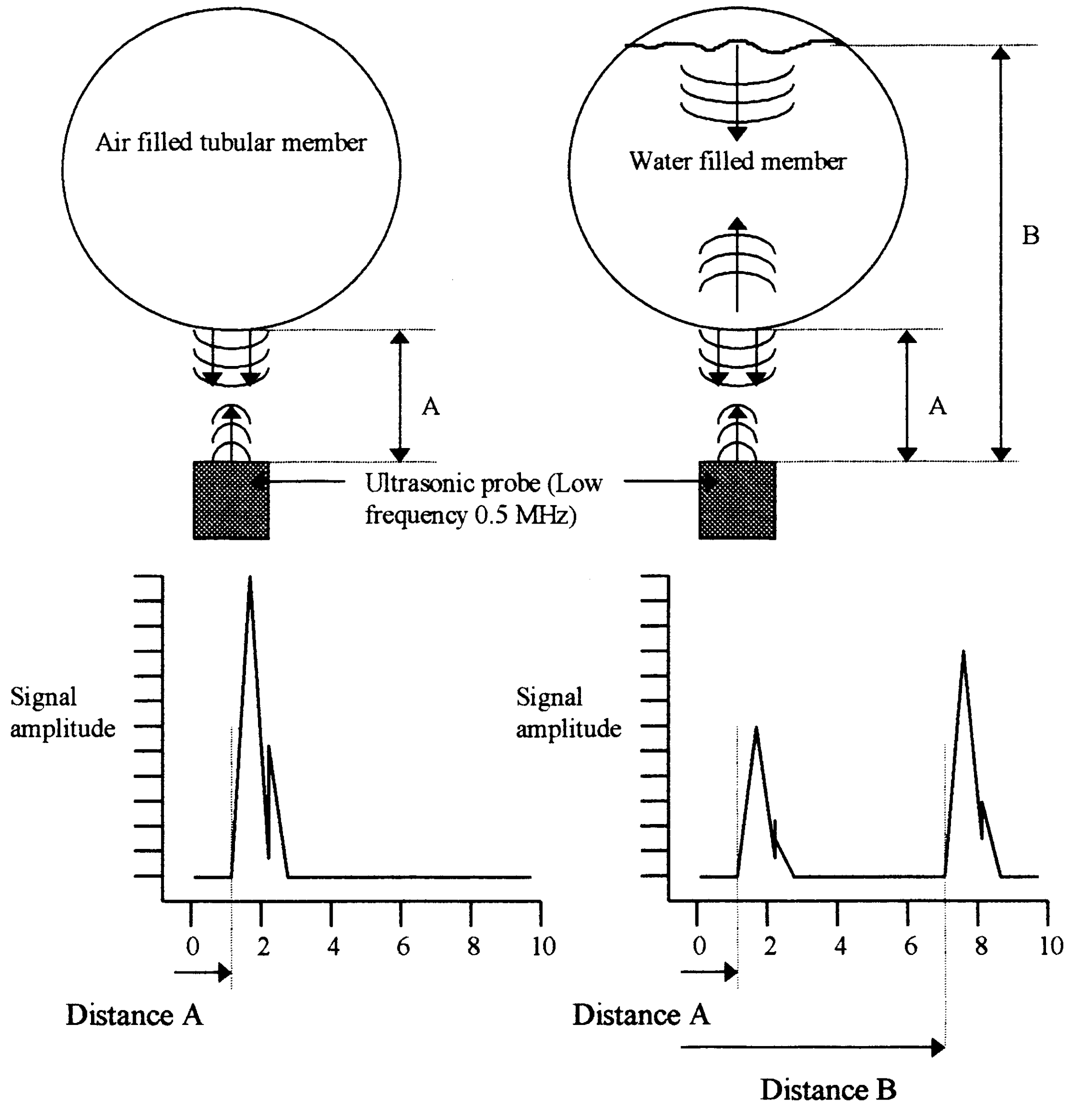


Figure 22.1 Ultrasonic Flooded Member Detection

GAMMA RADIOGRAPHIC F.M.D.

Gamma sources are now widely used for the detection of flooded members however there are quite high costs and of course the obvious safety considerations.

The technique relies on the fact that water absorbs radiation more than air. A radiographic source is placed on one side of the member and a radiation sensor will be placed on the opposite side.

When the radiographic source is exposed, there will be a count evident on the sensor, this can be interpreted as to whether the member is flooded or not, also the depth of flooding can be assessed by noting the number of counts per second. The wall thickness of the member will need to be known to a relative high degree of accuracy in order for the results to be correct. There will normally be no cleaning required for radiographic FMD provided that the thickness of marine growth can be ascertained this can be compensated in the software. The most common radiographic source used for FMD is Caesium 137. A major advantage is that **there is no cleaning required**, as the systems can compensate for marine growth as long as the approximate thickness is known.

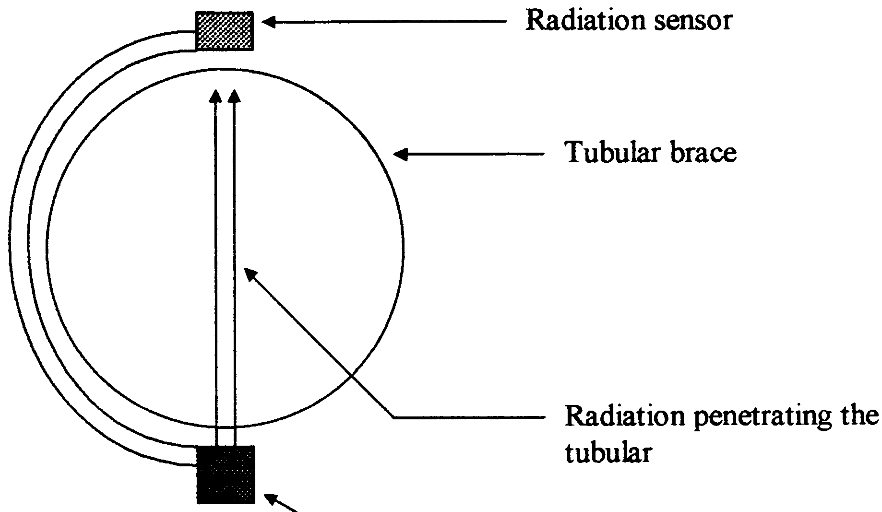


Figure 22.2 Radiographic Flooded Member Detection.

THERMAL F.M.D.

This is achieved by heating the tubular at a specific location and measuring the thermal drain, i.e. a flooded member will cool more quickly than a dry one. **The necessary cleaning standard is high, typically SA2.5 or SA3.**

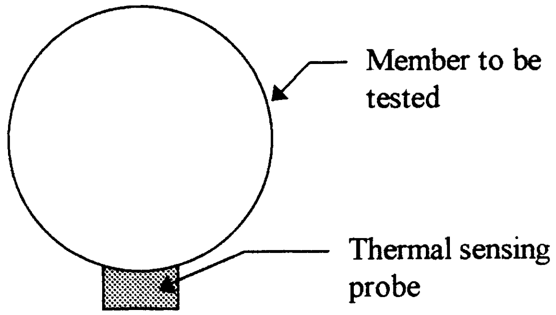


Figure 2.3: Thermal sensing FMD.

With all Flooded Member Detection it is important to note that for horizontal tubulars the assessments should be made at the six o'clock position. In the case of Vertical Diagonal Members and Vertical members the first position checked should be the lowest point and in these cases the clock position will not be important. And in all cases it will be important to know the specific diameter and wall thickness of the brace being measured.

CHAPTER 23

Electro-Magnetic Detection Techniques (Eddy Current Or ACFM)

Eddy Current testing of welds offshore has recently become more widespread with the advent of equipment better suited to the needs of the offshore environment. There are a number of tasks for which Eddy Current are well suited, these are as follows:

1. **Surface breaking crack detection and sizing in conducting materials.**
2. **Surface breaking defect detection in non-magnetic conductors.**
3. **Inspection of tubes and bar during production.**
4. **Sorting metals and alloys.**
5. **Coating thickness measurement.**
6. **Sizing for length and also depth of surface breaking defects**
7. **Stress assessment**
8. **Marine Growth Thickness assessment**

We are generally interested in the location and sizing of surface breaking defects in the weld zone. It would be an advantage if this could be done through paint coats, and as Eddy Current is a non-contacting method this becomes possible. How does it work?

If an electrical current is passed through a current carrying conductor a magnetic field will be generated, the orientation of the field will be 90° to the direction of current flow. If we then make the conductor in to a coil the magnetic flow will become a longitudinal flow through the coil, this is called the primary field and is illustrated in figure 23.1 below:

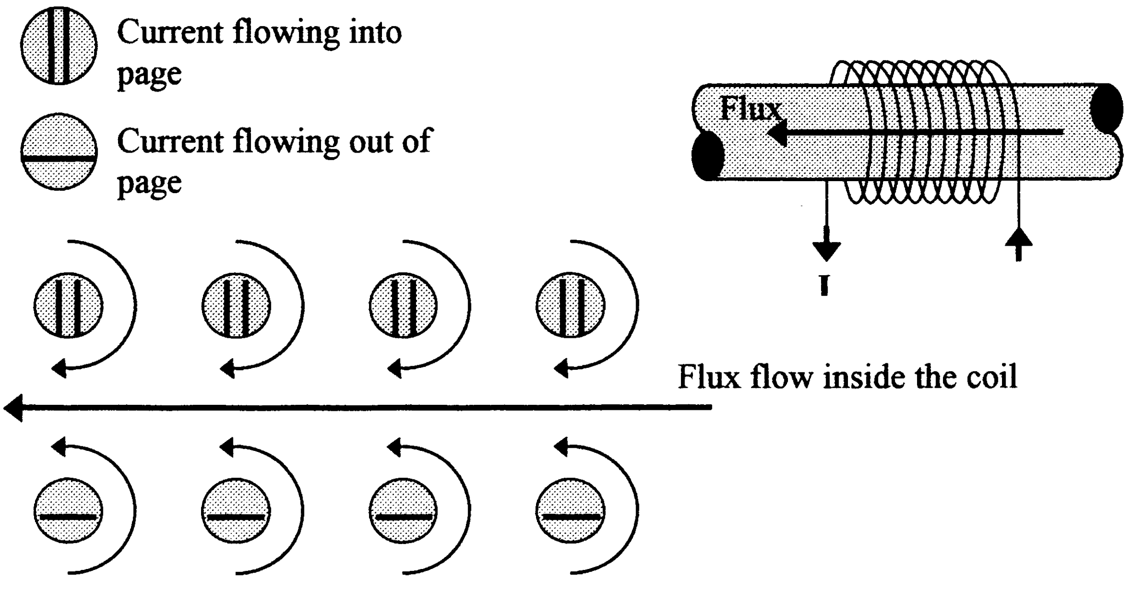


Figure 23.1 Magnetism Produced in a Coil

When the coil is brought into close proximity to a material the primary field will pass through it and will produce current of electricity running circular paths in the material (Eddy Current) at right angles to the primary field as shown in figure 23.2 below:

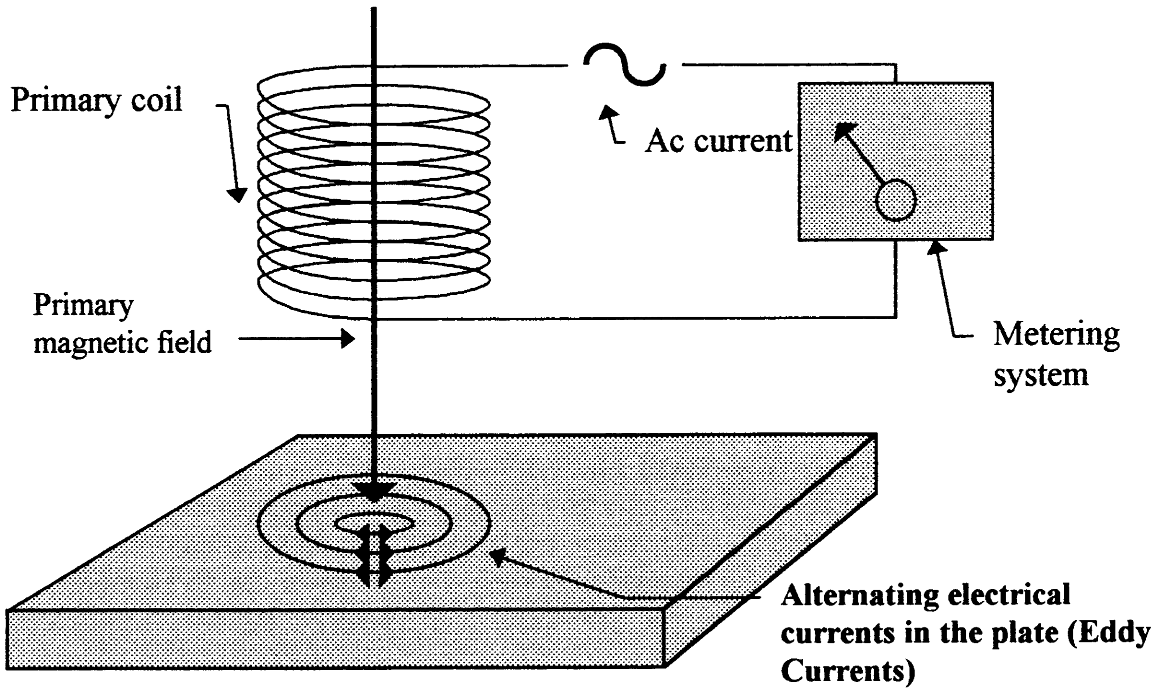


Figure 23.2 Eddy Currents Flowing in a Material

These electrical Eddy Currents will induce a secondary magnetic field to flow in opposition to the original primary field:

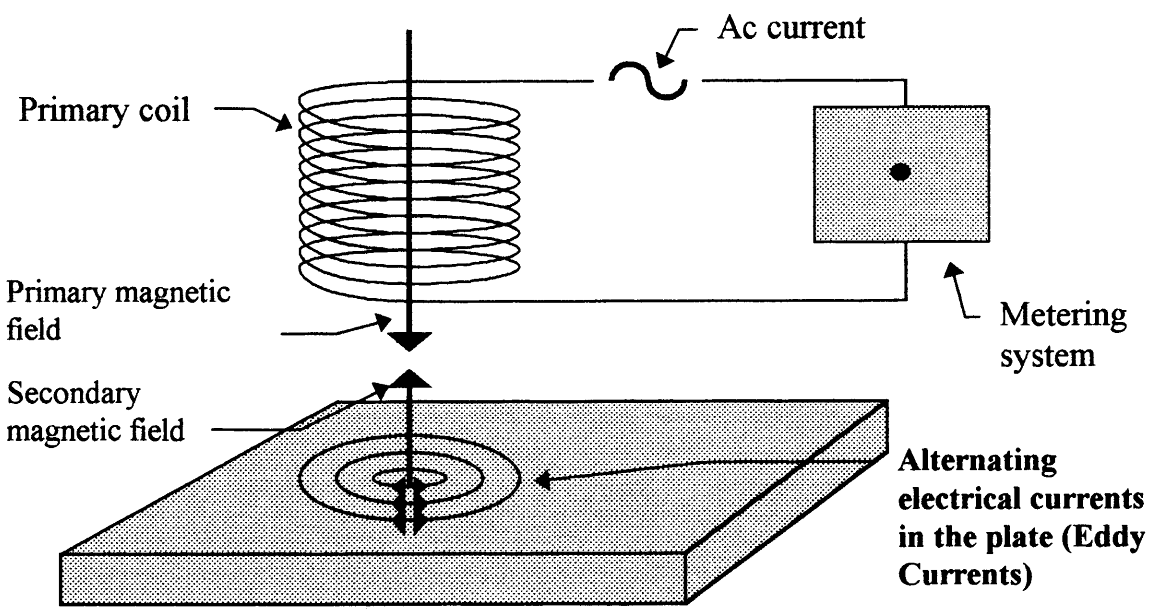


Figure 23.3 Secondary Field Produced By the Primary Magnetic Flow

This situation can be balanced and so the display can be set to read zero in the normal set of circumstances, (no crack) but if there is a change in the Eddy Current flowing in the material this will then alter the secondary field, which in turn will affect the characteristics of the primary coil. It is this change that will be monitored and so displayed, normally, on either a meter of cathode ray tube monitor.

There are several ways in which the eddy current can be affected:

1. If a surface-breaking crack is encountered, in this case the Eddy Current is forced to flow under or around the crack.

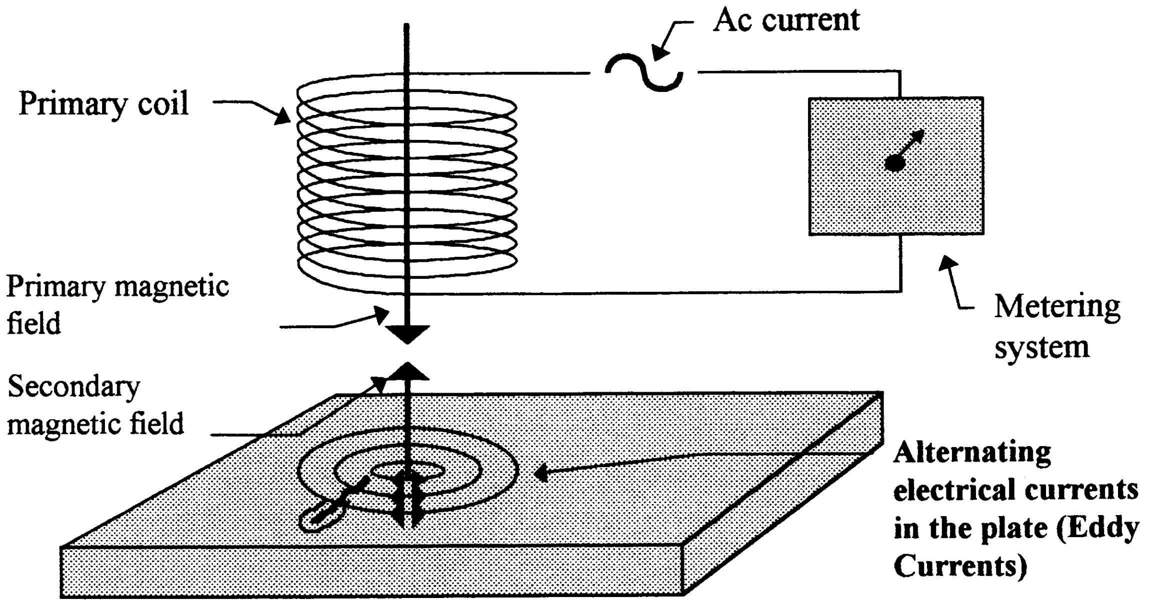


Figure 23.4 Eddy Current Behaviour Around a Defect

2. Lift off of the probe from the material surface, if this varies then the results can be affected, unless the probe has been specifically designed to limit the effects of lift off.

3. Varying permeability of the test material can affect the resulting flux flow in the test.

4. Edge effects, if the Eddy Currents come up against an edge then they will be compressed and this will affect the results again.

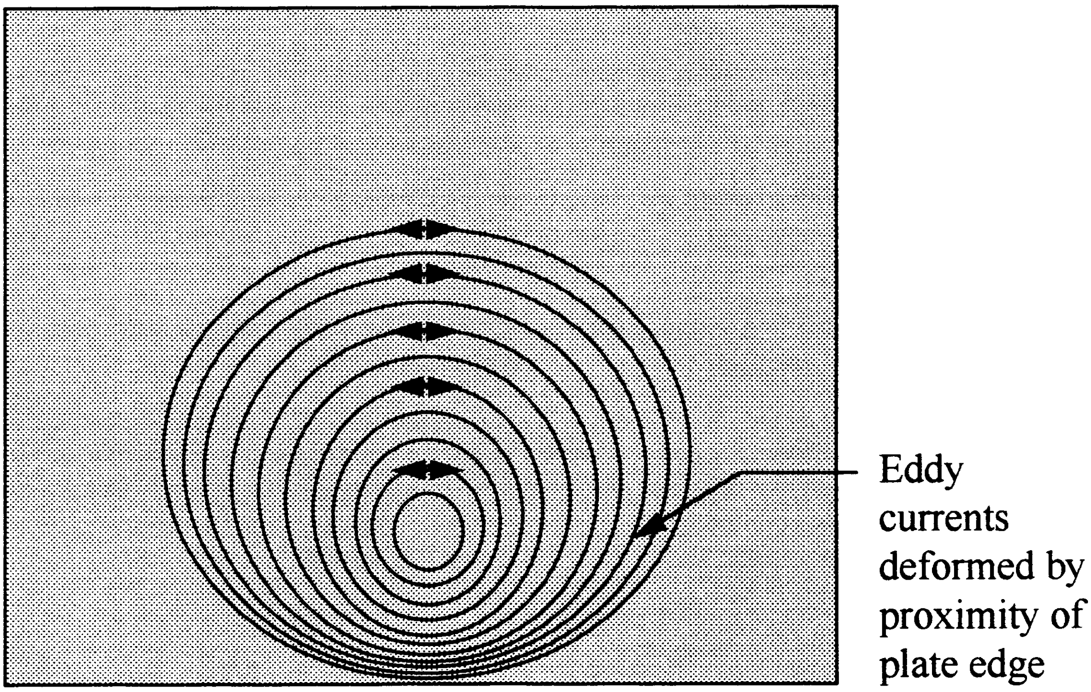


Figure 23.5 Edge Effect

5. Changing thickness of the material under test, again this can affect the results.

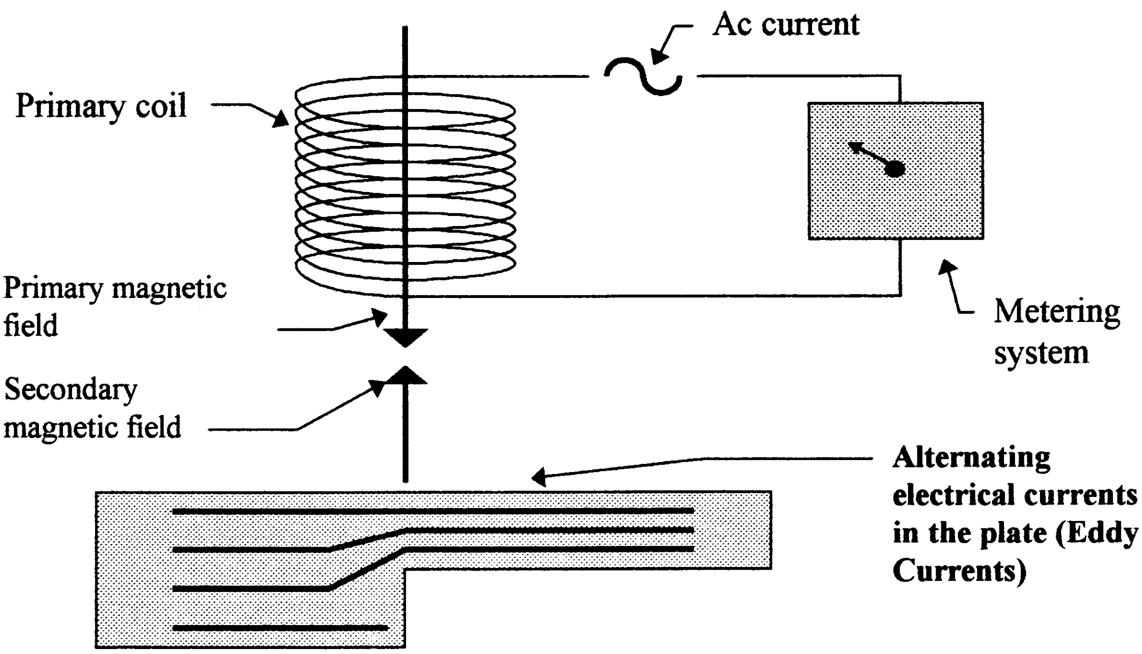


Figure 23.6 Varying Material Thickness

All of the above will cause a change in the primary coil, which is measurable and so can be displayed.

Below is a block diagram (figure 23.7) of an Eddy Current system

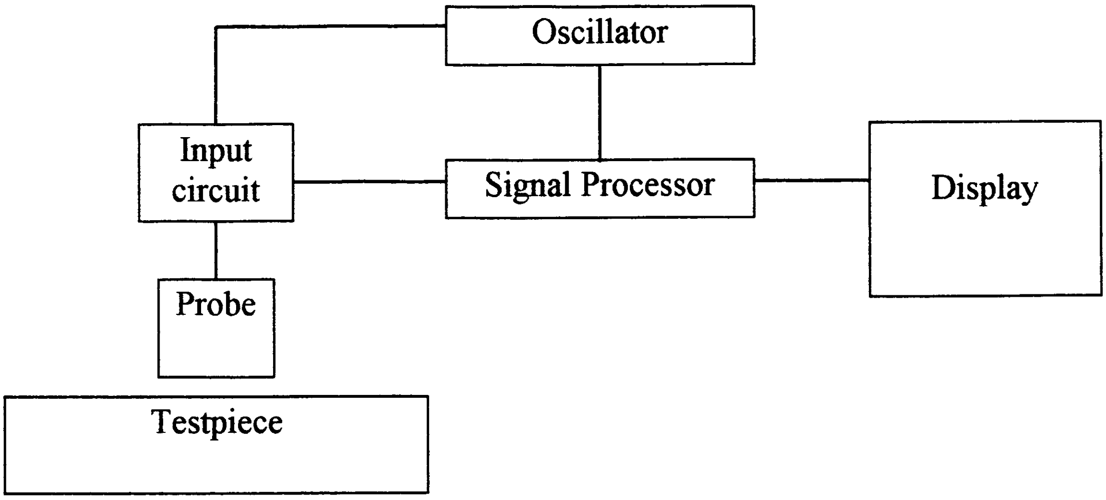


Figure 23.7 Block diagram of an Eddy Current Test System

Depth of Penetration of Eddy Currents

Eddy Currents will not penetrate very far into the material, the factors, which dictate how far Eddy Currents will penetrate, are:

1 Frequency of the test probe
2 Permeability of the material under test
3 Conductivity of the material under test

Frequency:

As frequency of the test probe increases the depth of penetration will decrease

Permeability:

As the permeability of the material increases the depth of penetration will decrease

Conductivity:

As conductivity of the material increases the depth of penetration will decrease

Advantages of EMD or ACFM over MPI

1 - Sizing for length of defect and also for depth
2 - Works through non-conductive coatings
3 - Information recorded on computer disk
4 - Permanent re-playable record
5 - Quicker than MPI
6 - Lower cleaning standard than MPI
7 - Works on non-magnetic materials
8 - Interpretation is carried out topside
9 - Off-line interpretation possible
10 - Lighting is not a problem
11 – ROV deployment may be easier when using array probes

Advantages of MPI over EMD or ACFM

1 - Proven technique
2 - Easier for use on complex geometry
3 - Good for transverse cracks or complex cracks
4 - Good for shallow cracks
5 - Gives a visual indication
6 - May be better for grinding of defects
7 - Less complex equipment
8 - Less costly equipment

Important points for EMD or ACFM inspection

1 - Ensure probe operation is agreed and carried out correctly
2 - Ensure probe operator/machine operator dialogue is known
3 - Cleaning standard required (SA2 minimum)
4 - Note important points of probe handling and manipulation (Parts of the probe etc)
5 - Carry out correct weld marking procedure
6 - Ensure awareness of limitations of the technique (Geometry, seams, weld profile etc)

CHAPTER 24

Alternating Current Potential Drop (ACPD)

A.C.P.D., Is the method by which the depth that a surface-breaking defect has penetrated can be assessed.

Normally this method is not used as a detection technique but used as a technique to explore a defect previously found by another technique such as M.P.I. It will however be invaluable if the defect depth needs to be taken at intervals along it's length, ACPD will allow a profile of the crack to be built up.

When an alternating current is passed through a conductor, the so-called "skin effect" forces the current to flow in a thin layer on the outer surface. This means that the effective cross-section carrying the current is small, so that currents of only an Amp or less can generate relatively high surface voltages. This feature offers benefits compared with the direct current method (DCPD), particularly on large specimens.

The thickness of the current-carrying layer, the so-called "skin depth", δ, is given by:

$$\delta = (\pi\sigma\mu_r \mu_o f)^{-1/2}$$

Where σ is the electrical conductivity of the material, μ_r is its relative magnetic permeability, μ_o is the permeability of free space, and f is the frequency of the applied alternating current.

Materials of high permeability or conductivity thus have relatively small skin depths. At a frequency of about 5KHz, for example, ferromagnetic mild steel has a skin depth of the order of 0.1mm, high conductivity materials such as aluminium, tungsten and zinc have skin depths of 1-2mm, and low conductivity metals such as titanium, stainless steel and Inconel have skin depths of 5-8mm.

We will be dealing only with ferritic steels in this chapter, this being the dominant material in our field.

The input current produces a surface voltage, which is measured by a two point contacting probe. The value of the measured voltage is dependent on the strength of input current, the separation of the two measuring points, the skin depth, the material conductivity and the specimen geometry.

For a given material, keeping the current and the probe gap constant, and ensuring a uniform current distribution makes the measured voltage dependent only on the conductive metal path length between probe tips. When the prove straddles a surface-breaking crack, this path length is obviously longer than with no crack.

A combination of two voltage readings, one across a crack and the other on an adjacent uncracked area, allows separation of the effect of the crack from the other effects. In this way crack depth can be calculated without the need for any calibration on notches.

The condition necessary for the successful operation of the ACPD technique as follows:

a) The output circuit of the ACPD instrument maintains a constant current amplitude (generally about 1 Amp) for any load up to certain limits (generally a few Ohms).

b) The input circuit of the instrument ensures that only the voltage produced directly by the surface current is measured. Other voltages, such as those induced in pick-up loops, are rejected.

c) The field needs to be of uniform strength, which is usually achieved by adequate separation of the current input points, and ensuring a minimal distance between the location of the cross-crack and adjacent reference voltage measurements.

PRACTICAL DEPLOYMENT

The ACPD technique requires two connections between the instrument and the specimen under inspection - namely the current output or field connection, and the voltage input from a manually deployed single probe. This section describes the general rules for deployment on the types of structure found underwater such as flat plates or welded tubular intersections.

FIELD CONNECTION

The field lead is generally used to inject a current into the specimen by direct contact. In this case the two contacts should be placed reasonably far apart, equidistant on either side of the crack site and with the crack lying perpendicular to the line between the contacts (see figure 24.1 below for deployment on a flat plate, and 24.2 for deployment on a tubular intersection). The contacts should be about 300mm away from the crack, if possible. The further apart the contacts are the more uniform the field is. However, the surface current density (and hence the measured voltage) drops and the load increases as the current contact distance increases, so there is a limit to how far apart the contacts can be.

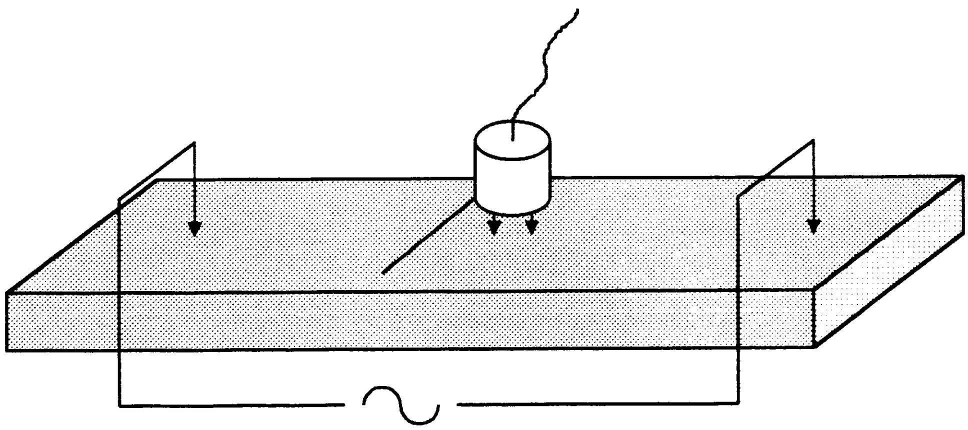


Figure 24.1 Deployment on a Flat Plate

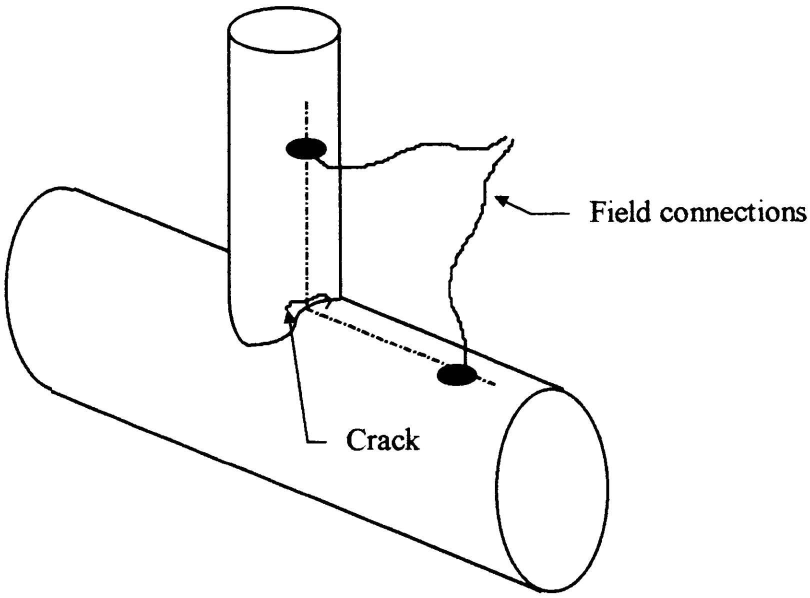


Figure 24.2 Deployment on a Tubular Section

In order to minimise inductive pick-up, the field leads should be taken away from the contacts at right angles to the injected current as shown, and should be brought together away from the crack site. Any relative movement between the field leads and the specimen should be kept to a minimum.

PROBE CONNECTION

In order to minimise unnecessary electromagnetic pick-up by the voltage probe leads, they need to be as widely separated from the field leads as practicable. A good way of ensuring they are kept apart during manual inspection is to loop the voltage probe lead behind the neck of the user.

TAKING MEASUREMENTS

In its simplest deployment, the ACPD technique requires three parameters in order to produce a crack depth: these are a voltage reading with the probe straddling the crack, a voltage reading with the probe adjacent to but not straddling the crack, and the spacing between the voltage probe contacts. The voltage readings are in arbitrary units because only the ration of the two is used.

Generally, fatigue cracks underwater occur at weld toes so that their position is well defined. If the position of a crack is not known however, the voltage probe should be moved along a line perpendicular to the expected crack edge. The display should be watched for any sudden changes in reading. The reading will jump up from one steady value to another higher value when the leading probe contact crosses a crack, and/or from the higher value back down to a lower value when the trailing contact crosses the crack. Note that these values should be repeatable and non-zero; non-repeatable or very low readings indicate loss of electrical contact by either the voltage probe or the field input.

How ACPD works

First of all we must pass an alternating current across the weld at a position, which is known to have no defects. While this is being done we put a probe onto the work piece, which has two contacts at a measured distance apart (A) the machine then computes the potential drop experienced between the two contacts, this will become the zero setting in terms of crack depth. If we then move the probe to span a defect without changing the measurement (A), the electricity will now have to travel a longer path, it will have to go around the crack or under it as electricity needs a conductor This will mean the electricity has to travel through more material, the further electricity travels through a conductor the greater the potential drop experienced will be, this increase in potential drop will be measured by the machine and displayed as an indication of crack depth (see figure 24.3).

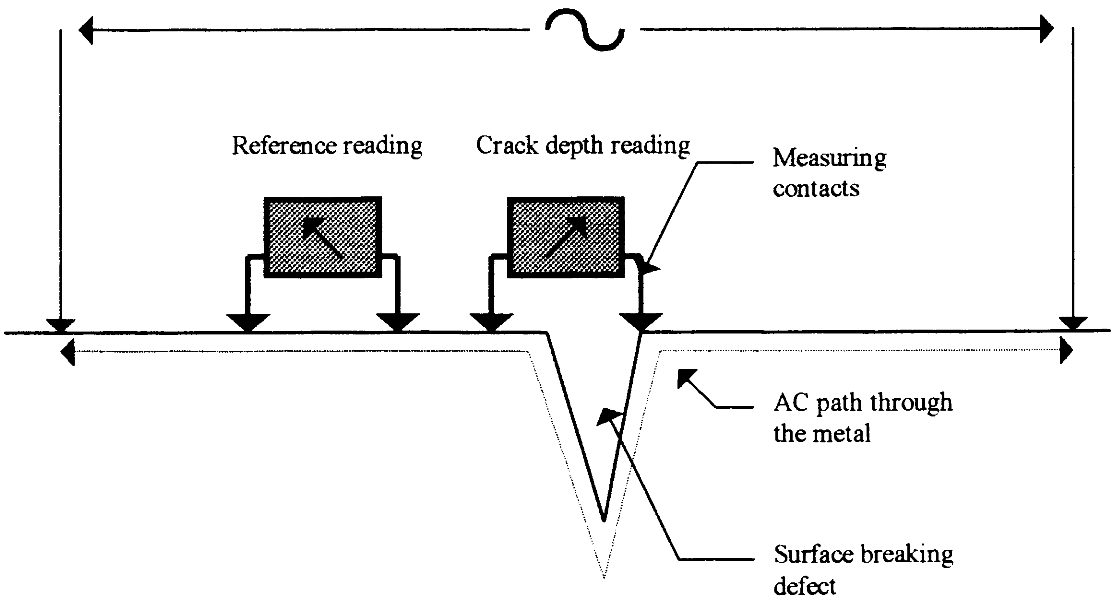


Figure 24.3 Alternating Current Potential Drop Testing Method

In practice having determined the crack location, the two required voltages should be obtained as shown in figure 24.3. The probe should be edged slowly towards the crack (e.g. on the parent plate towards the weld toe) until the voltage reading jumps up. This value should be recorded as the cross-crack voltage, V_c. The probe should then be slowly backed off until the voltage reading drops down again. This value should be recorded as the reference voltage, V_r. The purpose of this procedure is to obtain voltage readings as close together as possible to minimise the effect of any variation in input field strength. Such variations occur, even with a nominally uniform input field, around short cracks or cracks containing line contact or bridge points.

As long as the probe is deployed on the parent plate side of a weld toe, the spacing between the voltage probe contacts along the metal surface will be the same as the straight-line separation in air. The standard probe spacing is 10mm but the precise gap should be checked with a ruler. On surfaces of more complex geometry, the separation along the metal surface will be longer and should be measured directly, using a flexible tape, for example.

Deployment on Large Structures

When inspecting or monitoring on large specimens such as tubular joints, there is a limit to the region over which the field strength is uniform and large enough to measure. The usable width of field is considered to be roughly equal to half the separation between the current input points, centred on the line between these points as shown in figure 24.4. If it is required to inspect an area outside this range, the field input points should be moved by physical disconnection and reconnection.

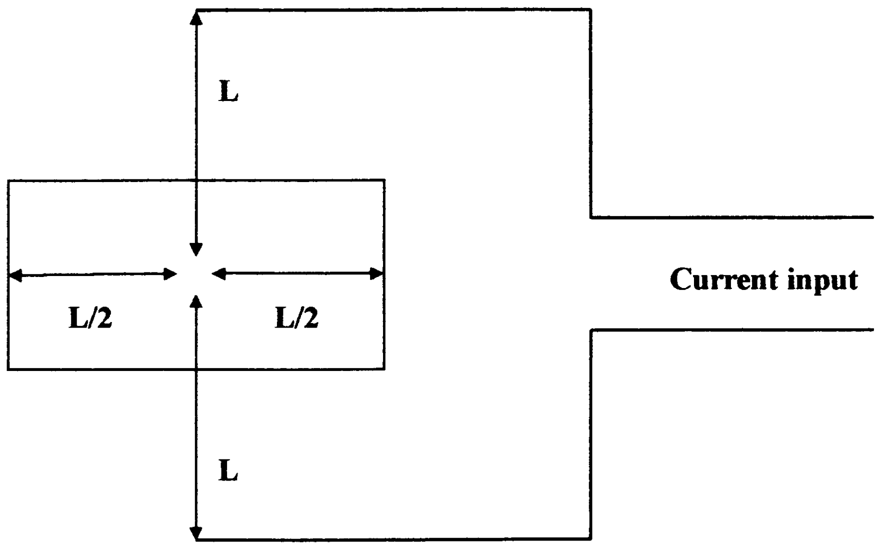


Figure 24.4 Deployment on a Large Structure

CRACK SIZING

Crack sizing using the ACPD technique is best carried out using theoretically derived results applicable to real fatigue cracks. Use of notches in calibration blocks should be avoided if at all possible.

The case where the skin depth is small compared to the anticipated crack depth (i.e. the usual situation underwater) has been extensively modelled and crack sizing is straight forward using simple formulae or computed look-up tables which can be programmed into the instrument.

In this case the electric field strength, E, is constant so that the reference voltage is given by:

$$V_r = E\Delta$$

Where Δ is the voltage probe spacing, and the cross-crack voltage is given by:

$$V_c = E(\Delta+2d)$$

Where 2d represents the extra current path length introduced by a crack of depth d.

Eliminating E, the crack depth is thus given by the following simple formula:

$$d_1 = \frac{\Delta}{2}\left[\frac{V_c}{V_r} - 1\right]$$

For example, for a probe of spacing 10mm, a cross-crack voltage of 800 and a reference voltage of 400 indicates a crack depth of 5mm.

The subscript 1 indicates that this is the so-called 1-dimensional depth estimate. This first estimate of depth is only strictly true for the conditions of long cracks in a thin skin, but it is accurate for most defects found underwater. For the few cases where it is not, such as short, deep cracks or depths measured near to electrical bridging points, this initial estimate is modified to take account of the pertaining conditions, such that the true depth d is given by:

$$d = Md_1$$

The modifier, M, is in general a function of probe spacing, probe position relative to the crack, surface breaking crack length, 1-dimensional depth estimate etc. Theoretical modelling has produced a series of graphs and look-up tables of these modifiers for easy use.

As long as care is taken over field input placement and probe deployment as described above, ACPD is a very easy technique to use to obtain accurate crack sizing in a wide range of applications.

CHAPTER 25

Alternating Current Field Measurement (ACFM)

The A.C. field measurement (ACFM) technique was developed to combine the sizing ability without calibration of ACPD with the ability to work without electrical contact of conventional eddy currents. This is achieved by maintaining the uniform input field (induced rather than injected) but measuring the magnetic field above the specimen surface instead of the surface voltages.

As with the ACPD technique, an alternating current passing through a conductor is forced to flow in a thin layer on the outer surface. The thickness of the current-carrying layer, the so-called "skin depth", δ, is given by:

$$\delta = (\pi \sigma \mu_r \mu_o f)$$

Where σ is the electrical conductivity of the material, μ_r is its relative magnetic permeability, μ_o is the permeability of free space, and f is the frequency of the applied alternating current.

Materials of high permeability or conductivity thus have relatively small skin depths. At a frequency of about 5KHz, for example, ferromagnetic mild steel has a skin depth of the order of 0.1mm, high conductivity materials such as aluminium, tungsten and zinc have skin depths of 1-2mm, and low conductivity metals such as titanium, stainless steel and Inconel have skin depths of 5-8mm.

As with ACPD, the sizing capability depends on theoretical modelling of the expected probe measurements. This has so far only been carried out for materials with a thin skin and the solution is then dependent on the relative permeability, μ_r. This chapter concentrates on inspection of ferritic steels, this being the dominant material in underwater structures.

The ACFM technique is easier to deploy than ACPD but the signals are harder to interpret. In the ACPD only one component of the surface electric field is measured since the voltage probe is always placed parallel to the current flow.

In ACFM, on the other hand, use can be made of all three components of the magnetic field, although usually only two components are needed. The three components are defined in figure 25.1. The "Y" component, B_y, is parallel to the input current, the "X" component B_x, is perpendicular to the current and parallel to the metal surface, and the "Z" component, B_z, is perpendicular to the metal surface. For deployment on weld toes where a crack is parallel to the weld, the x-direction will be parallel to the crack edge.

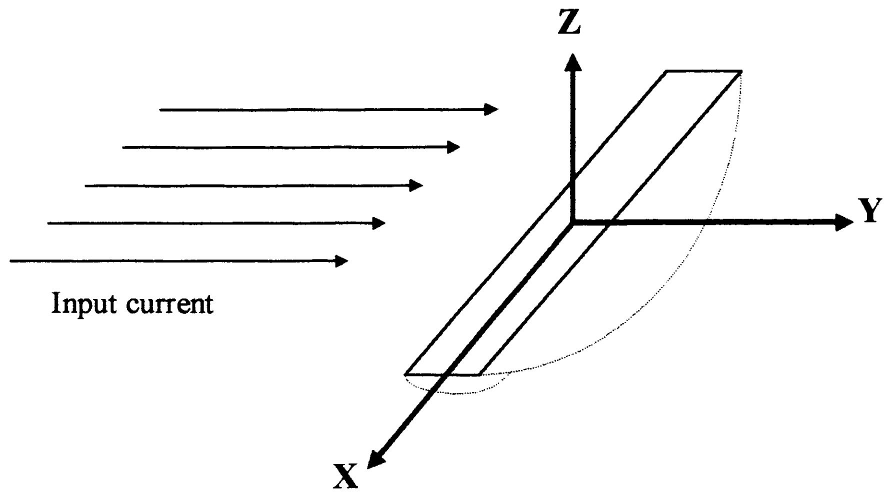


Figure 25.1 The X, Y and Z Components for an ACFM Field

In general terms, the theoretical modelling shows that the magnetic field components are related to the rates of change of the surface potential differences. With no crack present and a uniform current flowing in the y-direction, the magnetic field is uniform in the x-direction perpendicular to the current flow, while the other two components, B_y and B_z, are zero. The presence of a crack diverts current away from the deepest part and concentrates it near the ends. The effect of this is to produce strong peaks and troughs above the crack ends for B_y and B_z, while B_x shows a broad dip along the whole length of a crack. An example of the B_x and B_z signals above a defect is shown in the chart recorder plot on the left in fig 2.

Underwater ACFM probes measure B_x and B_z, the former being used to estimate crack depth and latter giving an estimate of crack length.

PRACTICAL DEPLOYMENT

The standard ACFM probes contain both the field induction unit and the magnetic field sensors in one integral probe head. No electrical connection is required to the structure being inspected, so a minimum of cleaning is required (marine growth must be removed, but not paint or rust).

PROBE DEPLOYMENT

The cables carrying the input current and output voltages run together in a single probe umbilical so that no special precaution is needed to keep them apart as is necessary with ACPD. Care should be taken to prevent the umbilical trailing along the structure close to the probe head, however because this can alter the induced field strength.

A number of different ACFM probe types exist, each one purpose designed for a particular application, and it is important to use the right probe for a particular job, the standard weld probe should be used for most inspections, since it has an optimised physical stability to reduce spurious signals. In contrast, pencil probes should only be used when no other probe can gain access because their small contact area makes them prone to rocking and twisting.
The probes are designed primarily to run along a weld toe, where most fatigue cracks are found. A standard weld inspection will therefore involve two probe passes, one along each weld toe. A standard ACFM probe can inspect an area about 10mm either side of the probe centre so that complete welds up to 20mm wide can be inspected in this ways. For wider welds, additional scans along the weld cap are required.

TAKING MEASUREMENTS

Underwater ACFM is a two-man operation. There is no underwater display at present, partly because the technique does not suffer from effects due to poor probe contact as with ACPD and partly to allow the underwater operator to concentrate on probe movement. The signals measured by the probe are displayed on a topside monitor and all interpretation is carried out by the topside operator.

Full details of the inspection operation are described in the appropriate instrument manuals and inspection procedures, and are not our concern here. Briefly, an inspection consists of a series of initial probe scans for detection, covering the whole weld circumference in overlapping lengths (e.g. 6 scans each covering a quarter of the weld). Defect detection is possible by watching for coincident deviations on the timebase plots of B_x and B_z. Figure 25.2 shows an example of timebase and butterfly plots obtained from a simple defect. The butterfly plot shows a loop, which starts from the top and returns to the same region of the screen when a defect is present. The butterfly plot has the timebase removed and so is independent of the speed of probe movement. Any scans producing significant loops in the butterfly plot would be re-scanned for confirmation.

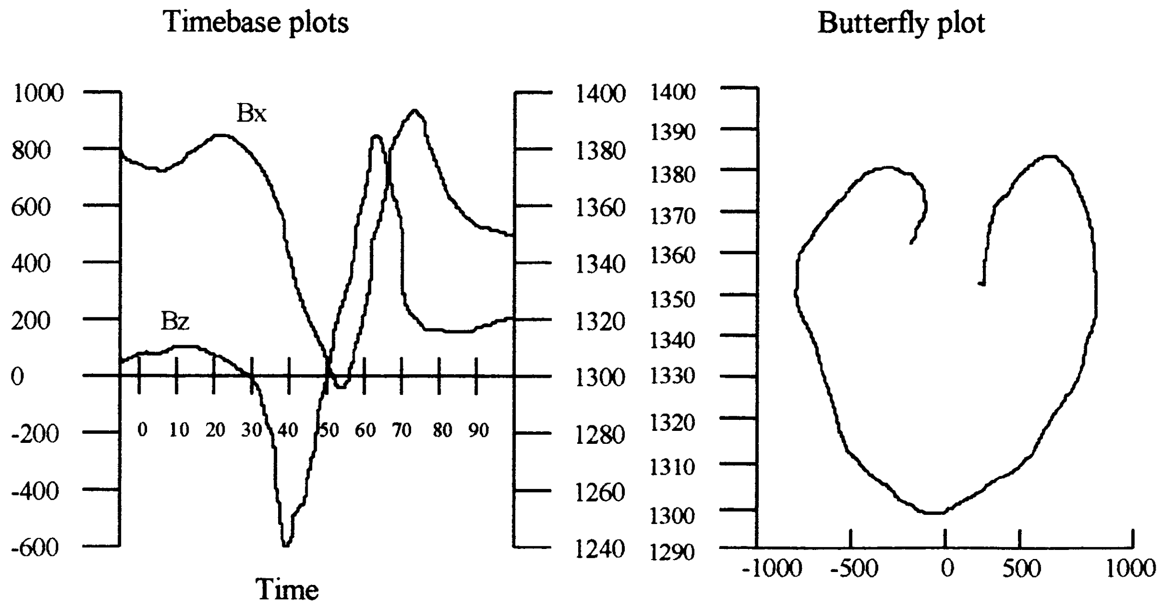


Figure 25.2 ACFM Scanning

CRACK SIZING

Having found a defect indication, a crack size estimate is made as follows. The length is found by moving the probe along the weld until the B_z peak associated with one end of the defect is maximised. The probe position is then marked on the specimen, using a magnetic arrow for example. The B_z trough associated with the other end is similarly marked and the distance between them is measured with a flexible tape. This length is close to the true defect length and is used as an input to the sizing routine. Two measurements are taken from the B_x plot. These are the background level either side of the defect, and the minimum value in the middle of the defect trace. These two signal levels and the initial crack length estimate are then entered into a software routine which searches through theoretically based look-up tables to produce a final estimate of the length and depth of the defect. The latter part involving the software can be done off line at a later date ashore by the engineering department, so long as all of the Subsea information has been gathered in the correct manner as per the procedures.

CHAPTER 26

Stress Relief

Stress can be a big problem for a structure the highest stress areas will be at any point where the structure changes shape or section. Quite often there will also be a weld at this location and this will just add to the stress concentration in an already highly stressed area. As has been said stress in a weld can be a very big problem, the design team and the fabricator will attempt to minimise the amount of built-in stresses as follows:

1. Design - Stress computation and appropriate joint design to cope with the stresses.
2. Fabrication - Pre heat and post heat of the weld to ensure uniform properties across the weld zone.

During the fabrication the weld area will tend to show the following heating and cooling characteristics:

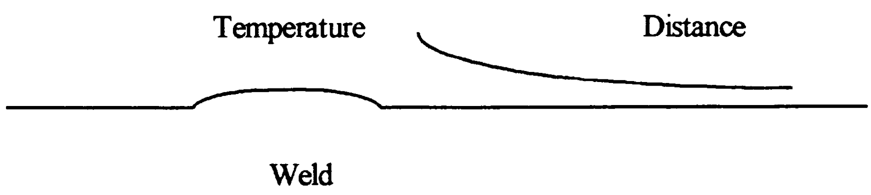


Figure 26.1 Temperature distribution in a weld zone.

The ideal is to achieve an even drop off in temperature in order to cut down on residual stress, which could become locked up in the material. In addition some stress raising materials can be present in the weld. The following are the main stress raising materials that may occur during welding:

1. Sulphur
2. Hydrogen

Sulphur:

Sulphur will always be present in steel making. In a weld pool it will solidify after the rest of the weld pool and will tend to gravitate to the centre of a crater, this can cause crater cracks (sulphur is a brittle material so a low sulphur steel is used i.e. 50d for the building of offshore structures)

Hydrogen:

Embrittlement of the parent metal can be caused by the hydrogen being dissolving into the parent metal, this could arise from the use of welding electrodes that are damp.

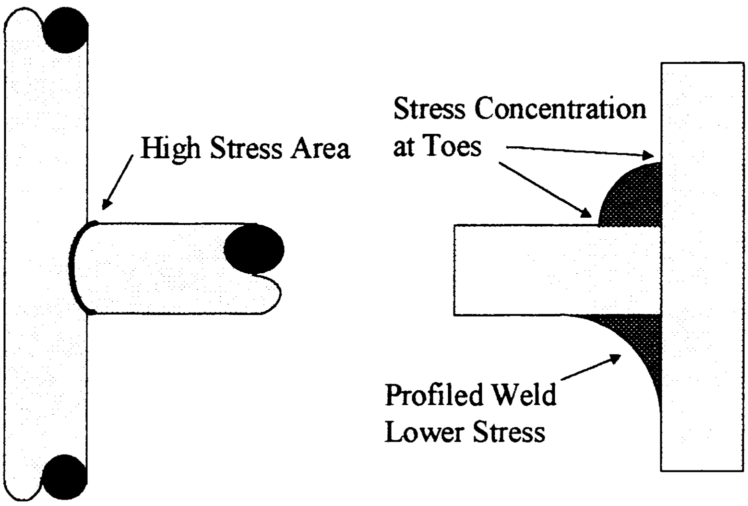


Figure 26.2 Stress and welds.

Cast nodes:

Any node will be a high stress area, casting the node joint will remove the weld to a point outside of this area, since the actual geometric change point tends to be the area of highest stress it makes sense to form the node as a one piece casting as opposed to putting a weld at the highest stress area. Thus a cast node moves the weld away from this point and will allow a smoother transition from one tubular to the other thus removing stress concentration points

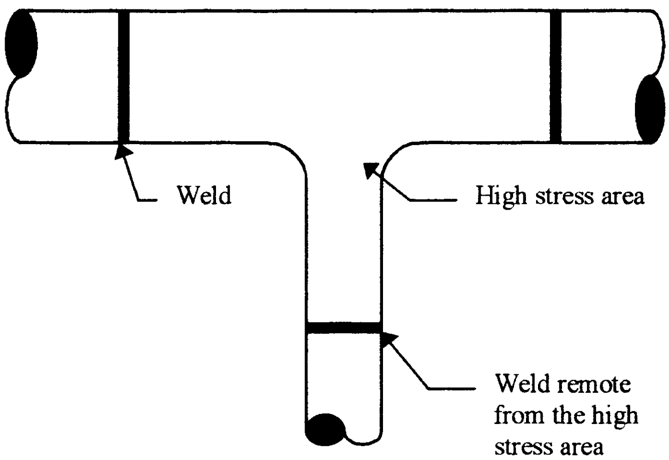


Figure 26.3 Cast node.

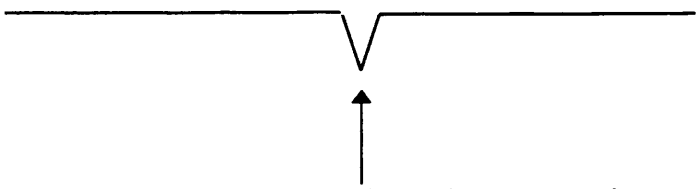
Profiling:

Profiling can be used to remove any sharp notches, if left alone notches will become stress concentration points and so possible problem areas, profiling will have the following effects:

1. Reduces the cross section, this can be a problem in high stress welds but normally welds can take a certain amount of reduction in cross section without much loss of function provided the finished product has a smooth profile.

2. Notch effect, this is far more serious effect as the notch becomes a stress concentration point and may overload the material, as an example, this is the method normally used to cut glass i.e. a small notch is scored into the surface of the glass which can then be broken along the score line.

As the thickness of the material reduces stress increases.



Stress increases at the notch will be a square of the overall increase of the stress i.e. sigma^2

Immediately following the production of a weld profiling may be required at the following locations:

1 Excessive weld metal may cause high stress points at the toes of the weld and may need to be removed in order to reduce the stress concentration to an acceptable limit.

2 Undercut will cause some problems it normally has a rounded form and so not much of a notch, in fact some may even be allowable.

3 Any other welding feature which produces a change of section such as poor restart, stray arc, spatter or elongated cavities to name just a few.

Profiling will be carried out to a maximum depth specified by the duty holders engineering department, this will be conveyed to the offshore personnel as part of the criteria of non-conformance and will make a nice smooth profile so reducing the notch effect. Pressure vessels i.e. caissons (suction and pressure), BS 5500 states that all welds should be profiled (dressed).

If profiling is carried out the fatigue life of a weld will be greatly increased.

Post-production in service profiling may be necessary if a crack is found for the following reasons:

1. To prove a crack exists during MPI or EMD inspections.
2. To remove cracks found during inspection.
3. To remove stress raisers caused during the service life of the structure.

Grinding of defect indications can normally be instigated to a depth of 2mm by the offshore personnel, this grinding will normally be carried out in half millimetre increments or to duty holder specifications. At some time a report of the grinding or defect including a sketch and text will go to the shore based engineers, these engineers may sometimes authorise deeper grinding but this will only be the case after consultation.

SUMMARY

1. Design	-	Stress relief is computed and the design should reflect this.
2. Fabrication	-	Pre and post heating of welds will attempt to remove stresses and will ensure uniformity of the weld zone as far as malleability is concerned.
3. In service	-	Profiling increases life, corrosion fatigue effects can be reduced also increased load carrying capacity can be achieved for a component.

Post Inspection grinding

If a crack is found during MPI or EMD, it may be necessary to grind to prove the indication or to remove the crack, the following shows the steps to be taken. If at any time the maximum allowed depth of grinding has been reached then if the defect is still evident the area may well be profiled and monitoring carried out periodically.

a. Identify crack and re-inspect to ensure relevant indication.
b. Grind at 0.5mm increments (or to Duty Holder requirements)
c. Re-test post grinding
d. Profile to finish (Re-test after profiling)

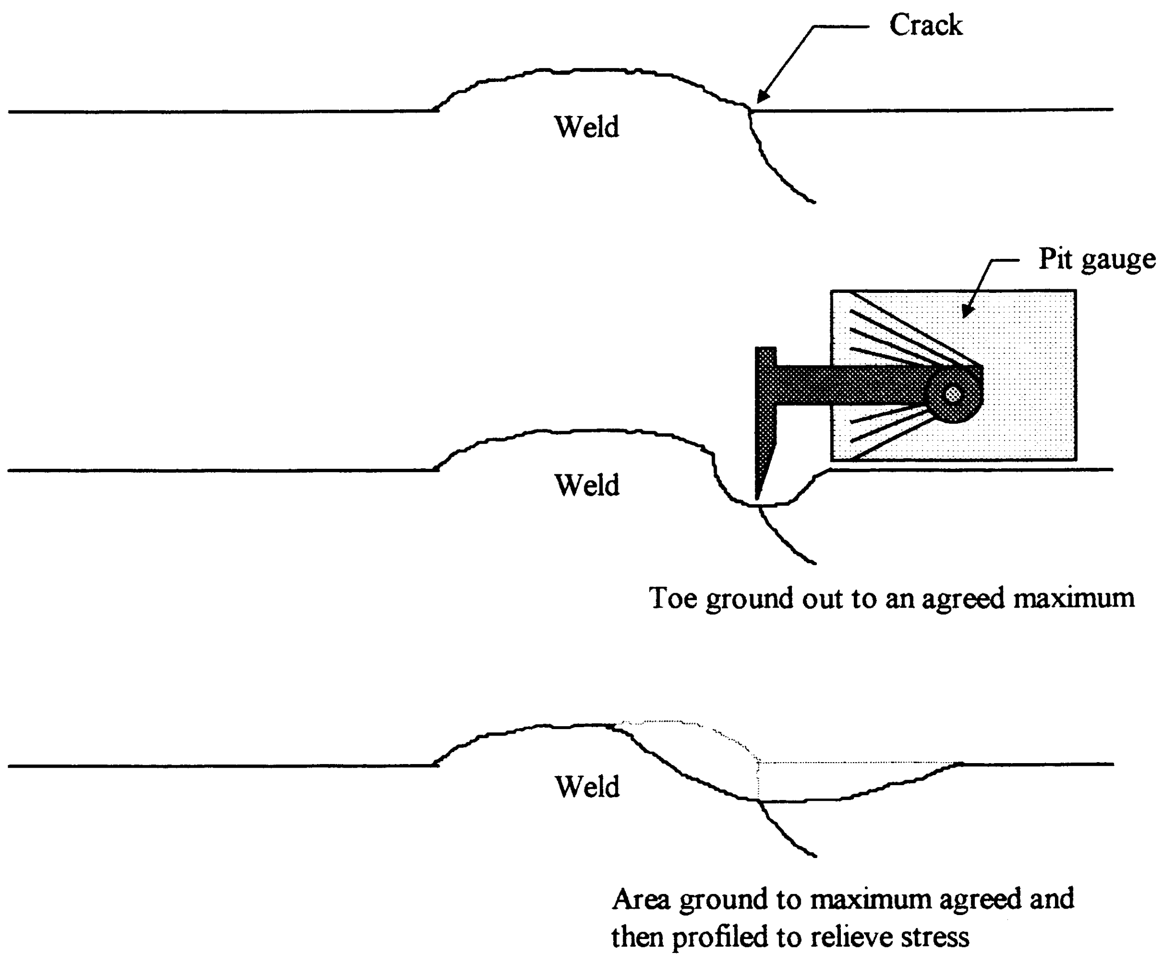


Figure 26.4 Crack Grinding and Pit Gauge Use.

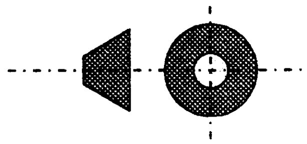
CHAPTER 27

Technical Drawings And Their Use In Inspection

There are a great many ways in which engineering drawings can be produced but from our point of view we need only be concerned with first angle as is the European standard, third angle as in American standards and isometric. All of these are regarded as the industry norm.

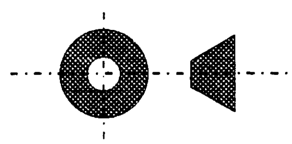
FIRST ANGLE PROJECTION

With first angle projection the view is that which would be seen if looking from the far side of the adjacent view.



THIRD ANGLE PROJECTION

With third angle projection the view is that which would be seen if looking from the near side of the adjacent view.



ISOMETRIC DRAWING

An isometric drawing is a drawing which gives the impression of the viewer being away to the side and slightly above the object on view, this will perhaps help to give an overview of an otherwise complex set of drawings. The vertical lines (or z axis) of the structure will remain vertical in the drawing, but the horizontal sections (x and y axis) will be portrayed at 30 degrees above the horizontal thus giving the impression of depth to the drawing.

All drawings convey information graphically, and as such writing on the drawing should be kept to the minimum.

Titles

Titles should be concise but accurate, they should convey the contents of each sheet using correct terminology.

Numbering

Drawings should be numbered in order to indicate the order of sequence.

TITLE AND INFORMATION PANEL

Every drawing will have a title and information panel, this will normally be located at the bottom right hand corner of the drawing sheet and it should contain the following information:

1. Project title
2. Drawing number
3. Drawing title
4. Description of the projection (maybe the symbol)
5. Scale
6. Date of drawing
7. Office of origin
8. Office project number
9. Identity of draughtsman
10. Approval signature

Technical drawings and their use in inspection.

1. Briefing the diver or ROV - as built drawings may be useless for briefing divers or ROV pilots so it may be better to produce isometric drawings for briefing purposes, the diver or pilot will be able to relate to these much more easily.

2. Technical reference – drawings can be used find the size of members and the thickness of metal etc.

In first angle and third angle projection, there are 3 elevations

Plan

End elevation

Side elevation

There will always be a symbol which should help to tell the difference between projections, it will be located in the bottom right of the page.

So what should be located relating to the drawing will be as follows:

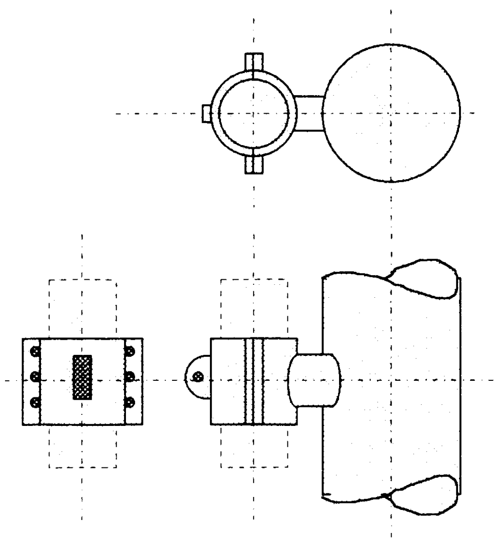
1. Which projection is being used
2. Which lines are there i.e., bold or fine, broken or continuous

Pipe outer will be a bold line inner will be a fine line

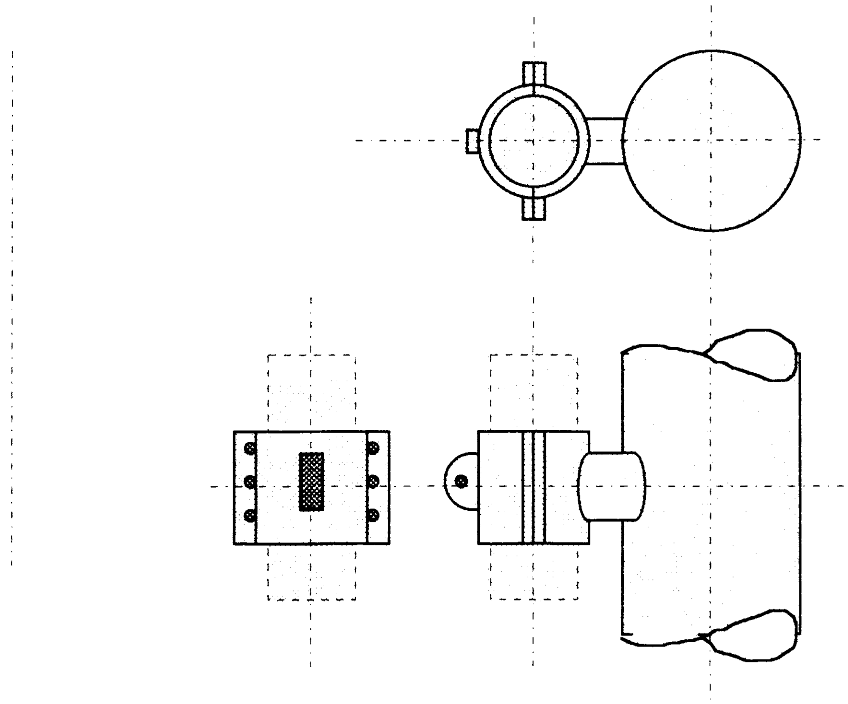
If at any time a copy has to be made of the drawing then be careful as a photocopy can loose fine lines and detail, which of course will render a drawing less readable.

Building up an Isometric drawing from a third angle projection

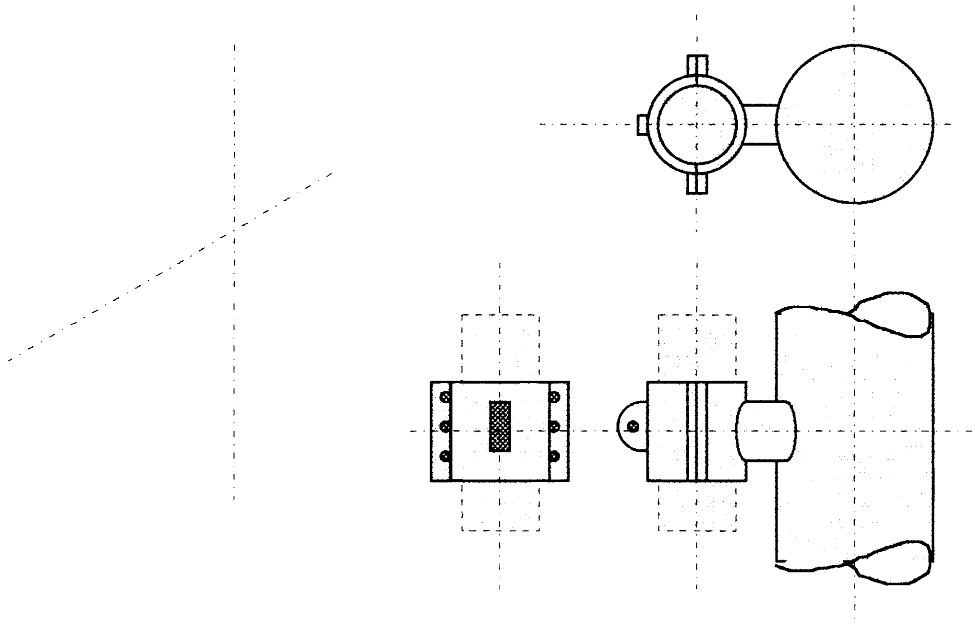
3rd Angle projection



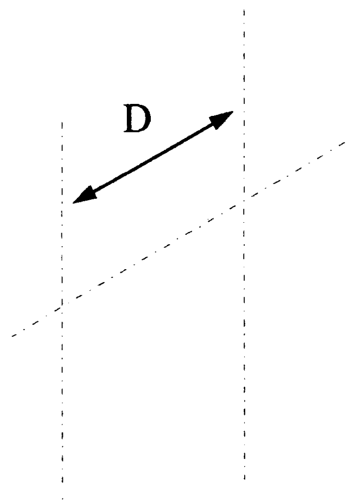
Put in Vertical centreline

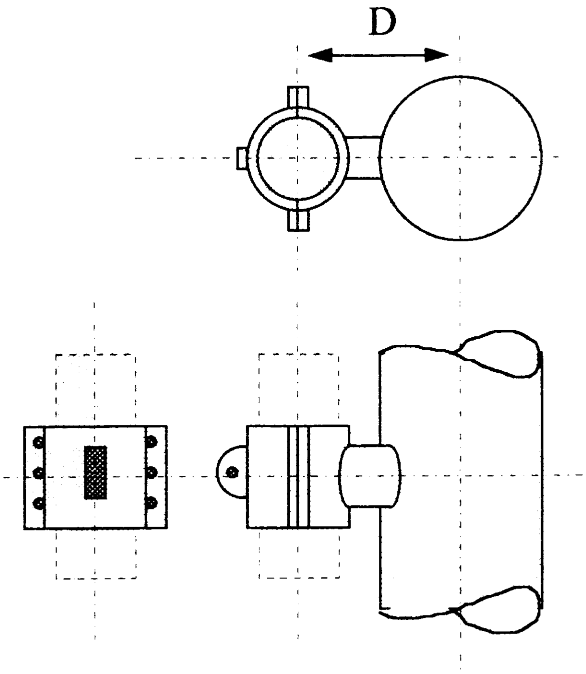


Put in Horizontal centreline

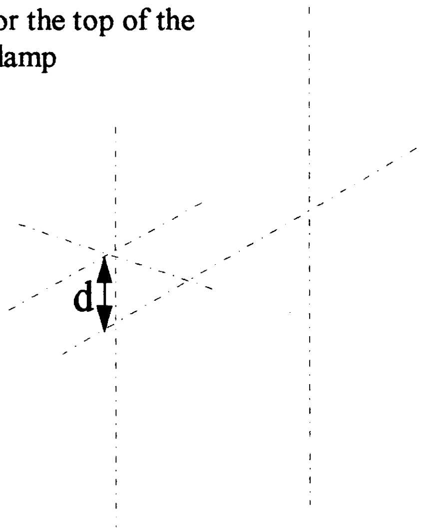


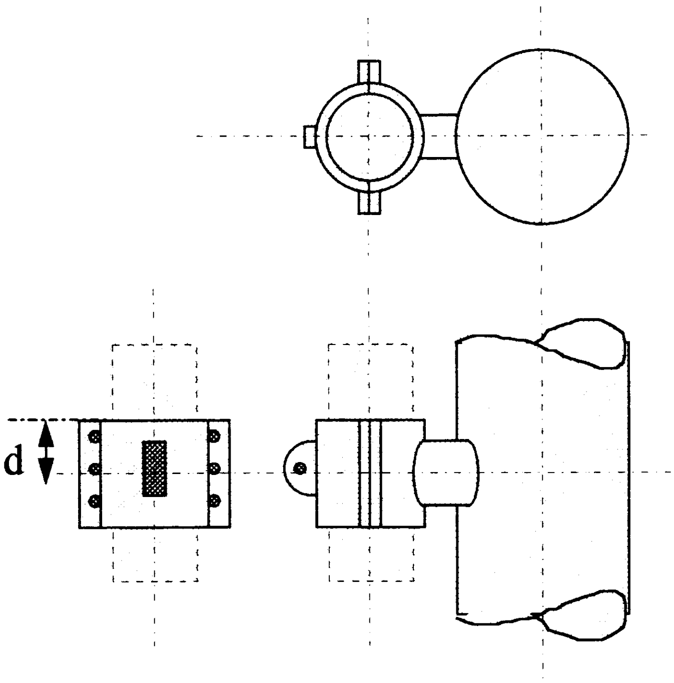
Put in Riser
Vertical centreline



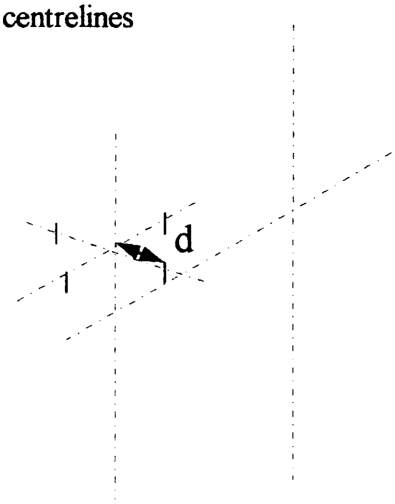


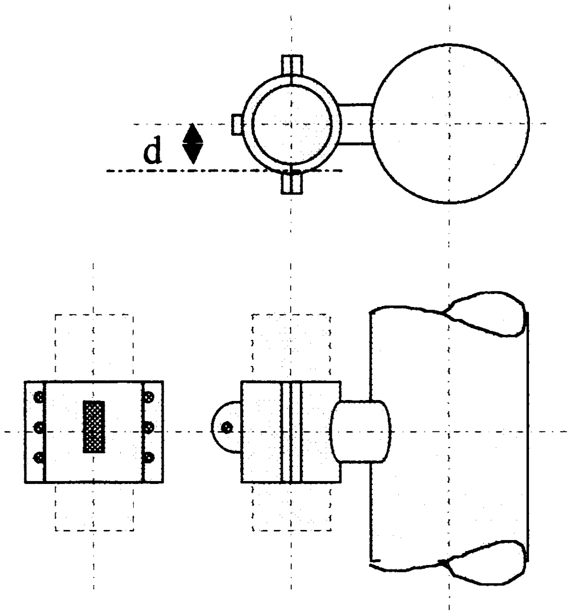
Measure up and
put in centrelines
for the top of the
clamp



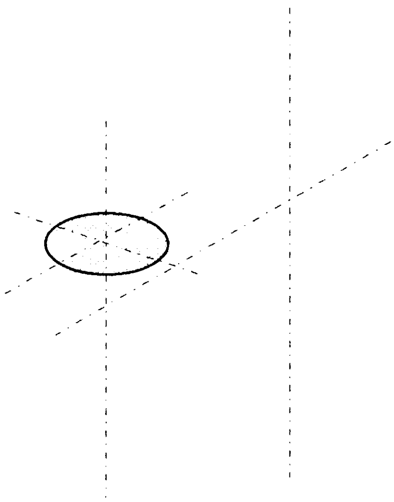


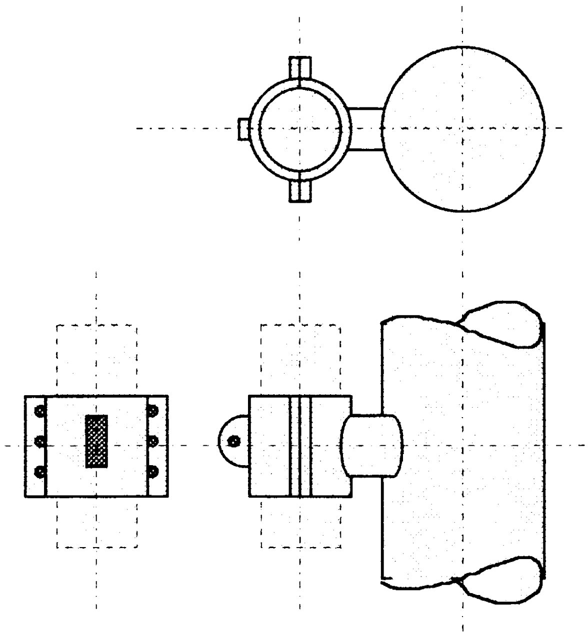
Find the edges of
the clamp on the
top centrelines



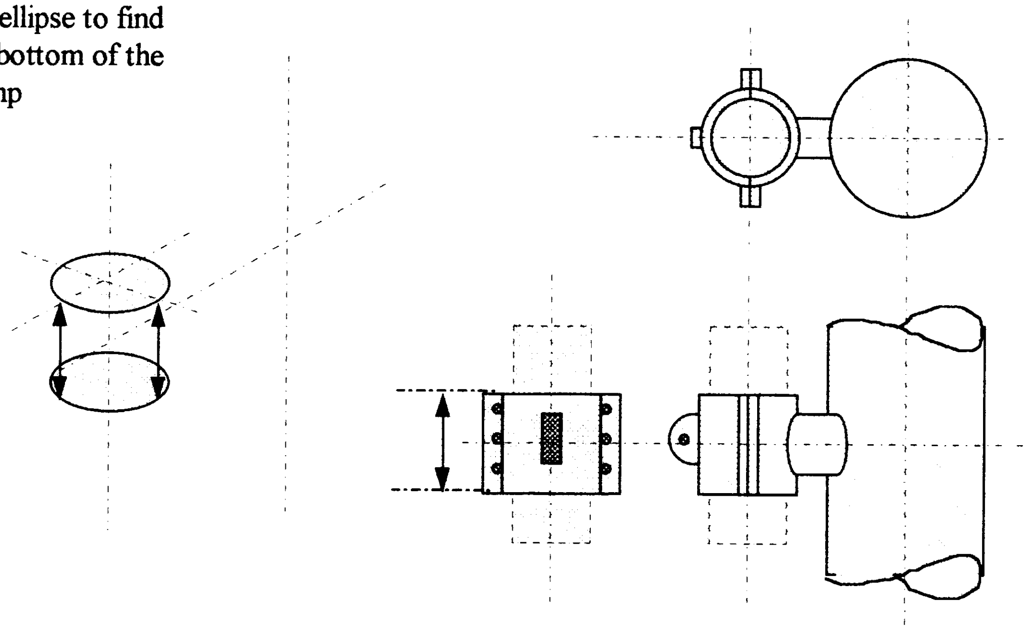


Put in ellipse for
the top of the
clamp

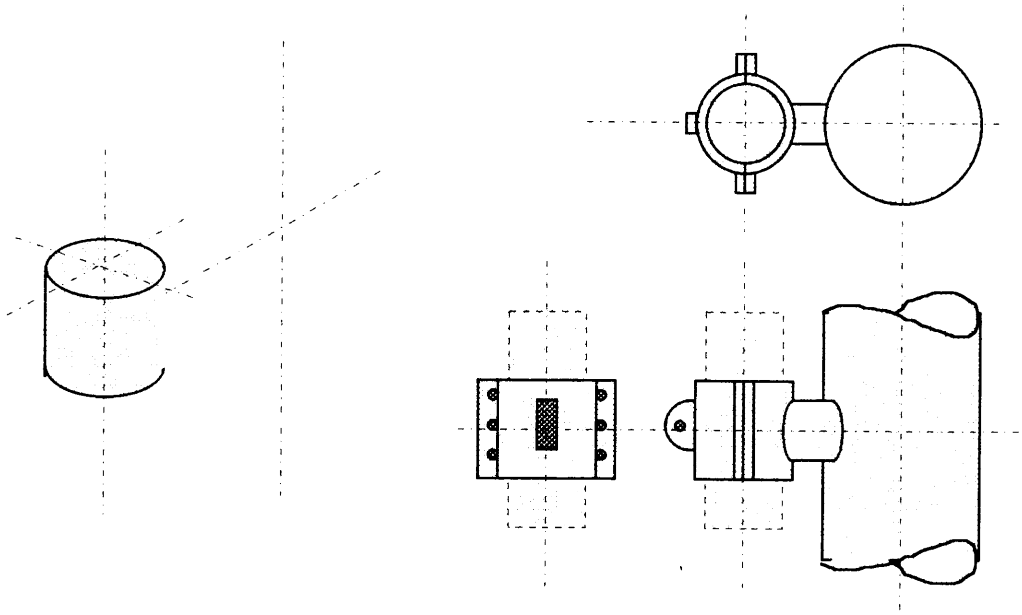




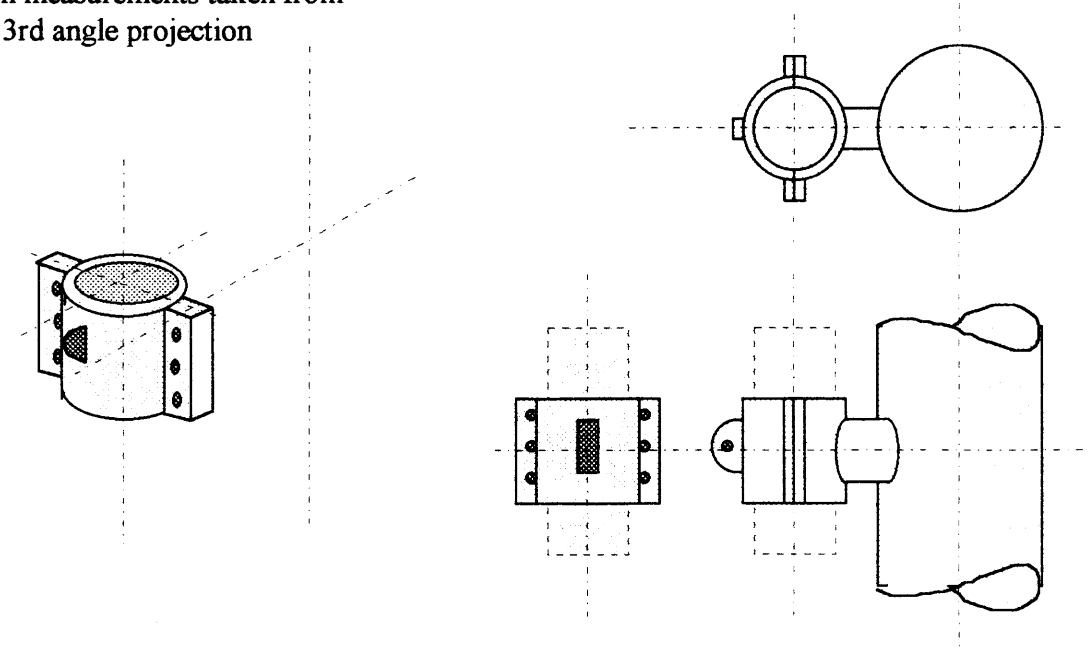
Measure from the top ellipse to find the bottom of the clamp



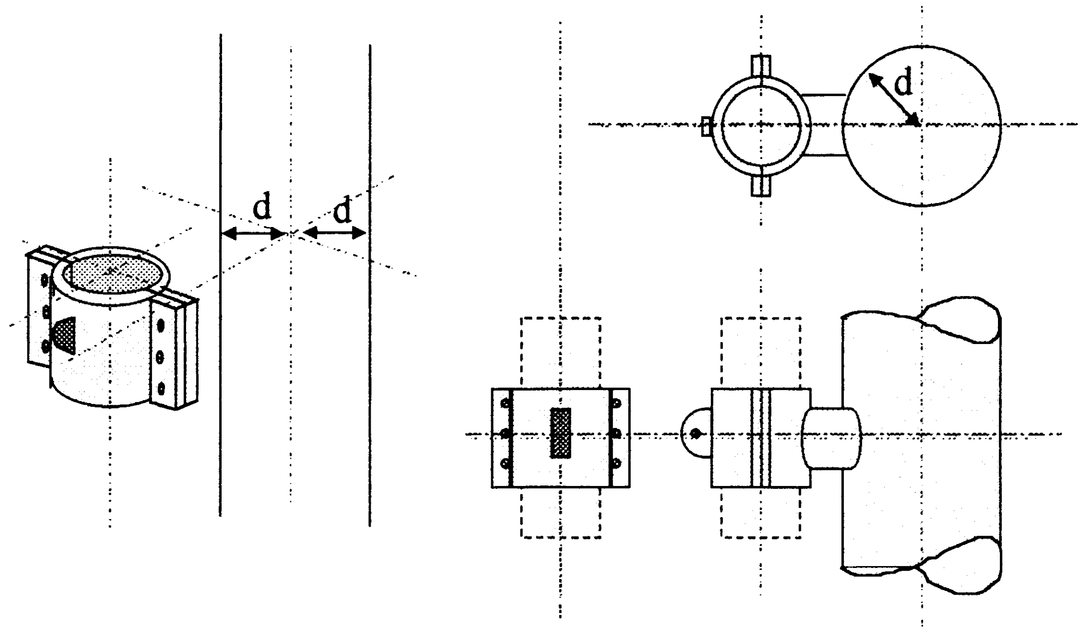
Put in Sides of the clamp



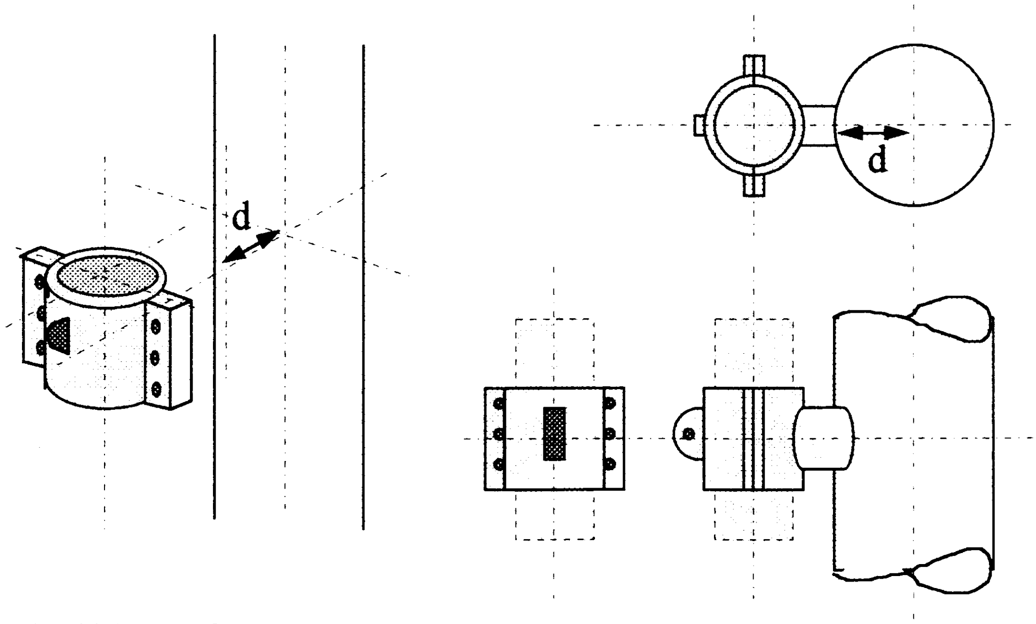
Build up the rest of the clamp from measurements taken from the 3rd angle projection



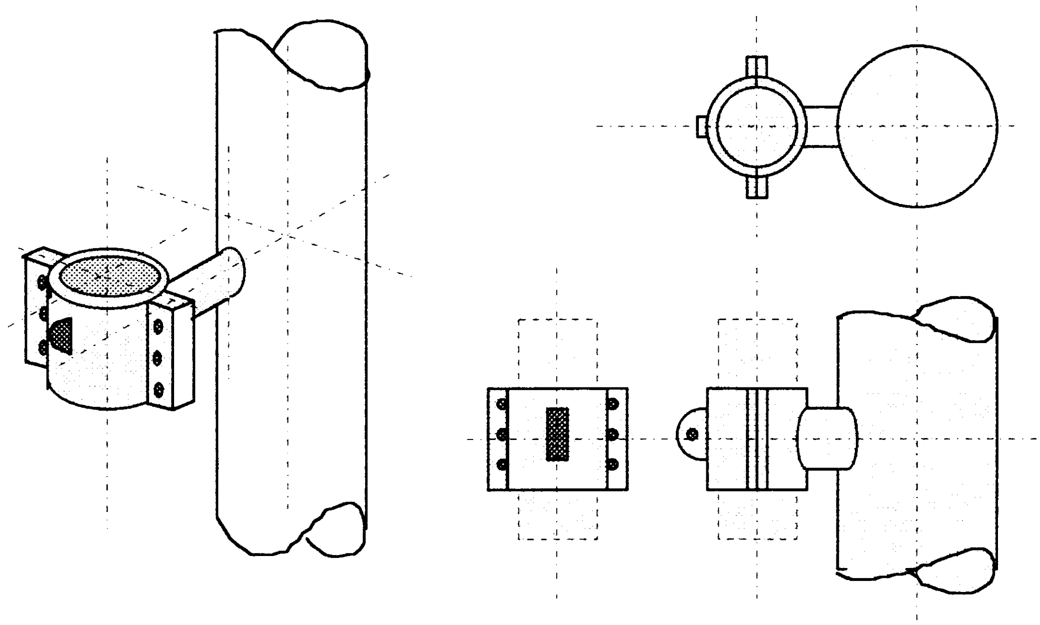
Find the edges of the main leg



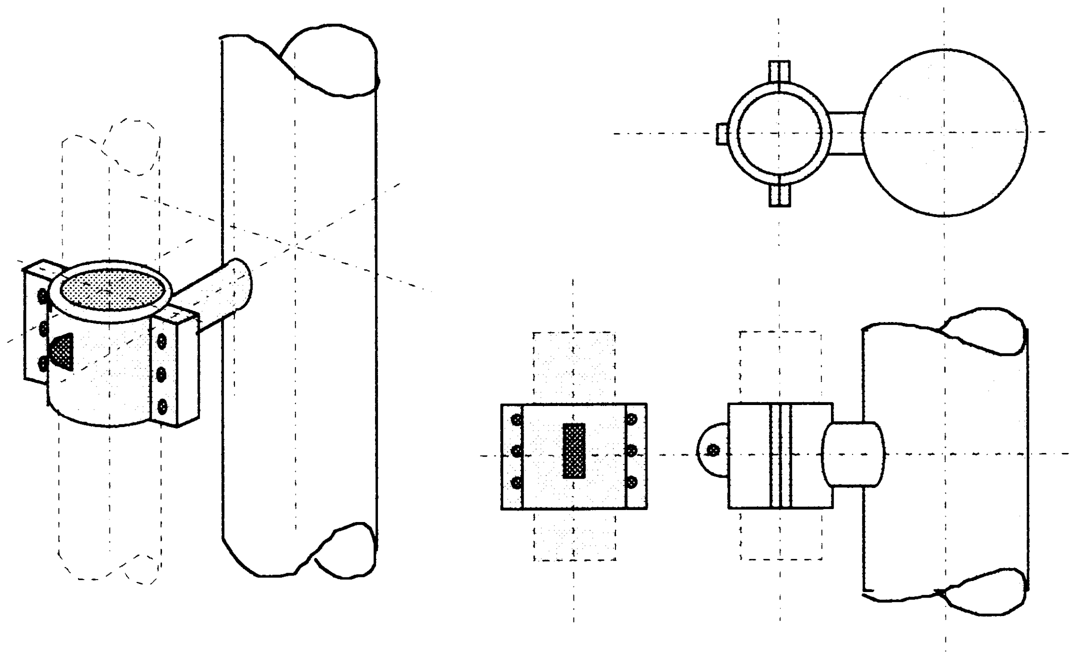
Position the intersection of
the stub



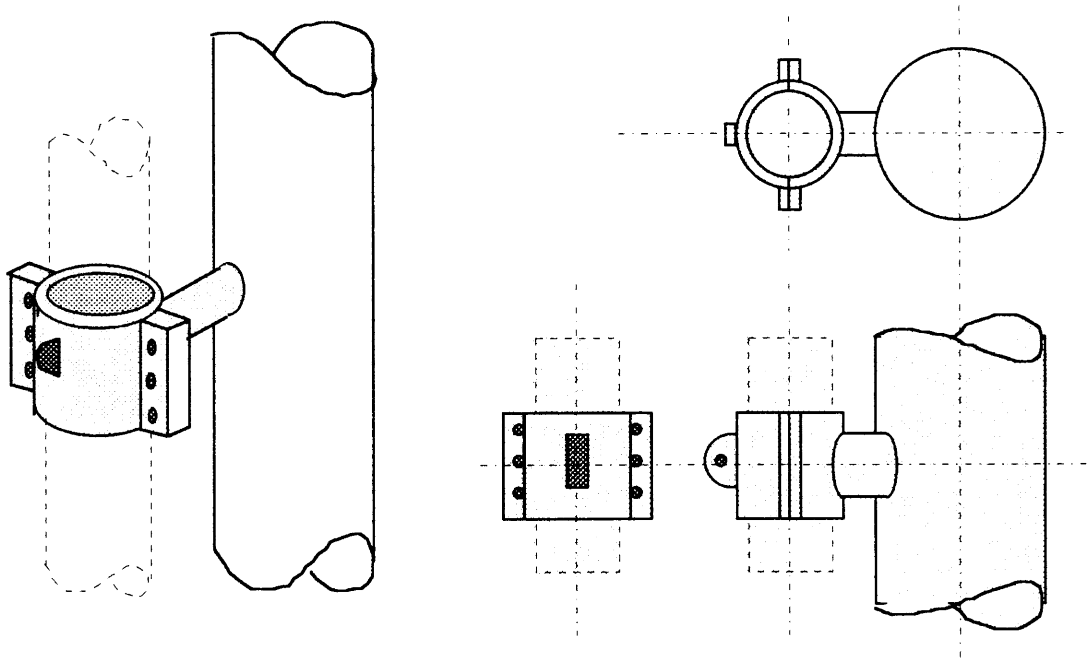
Put in the thickness of
the stub



Put in riser



Remove unwanted lines



CHAPTER 28

Quality Assurance In The Offshore Environment

Quality systems can be split in to two groups i.e. Quality Assurance and Quality Control or QA and QC. The most commonly used standard for Quality Assurance is the International Standard ISO 9000/2000.

The concept for both the above is as follows:

Any structural design suitability will have to be verified by an Independent Verification Body (IDVB). Fabrication will also be monitored by the IDVB prior to launch

In service

1. **Assurance** - Ensuring confidence in the operation or project

Where does it come from?

Procedures ---------------------- Book keeping

Project (could be inspection) -- Design
Manufacture
Materials - consumable's

Personnel ----------------------- Coding - CSWIP etc on file

The procedure will include:

Acceptance criteria and the means by which it can be achieved, they may quote British standards or in house standards. As with everything it will be very important that everything is recorded. To show how this can work the following analogy can be used:

As far as an offshore structure is concerned tubular members are to be used, so welders must be approved for welding of tubular joints, the duty holders engineering department will specify the necessary dimensions of the tubular members to be used, metallurgists will choose the correct metals and consumable's, and all will be joined by welders who are coded for the specific joint variation to be used, and they will be working to specified proven procedures.

Materials - The steel used could be "50D" steel; the specific nature of this steel type will be detailed in the relevant British Standards. Manufacturers of the steel will guarantee the limits of sulphur content, carbon etc.

2. Quality Control - Will be the policing of the whole project and maintaining records of the job.

Throughout a project there will be several definite stages, as can be shown by the following example:

i) Concept

For an inspection contract, the concept will be discussed by the duty holders engineering department and the independent verification body, they will come up with what needs to be inspected (scope of work), also they will decide what needs to be found in order to ensure the structure remains in a safe condition and lastly which inspection techniques need to be used in order to find the defects which could affect the components.

ii) Design

When the concept has been decided there will be a need to design the specific procedures necessary for the inspections to be carried out to the required standards also any data sheets, log sheets and checklist will need to be designed. This may involve designing a computer package to satisfy the needs of the inspection.

iii) Manufacture

Once the inspection programme has been designed all of the paperwork will need to be produced together with any computer programmes in order to allow the findings of the inspection to be recorded using the clients specific methods. Workpacks will be produced for the use of the offshore personnel. There may be specific equipment, which needs to be manufactured at this stage. During this stage it will be important to ensure that Quality Assurance principles are adhered to and also Quality Control will be used to monitor the process. All of this will ensure Quality.

iv) Installation or Mobilisation

This will be the mobilisation of the contract; during the mobilisation there will be a need to monitor equipment installation etc. Audits will be carried out to ensure that there are sufficient consumables and that all specified equipment is available. The inspection controller may be required to comment on the following:

a) Mobilisation procedures
b) Draft procedures before the installation
c) Ensure procedures are followed properly
d) May be involved in ensuring the correct procedures are followed in the transport of individual components
e) Certification of equipment and personnel is documented correctly

v) In service

During the term of the project there will be a requirement to carry out audits from time to time, this may be the responsibility of the inspection controller. The inspection controller will be responsible for ensuring that all data is collected using the correct procedures and is the handled according to the clients laid down requirements. The inspection controller will also need to monitor consumables and ensure that only qualified personnel are used to carry out any task.

INSPECTION PLANNING AND BRIEFING

In order for proper planning to be achieved the following must be taken into account:

1. Interpretation of the requirements
2. Instigation of procedures
3. Gaining of relevant permits (Permit to work and where necessary hot work permits)

Planning

The plan will then start to address the individual issues such as:

i) Where is the item, who can be used to carry out the task (certification), when can the task be attempted, what is to be done and how long will it take.

ii) Keep an idea of the state of play at all times to allow for changes in case of the weather etc.

iii) Must be aware of the work outstanding (affected by the criteria of non-conformance especially in an anomaly-based system).

iv) Be aware of the criteria of non-conformance and the additional work, which will be generated by it.

Inspection briefing

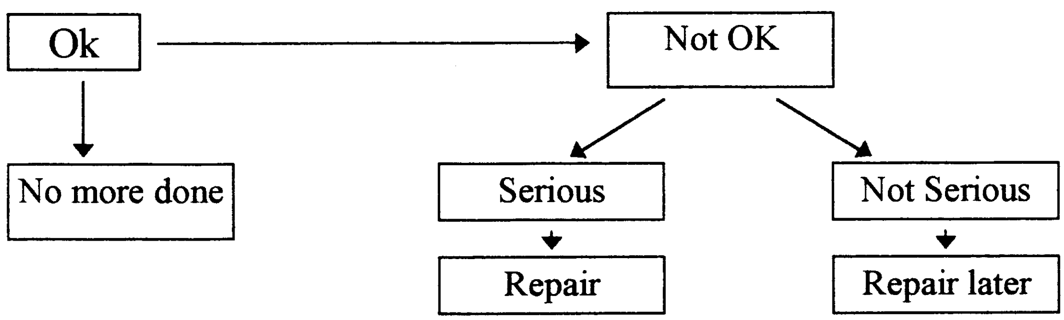
Any briefing will benefit from the Compilation of drawings to locate the component for orientation (use isometrics). Including Drawings of the component itself (isometrics to be used as a substitute for a photos)

	Adherence	The data acquisition
Procedures --------------	Compliance	personnel will need
	Interpretation	to be directed properly

Action to be taken in the event of identification of Anomalies or a non-conformance:

If there is an anomaly found, which falls outside of the allowance given by the criteria of non-conformance then the following, may occur:

a. Flag the report for the item
b. Contact the clients offshore representative
c. Fax or email to shore base
d. Send sketch and report ashore
e. When a crack indication is identified we may be expected to grind the indication to client requirements although while grinding is taking place there should be dialogue to shore base and this should not take place without the permission of the on site client representative.



SUMMARY

All of the above will enable the job to be done quickly and efficiently.

PERSONNEL AND EQUIPMENT CERTIFICATION

The CSWIP scheme is run along the following lines:

3.1U: Grade one inspection diver

This diver will be proficient in the following techniques:

a) Visual inspection
b) Closed circuit television (CCTV)
c) Photography
d) Cathodic potential readings (CP)
e) Ultrasonic inspection using a digital thickness meter

3.2U: Grade two inspection diver

This diver will be qualified and proficient in the 3.1u techniques and also the following techniques:

a) Magnetic particle inspection (MPI)
b) Grinding of weld toes (although this is not an inspection task)

The two grades above are for diving personnel only.

3.3U: Pilot/observer inspector

This will be an experienced ROV pilot or submersible pilot, and will be proficient in the following techniques:

a) Closed circuit television (CCTV)
b) Photography
c) Cathodic potential measurement
d) Ultrasonic thickness measurement using the ROV probe technique
e) Data management and handling
f) Capabilities and limitations of vehicles

3.4U: Underwater inspection controller

The 3.4U will have overall responsibility for the underwater inspection and so will be proficient in the following techniques:

a) Visual inspection
b) CCTV
c) Photography
d) Digital thickness meter
e) Cathodic potential meter readings
f) Magnetic particle inspection
g) Ultrasonic inspection using A'Scan
h) Advanced methods of NDT
i) Data management and handling
j) Capabilities and limitations of divers and vehicles
k) Work scheduling and planning
l) Quality assurance and control

In addition he will be able to liaise with the hierarchy and where necessary this may call for tact and diplomacy.

EQUIPMENT CERTIFICATION

All equipment must be certified according to the law and to ensure that the equipment will work properly, this will involve the following:

i) By law all electrical equipment must be tested every 6 months.

ii) Each piece of equipment must be tested for safety each time it is used, i.e. RCD (Residual Current Device) should be tested at least daily, visual inspection prior to use.

iii) Black lights should be tested for U/V every month, this will be done with a photometer (photometer should be calibrated annually).

iv) MPI ink should be tested at the beginning of each shift or as and when it is made up.

v) All inspection equipment must have the calibration checked before and after use in order to ensure correct readings.

vi) A competent person should calibrate all equipment, after the periods recommended by the manufacturer.

vii) Digital Voltmeter (DVM) to be calibrated annually.

At all times the calibrations should be logged in order to satisfy the quality system.

LINES OF RESPONSIBILITY AND LIAISON

This can be split into two categories:

i) Safety
ii) Inspection

SAFETY

This will normally be the responsibility of either the Captain, Offshore installation manager (OIM) or the Toolpusher, this will depend on the type of installation.

In the case of inspection the route may well be as follows:

DIVER OR ROV CREW
↓
DIVE/ROV SUPERVISOR
↓
INSPECTION CONTROLLER
↓
CLIENTS REP
↓
OIM OR CAPTAIN
↓
SHORE BASED PROJECT MANAGER
↓
CLIENT ENGINEERING DEPARTMENT

In the case of safety the following may be true:

DIVE/ROV SUPERVISOR

↓

CAPTAIN, OIM OR TOOLPUSHER

↓

HEALTH AND SAFETY EXECUTIVE

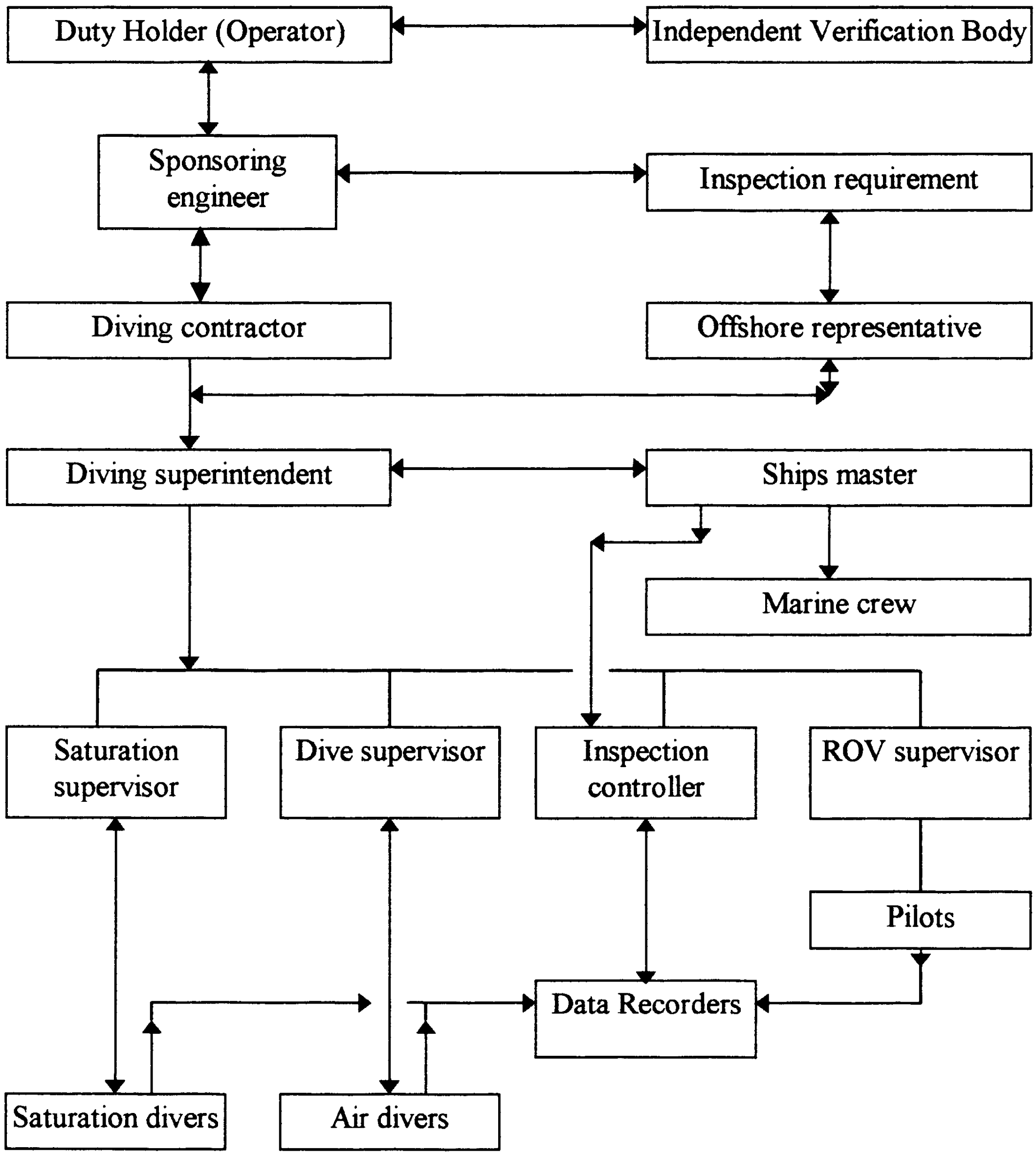
Now these are all just the major routes but of course there will be some minor routes as well, such as in the event of a diving incident there will be a good deal of communication with a diving doctor etc.

At all times all concerned should act with tact and diplomacy, as to antagonise will only cause problems.

CHAPTER 29

Ensuring Methodical Approach During Inspection Programmes

The following is an organogram, which shows a typical contract in terms of the lines of responsibilities.



ORGANOGRAM FOR TYPICAL OFFSHORE CONTRACT

In order for the above to work efficiently all concerned must work together and this will involve people with quite different personalities having to get along, if they do not then the inspection programme will suffer.

THE IMPORTANCE OF DOCUMENTATION AND RECORD KEEPING

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

1. Record keeping

i) Initial data from the diver or ROV, will be recorded in dive control or ROV control, if anomalies are found they will be followed up separately

ii) Recorded on data acquisition forms

iii) Anomaly-based system usually recorded direct onto a computer

iv) Reports drafted from raw data

Right up to this point record keeping is crucial in case we need to refer back!

2. Documentation

i) Reports required for Independent Verification proof

ii) Reports required for structural maintenance and long-term trend analysis

iii) Further routine or follow up inspections are generated as a result of reviewing current reports

iv) New designs are generated indirectly

v) 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.

Documentation and its use for damage management will be crucial to:

i) Update register with new damage

ii) Monitor existing damage

iii) Thereby provide confidence

a) Reassess to ascertain whether repair is required

b) "Manage" the existing damage

CRITERIA OF NON-CONFORMANCE (CNC), THE ABILITY TO RECOGNISE ANOMALIES AND ROUTINE VERSUS URGENT DATA

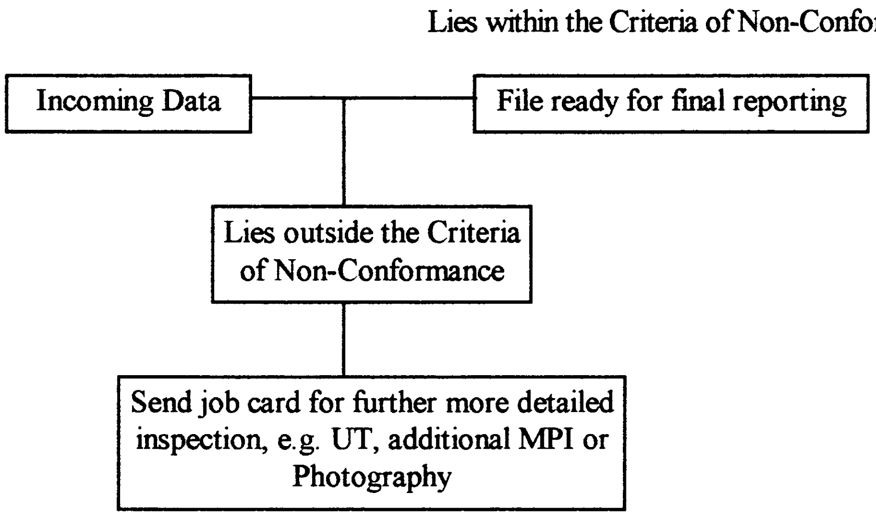
The "Criteria of Non-Conformance" is issued by the duty holders engineering department it defines the point at which a defect found will become reportable. The "CNC" is used by the offshore personnel as a way of deciding what is a problem and what is not, for instance a component may well be damaged in some way which is not seen as significant as far as its affect on the structures performance, this may well not need to be reported in an anomaly based system. Whereas in a full reporting system all information would be recorded in full.

For each inspection field the "Criteria of Non-Conformance", would be **determined by the duty holders engineering department**. The following table is a short list of typical criteria of non-conformance.

Inspection field	Possible anomalies	Anomaly code	Criteria of non-conformance (CNC)
General Visual Inspection	Coating damage Debris Physical damage	CD DB PD	Any Metallic/Hazardous Any
Weld Inspection	Corrosion (Welds)	CR	Greater than 2mm deep
CP Survey	Cathodic Potential	CP	Outside -850mv to -1100mv
Anode Survey	Anode Wastage	AW	Severe >75%
Riser	Leak	LK	Any

The above will allow us to distinguish the difference between relevant data and non-relevant data.

The magnitude of a defect found will determine whether it needs to be reported. The Criteria of Non Conformance is the limit of allowable faults, if a defect found is more than a certain size then it is said to fall **"outside the criteria of non conformance"** and would then be a reportable defect. **So the "CNC" could be said to be the limit of allowable faults on a structure.** If a defect is deemed to be reportable then this will raise a "flag" in the inspection system indicating that there will be extra work needed, this could be either further inspection or immediate remedial work or if it is less serious then may be remedial work to be carried out at a later date. Typically the data will be scrutinised and sorted into two basic categories, routine, or that which lies within specific limits/criteria of non-conformance:



The job card produced may well call for one of the following:

i) Carry out repair if feasible
ii) Carry out temporary repair
iii) Monitor if applicable
iv) Impose restrictions on use of the component if necessary

LONG TERM ACTION

The system outlined for immediate action is useful, in that if planning and decisions are made swiftly resources, which are on site can be utilised e.g. DSV or other diving spread. Long-term action will be necessary in any event. This can provide:

i) Scope of work, procedures and any necessary fabrication for a repair.

ii) Analysis of data to highlight other areas liable to damage or failure.

iii) Level and frequency of inspection monitoring after repair.

iv) Modification of inspection techniques.

v) Modification of inspection programme.

vi) Preventative maintenance from trend analysis (there may not be so much detail available for trend analysis with an anomaly based system).

FOLLOW UP PROGRAM OF WORK

The **INSPECTION, MAINTENANCE, REPAIR** program will be implemented to take all inspection data and formulate a repair or maintenance program in order to assure the structures continued reliability.

On finding an anomaly as detailed in the previous section the inspection controller would follow the further actions and checks as specified by the client and detailed in the technical specification. The following tables list typical examples of the actions and checks that would be called for by the client:

Anomaly	Actions to be taken	Additional checks
AW	Record anode identification and position	CR, CP, DB, LI
CP	Take additional CP measurements to establish extent	AW, CR, DB
CR	Measure corroded area, & cover in area, max and average depth and diameter of pits in the area	AW, CR, CP, DB
DB	Record type, position and dimensions, include a sketch	AW, CD, CP, DB
LK	Record flange identification and location, sketch and estimate rate of loss	PD, LI, DB, CR, SD
WT	Record element and location, take additional WT readings to assess the extent of the area	CR, PD, CP

Key to abbreviations:

AW = Anode wastage.
CP = Cathodic potential readings.
CR = Corrosion.
DB = Debris.
LK = Leaks.
WT = Wall thickness.
LI = Loss of member integrity.
SD = Seal displacement.
PD = Physical damage.
CD = Coating damage.

REAL TIME AS OPPOSED TO RETROSPECTIVE DATA GATHERING

Real time data acquisition involves the gathering and assessment of the information at the time of the inspection.

Real time gathering has the advantage that if there is anything found it can be acted on at once, this means that the ship will still be on site and so any remedial work can be done with minimal cost.

Retrospective data inspection is becoming much more popular these days as the client can keep a record of the inspection done which can be viewed at a later date as many times as is needed.

Retrospective data acquisition will mean that the data will not be assessed on the job site at the time of gathering. This may allow much more information to be gathered in a given time but this information may not be complete, by this I mean that the inspection may show up a possible defect which should be inspected more fully with say another method, but as the data is not interpreted immediately the ship may already have moved on to another location, this means that at the very least the ship will need to be relocated in order to carry out the work.

On the other hand the advantages are that personnel with plenty of time can inspect the component at their leisure, ashore if necessary.

Some of the methods, which can be used, are as follows:

i) Closed Circuit Video
ii) Eddy current
iii) A.C.F.M.

DATA MANAGEMENT SYSTEMS

The data management system will in an ideal world have the potential to define the workscope, produce the workbooks, store data, carry out analysis and produce reports all in the one package.

Workscope - Based on a plan which will satisfy the need for inspection thus satisfying the Independent Verification Body, plus additional work from previously reported anomalies, the system should be flexible enough to incorporate new inspection techniques and procedures by outputting the workscope the system would identify the work to be carried out on each component.

Workbook production

Once the workscope has been defined the system could output blank data sheets, log sheets, anomaly details, inspection procedures, drawings and work monitoring sheets as a complete package.

Data storage

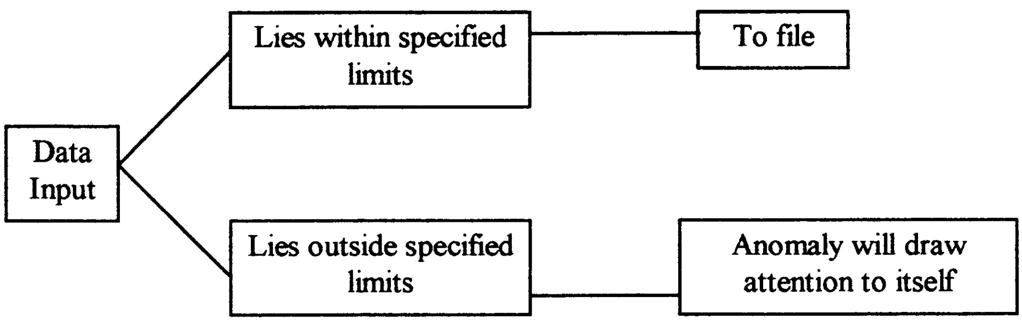
The system should be flexible enough to store all inspection repair and maintenance data using either on-line or off-line input.

Reporting and analysis

The system should be capable of printing the completed data sheets etc set-up during the workbooks production. This facility could include the up dating of drawings as required using the input data. A report writer using various analysis packages could produce reports.

In practice

Presently typical data management systems are used to provide the information required for instigation of immediate or long term action this is initiated by a system of flagging this means that any data entered will lie in two categories as shown below:



A flag is an additional piece of information added to a data item which gives information about the data item itself, this will occur through a flag event which is a condition occurring in a computer program which causes a flag to be set. The condition would be the specified limits or criteria of non-conformance.

DATABASES

Simply these are files of data, in order for the data base to work efficiently in terms of an offshore inspection, the inspection controllers datasheet and the data base input should be as similar as possible, it should be.

i) User friendly

ii) Have only one master point at which the database can be modified, although there may be many terminals into which information can be entered, all information entered will be logged through the main computer which is probably based in the co-ordinators office.

iii) Have a network allowing access to all areas within the database.

TREND ANALYSIS

Computerised data storage in a database system allows trend analysis to take place for more easily than using a manual system, for example CP values can be analysed for trend by using:

i) Colour representation on diagrams, which allows instant trends to be visualised.

ii) Actual values can be compressed onto one diagram.

iii) Histograms and other graphical and statistical manipulation of the data can show averages and ranges.

WORKSCOPES, TECHNICAL SPECIFICATIONS, PROCEDURES

Technical specification

This is a document which will contain all design/fabrication drawings (as-builts) it will also contain the procedures for inspection and any other tasks such as remedial grinding, in short the specification is the place where we look for the technical information regarding the structures (such as wall thickness).

Scope of work

Designed to precisely identify where the work is to be done during the next inspection, this can be simply presented as a complete task code listing, as a written statement or in a tick box format, the exact format will depend on the client.

It should not change from year to year thus it needs to be flexible

Task code listing

The use of task code listing enables each inspection task to be identified in a concise shorthand manner for record and reporting purposes; it will simplify the monitoring of the inspection programme. The level of operational reporting will be determined by the degree of refinement of the task numbering system.

It should be logical and capable of development to convey all the required information; each task will be allotted a group number in sequence from the established workscope and technical specification.

Task	Task code group
General swim round	100
Weld inspection	200
Marine growth survey	300

There may also be a prefix to denote the platform and type of intervention technique to be used i.e. for ROV it may be R200 for a weld inspection by ROV. This means that on this platform there can be 99 weld inspections by ROV from R201 to R299.

Workbook

This is the most important document to the inspection controller all operators have their own approach to the work pack and subsequently a large variety of formats exist, it should contain all the documentation necessary to carry out the inspection offshore, it will contain:

i) The inspection programme allowing the controller to schedule the inspection activities.

ii) Platform drawings indicating areas to be inspected.

iii) Inspection procedures to be used, detailing how to inspect with what equipment and using which technique.

iv) Datasheets for the recording of inspection data normally tailored to suit the particular inspection being undertaken and general non-specific datasheets video logs photologs etc.

The most basic workbook will contain five sections as follows:

i) Workscope gives information as to the specific inspection to be carried out and the locations where this inspection will be required.

ii) Technical specification, this gives detailed information as to wall thickness, brace diameter etc as well as Inspection equipment to be used and format in which data is to be reported (e.g. pipeline data may be required in UKOOA format)

iii) Field and platform data: This will be all the relevant data relating to the field such as platforms and pipelines will be listed together with structural drawings illustrating all facets of the platforms, risers, caissons, conductors and cathodic protection systems. Environmental information would be detailed for each platform in the form of water depth, tides, currents and seabed conditions. As built drawings etc that will be used for planning work and locating specific items for inspection etc. Field drawings, pipeline track data used during inspection of pipelines etc.

iv) Anomaly report and additional inspection programme: This will detail the clients philosophy and the criteria of non-conformance together with the step by step actions and checks to be followed should an item be outside the stated criteria. Specifically this will include details of the client's anomaly types, anomaly criteria, details of how anomalies are to be reported, and any extra inspection required to be carried out when anomalies are located.

v) Datasheets & Log sheets: Would contain all the datasheets as required these may now be in computer form, these sheets/computer data entry forms will prompt the inspection personnel to record all the relevant information required by the client efficiently. Standard data sheets (manual or computer generated) can still be expected where sketches of anomalies or MPI or EMD results have to be reported. Log sheets are general sheets, which will need to be included such as video logs, and photo logs.

PROCEDURES

In practice all items contained in the workscope are inspected and **<u>the fact of their inspection must be recorded</u>** if the method used is the anomaly based system then only components, which fall outside the criteria of non-conformance, will be reported in detail.

The procedure for inspection will dictate the exact method by which a particular inspection is carried out and with what equipment, it should be followed exactly, it may also indicate the method of reporting or further action regarding an anomaly.

Keeping track of the inspection can be very difficult, but if we do not have a simple method something may well be missed. The following spreadsheet system may well help:

Co-ordinate reference	Visual	MPI	CP	Photo	ACFM	DTM	FMD
NJ56	✓	✓		✓			
MF55	✓		✓			✓	✓
FF31	✓		✓		✓		
MF49	✓		✓		✓		
NC14		✓		✓	✓		

The above indicates the level of inspection, which would be needed at the Co-ordinates, mentioned, for instance MF49 would require Visual inspection, Cathodic Potential readings and ACFM, this would be built up from the workscope. When the inspection progresses the crosses can be modified to show that this particular part of the overall plan has been completed.

CHAPTER 30

Report Writing And Daily Log Précis

Report writing - The format of a report will normally be dictated by the clients requirements, but it should typically have the following components:

1	**Title**:	This should be as short and as descriptive as possible, it is usually presented as a frontispiece 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, 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.
5	**Summary**:	Should be a highly condensed précis of the report to enable the engineer to skip reports which do not need his attention. It should indicate the following: i) The extent of the report. ii) The findings of the writer.
6	**Results**:	The main body of the report, should be concise but clear and include all photographs etc.
7	**Conclusions**:	May not be required, if required they should follow from the facts logically, opinions can be include but you must make sure that they are just 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.
9	**References**:	Should list all material relevant to the report which has been drawn on to provide additional background data or support.

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:

i) Copy of the workscope
ii) Raw data sheets
iii) Sketches
iv) Calculations
v) Printouts

DAILY LOG PRÉCIS

The specific content of a daily report will depend on the client but typically it will be used to record diver/ROV activity over a 24 hour period and also vessel movements, it will be split into the following categories:

i) Non-diving activities including delays
ii) Diving activities
iii) Diver activities
iv) DSV activities

Data Sheets, Log Sheets, Video/Photo Logs, Photographs And Sampling As Recording Methods

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 certifying authorities we must record the details of the inspections, there are several methods currently in use offshore and 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.

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

Written reports, most of the information from an inspection program will ultimately be presented to the client in the form of a written report but 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 as is the most common, or the diver could transfer the information from his underwater scratchboard on to paper in order to make a written report of the inspection.

3. Photography.

Both of the above methods have relied exclusively on the divers interpretation during the inspection, photography is a method 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 the need 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, 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 on the other hand 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 for this is that 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 but 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 transport 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, can also be used to record the results of a magnetic particle inspection by trapping the particles in the cast enabling the position 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 of the diver with regards the interpretation of weld inspection, the route that seems to be most likely is to use electro magnetic methods in which the topside operator will both record and interpret 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 somewhat better conditions than the diver would have had, this leaves the diver as little more than a probe pusher and some of the systems are likely to be deployed by R.O.V.

SAMPLING

This is used extensively for marine growth and seabed analysis and involves the recovery of a small piece, which must then be labelled properly and included in the final reports.

CHAPTER 31

Communications Above And Below Water

Introduction

The need for good communications is of course paramount especially where divers or submersible pilots are concerned, if the communications are not good then it will be very difficult to interpret results.

Diver or Sub sea communications:

1. Rope signals (useless)
2. Two wire press to talk
3. Round robin
4. Through water comms

Communications will obviously need to be kept serviceable and so the need for programmed down time may need to be liaised with the controller and perhaps the company representative, this may be another advantage of ROV as there is no sub sea communications needed.

Topside communications:

The communications topside will consist of the following:

1 Telephone
2 Two way intercom (open line comms)
3 Walkie talkies
4 Ship to ship radio
5 Ship to shore radio
6 Satellite communications
7 Cellphone
8 E-mail

The communications will need to be good between the dive control and the ROV suite (ROV's can not be recovered or deployed without the permission of the dive supervisor), dive control and D.P. bridge, ROV suite and D.P. suite, crew working on the deck related to the diving operation (crane drivers etc).

If using radio communications the following technique should be applied:

i) Always give precedence to distress or urgent calls
ii) Do not jam channels with unnecessary conversation
iii) Avoid interrupting
iv) Avoid swearing
v) Try not to "um" or "er"
vi) Speak steadily and slowly
vii) Do not shout or mumble
viii) Where possible use procedure words or correct terminology

The Phonetic alphabet can be a good way of conveying a message if communications are poor, as it can help the other party to understand if the word is spelt out. The following is the phonetic alphabet:

A - Alpha	N - November
B - Bravo	O - Oscar
C - Charlie	P - Papa
D - Delta	Q - Quebec
E - Echo	R - Romeo
F - Foxtrot	S - Sierra
G - Golf	T - Tango
H - Hotel	U - Uniform
I - India	V - Victor
J - Juliet	W - Whisky
K - Kilo	X - X-ray
L - Lima	Y - Yankee
M - Mike	Z - Zulu

In addition the numerals can be pronounced in a special way so as to make them more understandable:

0 - Zeero	5 - Fiver
1 - Wun	6 - Sickser
2 - Too	7 - Sehven
3 - Thuh-ree	8 - Ate
4 - Fow-er	9 - Niner

All figures should be preceded by the word "figures"

CHAPTER 32

Aural Examination Of An Object

Aural explanation is not in itself hard, the problem is what questions to ask, all questions must be relevant and designed to lead on to a final adequate description of the item. The key is to have a methodical plan of attack; this will mean that some questions will always be asked for each different component:

1 What material is it made of?
2 How big is it
3 What shape is it?
4 Can you see damage?
5 Are we close or at a distance?
6 Is there scale in the picture?

And so on until the object or defect can be identified, **always make notes** and refer to them.

CHAPTER 33

Engineering Description Of A Component

During the CSWIP 3.3U or 3.4U examination there will be a requirement for a written description of a component. A photograph of a feature will be provided and the candidate will have to write a description of the feature. It is most important to note that this is **not and inspection** and as such marine growth etc can be ignored.

When putting together the description the following should be taken into account:

1 From what material has the item been constructed, this may need to be an educated guess i.e. if it is a clamp then the most likely material of construction would be steel.

2 Describe the specific features of the item.

3 For what purpose has the item been constructed?

4 What method of manufacture has been used, i.e. is it welded or bolted or perhaps both methods have been used.

5 Is there any evidence of corrosion protection methods, perhaps there is a sacrificial anode visible or maybe there are bonding leads etc.

6 Are there any redundant items visible such as pad eyes or redundant installation equipment?

7 Can any bolts, liners or associated items be seen in the photograph?

The candidate will have to write a short description of the component taking into account all of the above points, the description will need to be written using not more than one hundred and fifty words.

CHAPTER 34

Intervention Techniques Employed Offshore For The Gathering Of Inspection Data

The Statutory Instrument SI 2776 (1997) governs commercial diving, or diving for commercial gain, in the United Kingdom, this is the instrument which implements the health and safety at work act. This is actually achieved by implementation and use of **Approved Code of Practice (ACoP)** of which there are five, each covering specific diving fields, these are as follows:

1 *Commercial diving projects offshore*
2 *Commercial diving projects inshore*
3 *Media diving projects*
4 *Recreational diving projects*
5 *Scientific and archaeological diving projects*

Intervention techniques can be split into the following groups:

1. Air divers
2. Saturation divers
3. Remote Operated Vehicles
4. Manned submersibles

To properly understand the advantages and limitations of the above we should look at some of the physical problems, which will face a diver as he enters and descends into the water. The most significant of these are as follows:

Pressure

The unit for pressure measurement is the Bar (1 bar = 1000 millibar), it will be measured either as absolute or gauge pressure.

Absolute pressure will take into account the pressure exerted by the air in the atmosphere i.e. there is one bar of pressure at the surface of the sea, this pressure is wholly because of the column of air above.

Gauge pressure is a measure of the increase of pressure over the one bar at surface in other words the gauge pressure ignores the atmospheric pressure at the surface, every increase of 10 metres depth in seawater will increase the pressure by 1 bar thus at 10 metres the gauge pressure will be 1 bar and the absolute pressure will be 2 bars.

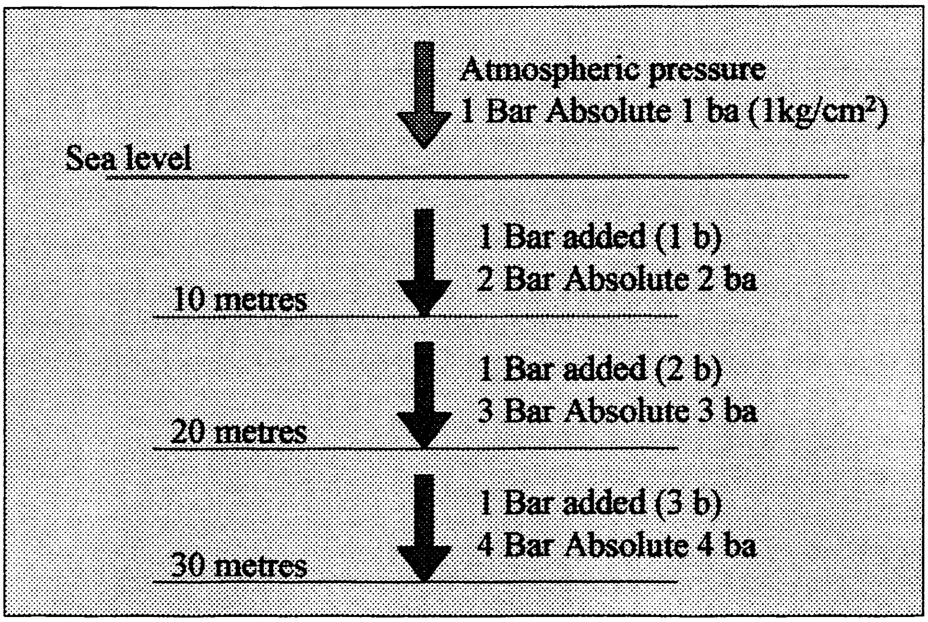


Figure 34.1: Pressure increase with water depth.

THE GAS LAWS

Because all gasses physically react in a similar way it is possible to have one set of laws governing all gasses.

There are three factors, which govern the actions of gasses these are:

1. Temperature
2. Pressure
3. Volume

BOYLES LAW - States that as pressure acting on a gas increases the volume of that gas will vary inversely provided the temperature remains constant.

This means that as the diver descends the pressure on his body will increase and the volume of air trapped in his suit, lungs or indeed any gas filled container will decrease. At 10 metres the volume will be half what it would be at the surface, as the pressure has doubled.

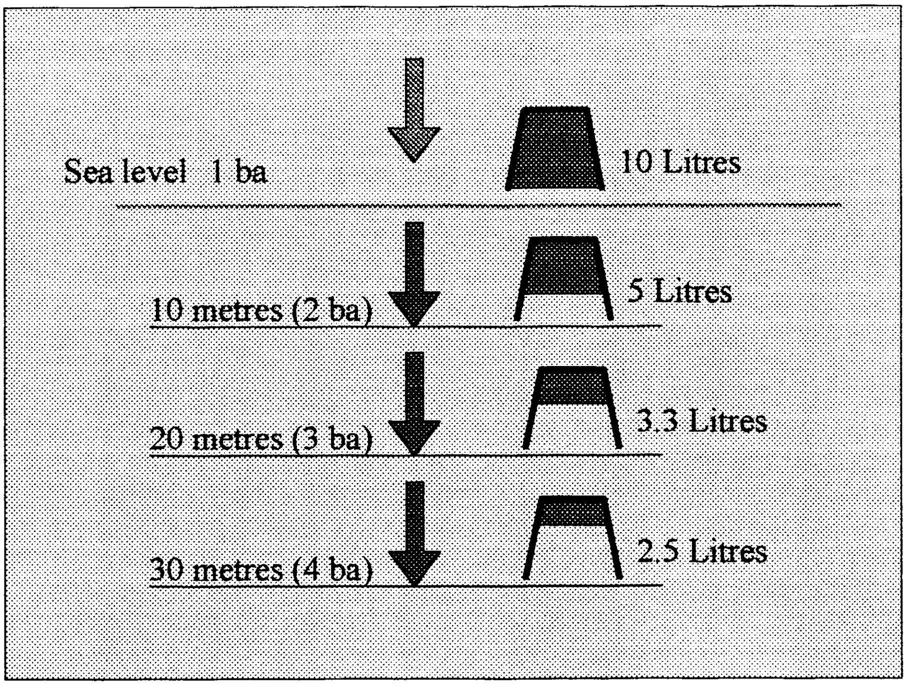


Figure 34.2: Boyles law gas volume change with increasing depth.

BAROTRAUMA

Barotrauma means Pressure Injury. As can be seen from Boyles law above as the diver ascends the pressure on his body will reduce, this will allow the gas which is inside of his lungs, ears, sinuses and other spaces in his body to expand, if this is allowed to continue without the diver being able to relieve the pressure then damage will follow i.e. burst lung, ear damage etc.

CHARLES LAW - States that the amount of change in either pressure or volume of a gas will be almost directly proportional to the change in absolute temperature.

This will mean that as the temperature increases then either the pressure or volume will also increase.

DALTONS LAW - States that the partial pressure of a gas is the pressure, which it would exert if it alone occupied the total volume of the container, or the total pressure will be the sum of the partial pressures of the mixture of gasses.

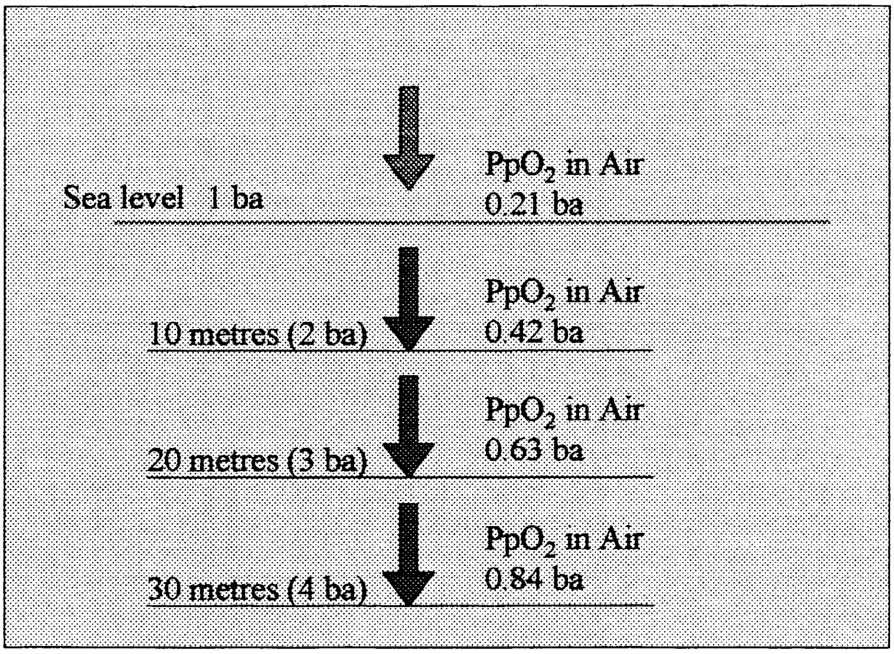


Figure 34.3: Daltons law partial pressure increase with depth (air breathing).

It is the partial pressure of the gas which affects the toxicity on the body, and as such the pressure must be kept within specified limits especially oxygen (IMCA limits the partial pressure to no more than 1.5 bars absolute when a diver is in the water).

OXYGEN (O_2)

Oxygen is necessary to support life, we will need about 0.5 litres per minute for our metabolic needs, but we cannot cope with too much pressure. If the partial pressure is allowed to rise above 1.6 bars absolute while a diver is in the water then the Oxygen will become toxic.

CARBON DIOXIDE (CO_2)

This is a waste product of our metabolism and is produced in roughly the same quantities as we consume oxygen (0.5 litres per min at rest), the partial pressure should not be allowed to increase above 20 millibar.

CARBON MONOXIDE (CO)

This is a product of combustion and is extremely toxic, Haemoglobin in the blood which is the vehicle used by the body to transport oxygen around the body has a far greater affinity for CO than Oxygen (approximately 200 times greater) consequently the concentration of CO should be kept as low as possible (Less than 1 part per million PPM).

NITROGEN (N_2)

Nitrogen will have a narcotic effect as partial pressure increases; this is the main reason why air diving in the UK is restricted to 50 metres maximum, beyond that depth Helium will normally be used as the dilutant gas for Oxygen.

HENRY'S LAW - States that the amount of gas, which will dissolve in a liquid, will be almost directly proportional to the partial pressure of that gas.

This will mean that if 1 litre of gas will dissolve at a partial pressure of 1 bar then 6 litres of gas will dissolve if the partial pressure of the gas is taken to 6 bars.

DECOMPRESSION

Owing to Henry's law when a diver descends and increases the pressures on his body, the amount of gas, which is dissolved in his body, will increase. In order to allow this gas time to safely come out of solution the diver will have to come up slowly in a controlled fashion thus allowing the gas to be expelled via the divers lungs. This is the basis of decompression, the first useable tables were those produced by J.S. Haldane who had worked out that it is the inert gas in the mixture which is going to cause the most problems to us as we are constantly using the Oxygen in our tissues so the Oxygen will never become saturated in the tissues.

If a diver ascends too quickly then the gas in his body will not have time to escape safely and so the diver will suffer from decompression sickness (the bends), this will mean that bubbles of gas have come out of solution in his body and are lodged at some location. Depending on the location will dictate the seriousness of the condition. For this reason any diver will need to have access to a decompression chamber for at least 12 hours after completion of his dive in case of symptoms becoming apparent.

One other principle is important to diving and that is Archimedes principle.

BUOYANCY

ARCHIMEDES PRINCIPLE - States that the weight of liquid displaced by a body wholly or partially immersed will be equal to the upthrust experienced by that body.

This means that as the body is lowered into the water it will displace some liquid (equal to its own volume), if this liquid is weighed then the body will experience an upthrust equal to the weight, this upthrust can be subtracted from the weight of the object to give an apparent weight of the object in water. There are 3 states of buoyancy:

1. Positive buoyancy - Upthrust exceeds the weight of the object in air
2. Neutral buoyancy - Upthrust is exactly equal to the weight of the object in air
3. Negative buoyancy - Upthrust is less than the weight of the object in air

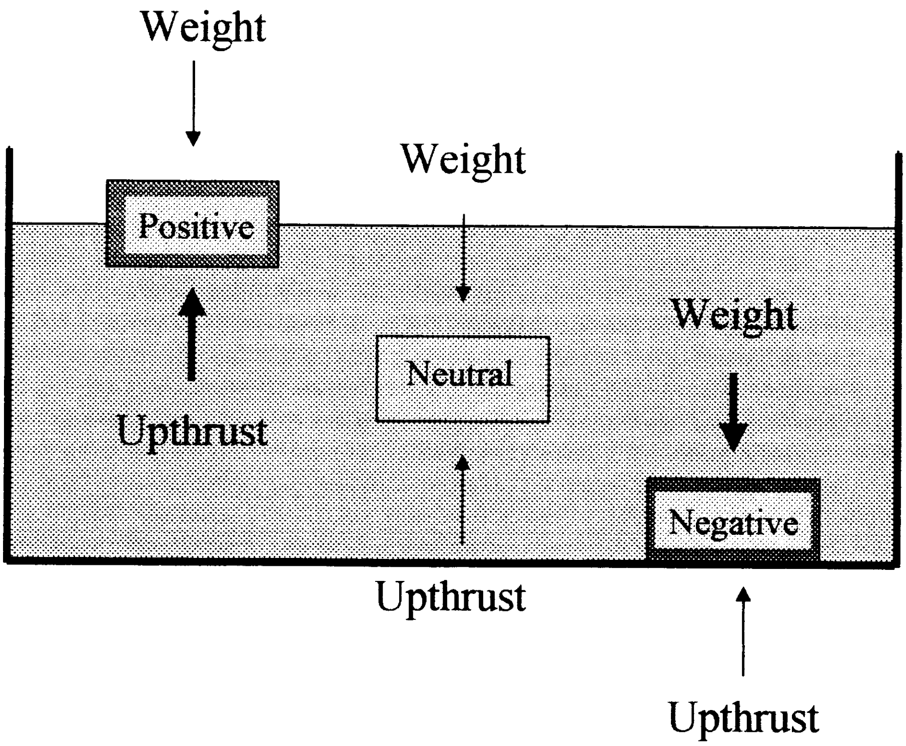


Figure 34.4: Archimedes principle, states of buoyancy.

AIR DIVING:

Air diving is limited to 50 metres depth by law, the main reason for this is Nitrogen Narcosis, if air is breathed at higher than 3.5 bars absolute pressure (approximately 30 water depth when breathing air) then the diver will experience some narcotic effects brought on by Nitrogen. Also the deeper the dive the shorter the time available, this is because of decompression needs. Air diving can be carried out by using the following techniques:

Self Contained Underwater Breathing Apparatus (SCUBA)
Surface Demand Diving (SDDE)
Wet bell
Mini bell

SCUBA diving

SCUBA is limited owing to the fact that the only air the diver has is contained in a bottle on his back. This system is not recommended for use offshore at all.

Surface Demand Diving Equipment (SDDE)

Surface demand diving equipment can be used to a maximum depth of 50 metres in the North Sea. The diver is supplied with all the required services via an umbilical that is running directly from the diver to the surface. This kind of diving will normally utilise a divers Basket for deployment, this is little more than a basket into which divers climb in order to be lowered into the water, there will be a small amount of "onboard gas" in the basket for emergencies, but there should be no other equipment carried in the basket.

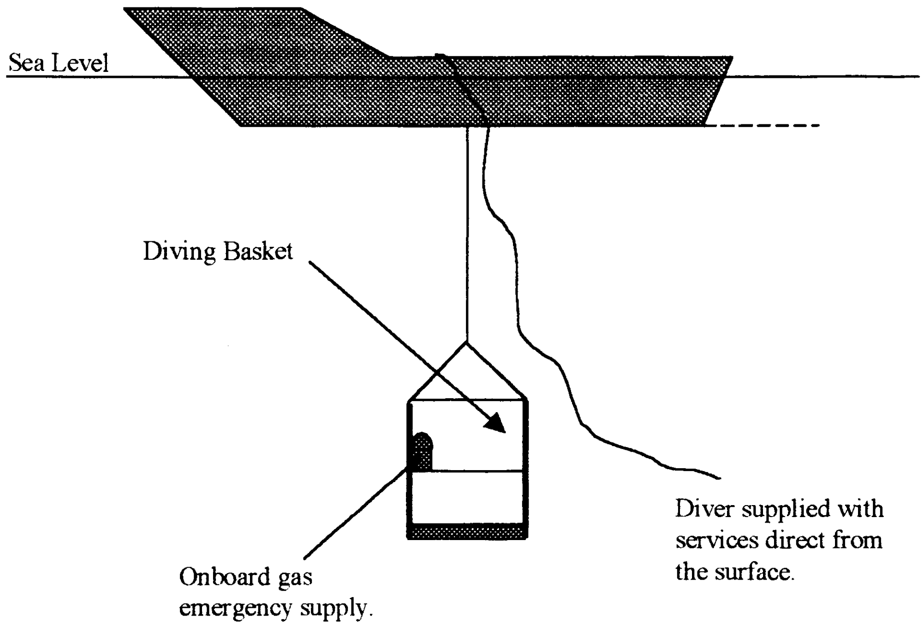


Fig 34.5 Diving Basket.

Wet Bell Deployment

The wet bell is an open device, which can be used to give the divers a relatively safe haven at depth. The Wet Bell consists of a frame into which the divers can stand, when in the bell the divers heads will be able to reach a pocket of air trapped in the dome of the bell. The divers are supplied with services through an umbilical that runs from the surface to the wet bell direct, the divers then have excursion umbilicals connected to a panel in the wet bell, the tending point will be the wet bell itself, so the diver is deployed from the wet bell and has a standby diver tending him from the wet bell.

There will also be a relatively large supply of air carried onboard for emergency use. When diving from a wet bell there will always be one diver left in the wet bell to act as an in-water standby diver. Usually if this diving is from a DP vessel the umbilicals used should not be buoyant.

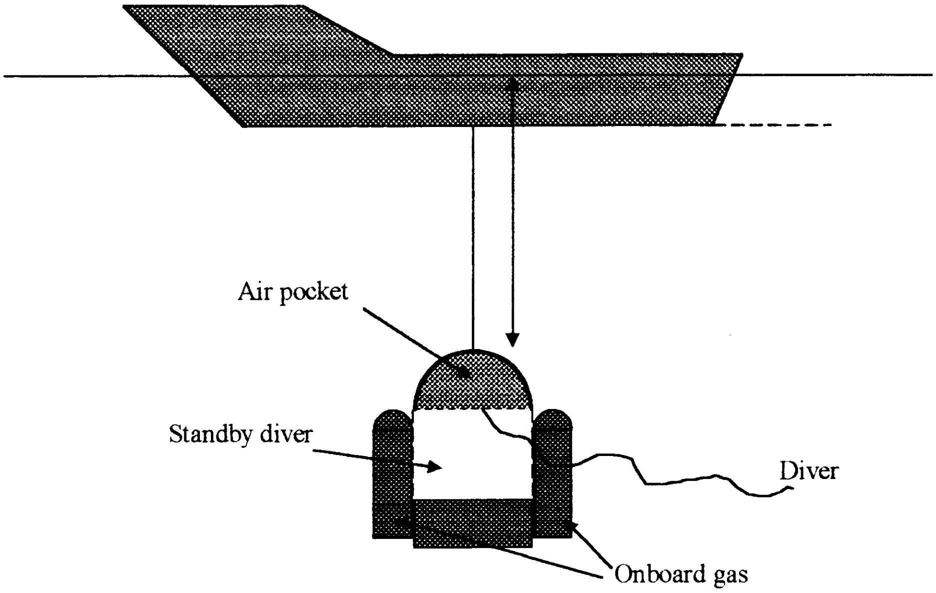


Fig 34.6 Wet bell deployment device.

Mini Bell Deployment

The "Mini Bell" is a closed bell designed to be used by air divers; it is used in order to cut out the "Surface Interval" during surface decompression.

Air diving decompression

As the diver descends he starts to breath air at a higher pressure. Because of the laws of solubility (Henry's law) the higher the pressure of the gas that the diver is breathing the more gas will be absorbed into his body in a given time, therefore if the diver goes to depth and stays there for a length of time he will have absorbed a certain amount of extra gas, as he comes back to the surface he will have to go slowly or stop for a time at given depths i.e. "step" the decompression to allow that gas to be expelled from his body again so the ascent has to be strictly controlled. If the diver spends just a short time at depth he may be able to return directly to the surface, this is known as a "No Stop" dive. In the event that the diver spends a longer time at depth he will have to stop on the way back to the surface, the following shows a typical dive profile for an air dive.

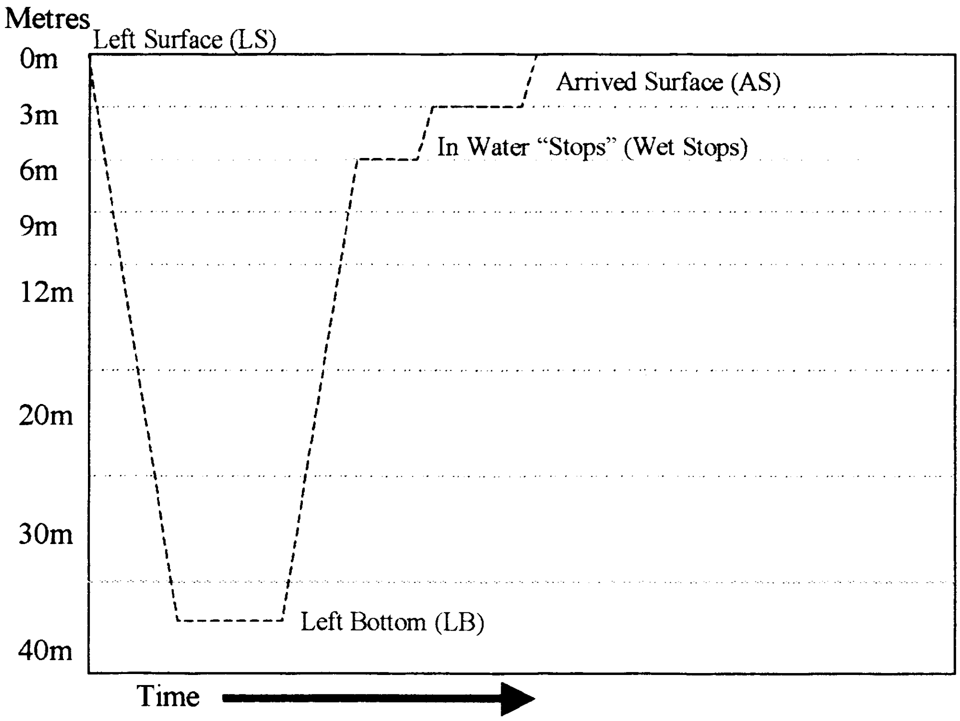


Fig 34.7 Stepped decompression.

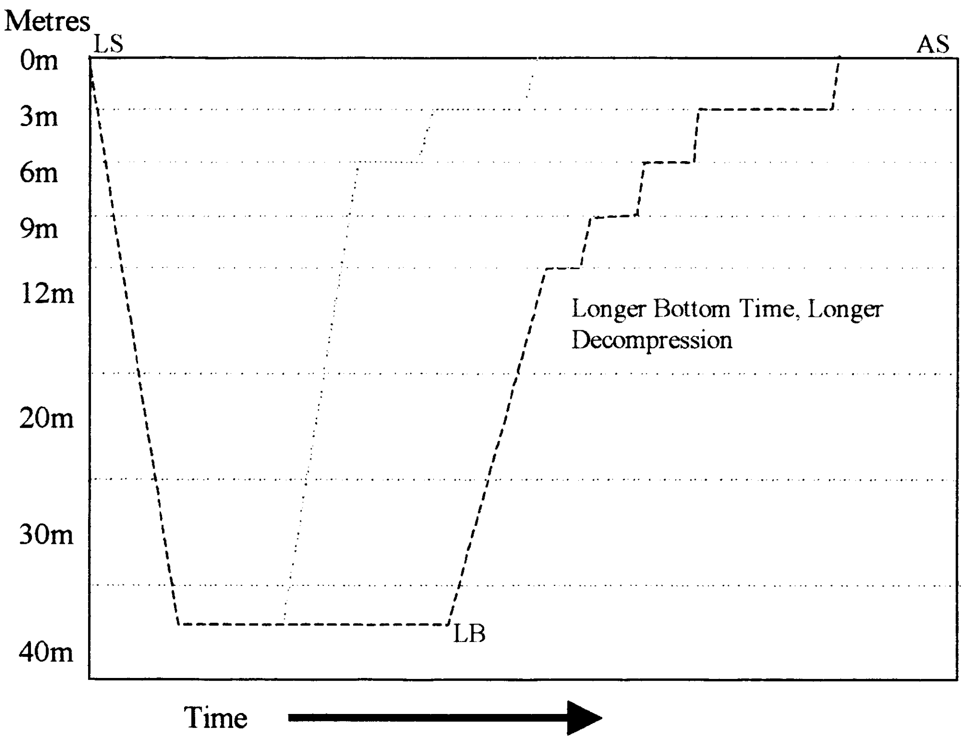


Fig 34.8 Stepped decompression with longer bottom time (Time spent at depth).
Stepped decompression is a compromise; the best decompression would be if the diver were able to follow a linear bleed decompression. This would involve the ascent being constantly varied as shown below, this is almost impossible for a diver to achieve while in water, so stepped decompression is the norm for in water decompression. As can be seen from the diagram below, during stepped decompression the diver is effectively zig zagging across the ideal linear bleed line. Linear bleed decompression is sometimes used for chamber dives but not for in water decompression.

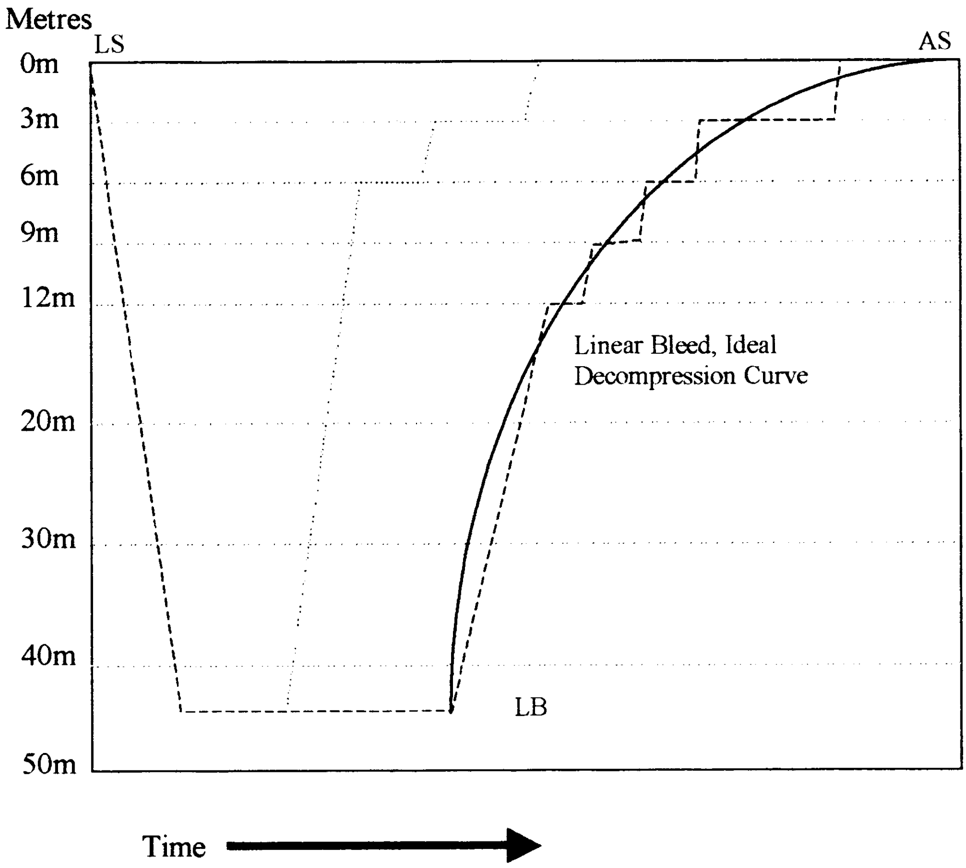


Fig 34.9 Linear bleed decompression curve.

There is another system, which could be used, termed surface decompression. Surface decompression may still require some "in water" stops, these stops will be of a much shorter duration however and most of the decompression will be carried out in a chamber on the deck of the ship or structure, this means that the decompression is carried out under more controlled conditions. It also means that the diver can be given oxygen to breathe when in the chamber this will accelerate the decompression process. Surface decompression will involve the diver arriving on surface before he is fully decompressed, he will have a short "surface interval" which is timed to be no more than a few minutes, he is then recompressed in the chamber on deck where the majority of the decompression will be carried out.

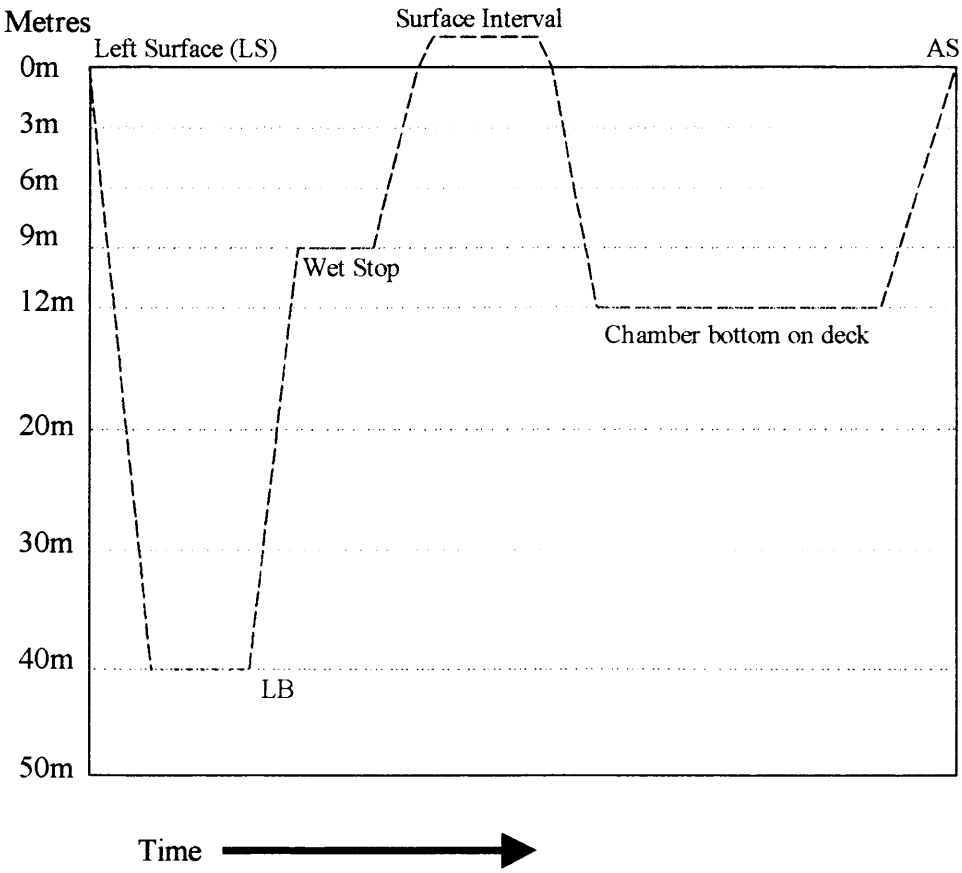


Fig 34.10 Surface decompression.

In any case the longer the diver spends at depth the longer he must spend decompressing. The Government have put stringent restrictions on the amount of time that the diver is allowed to remain at depth during an air dive, this can result in inspection being hurried because of the reduced bottom time available to them, in addition once a diver has completed his dive he will have to wait several hours prior to being able to dive again, this can be a problem which will mean air diving will be restricted.

The advantages of air diving are that he can back up his inspection using other senses such as touch and hearing, additionally he will have his brain on site. The diver will also have colour vision provided that he has a light source; this enables accurate interpretation of marine growth and perhaps concrete defects. The air divers spatial awareness will also be much improved over the ROV in that he is aware of his place in time and space. The diver will be able to give a commentary and on the spot assessment of any defects or discontinuities which he may discover.

A typical air diving site equipped for air diving and surface decompression offshore may have the following equipment, (this is not a complete list and only concentrates on the capital items):

1. Three air compressors (2 low pressure and 1 high pressure for charging bailout bottles) or air contained in banks.
2. There will also be a requirement to carry at least 90 cubic metres of pure oxygen for therapeutic purposes.
3. Hoses and pipework to supply the air to the diving control room.
4. Diving control room with air diving panel for at least two divers, each diver will be supplied independently and must have access to two independent supplies and each diver must have independent depth monitoring.
5. Communications systems for at least two divers, these must be independent and must allow for recording of the divers breathing pattern at all times apart from when the diving supervisor is talking to the divers.
6. Divers umbilicals, at least two, one for the diver and one for the standby diver.
7. Diving helmets or hats for use by the divers, these should allow air to be supplied from the surface to the diver, also there must be provision of a "Bail out" supply to be used in an emergency. In addition the hats must be equipped with voice communications systems.
8. Each diver must have a divers Bail out bottle, these will be held in a vest also holding weights, which can be jettisoned by the diver in an emergency. The bail out bottle must carry sufficient air to allow the diver to return to the deployment device where there will be additional emergency air.
9. Deployment device, this could be a diving basket or a Wet Bell; the latter is supplied with services (air, communications, depth monitoring and hot water etc) direct from the surface. The divers umbilical will be deployed from the wet bell at depth, this will allow the divers umbilical to be deployed and controlled from the diving depth, using this system will also allow a larger backup air supply to be deployed at depth for emergency use.
10. Handling system for the above deployment device.
11. Air diving recompression chamber, this is a chamber, which stays on deck, it will be used for surface decompression and recompression of divers in the event of decompression illness (DCI). This chamber will be a two compartment chamber which will allow personnel to enter or leave the chamber without bringing the main lock of the chamber to the surface, thus allow the diver to be tended to by a doctor or medic who does not have to stay in the chamber for the duration of the therapy. Additional equipment in the chamber will be as follows:

a) BIBS Built In Breathing Supply; this will allow the divers to breathe oxygen without contaminating the chamber atmosphere.
b) Communications systems to allow the supervisor to talk to the divers inside the chamber and vice versa.
c) Bunks for the occupants.
d) Food or medical lock, to allow items to be passed into and out of the chamber while it remains under pressure.
e) Lighting of the chamber interior.
f) Heating/cooling as required.
g) Supply of oxygen for normal decompression and therapeutic purposes.
h) First aid facilities.
i) Fire fighting facilities.

The main disadvantage of air divers are that they are restricted to time and depth this will involve strict adherence to decompression tables and limits.

SATURATION DIVING:

Saturation divers do not suffer from the same restrictions as air divers. All diving below 50 metres will be with divers breathing a mixture of helium and oxygen, some diving at depths less than 50 metres may also be conducted with helium and oxygen depending on the duration that the divers will be expected to stay at depth. All diving below 50 metres will also have to be done using a closed diving bell or a submersible chamber.

With a diver that is in saturation Henry's law will still apply in that at the depth the diver will have absorbed more gas than he would have absorbed on the surface due to the increased pressure, but after approximately 6 to 8 hours the diver will no longer be absorbing any more gas as his tissues will have become saturated, after this time the diver can stay at depth for as long as he likes without the need for any further decompression so the decompression requirements from a given depth may be 2 days, after the diver has been there for 24 hours, but if he stays there for 28 days the decompression would still be the same length of time.

Helium will be the normal gas used as a dilutant gas for the mix, the reason for using helium is that it does not have the same narcotic effect as nitrogen and because the molecule is much smaller the rate of tissue saturation/de-saturation would be quicker.

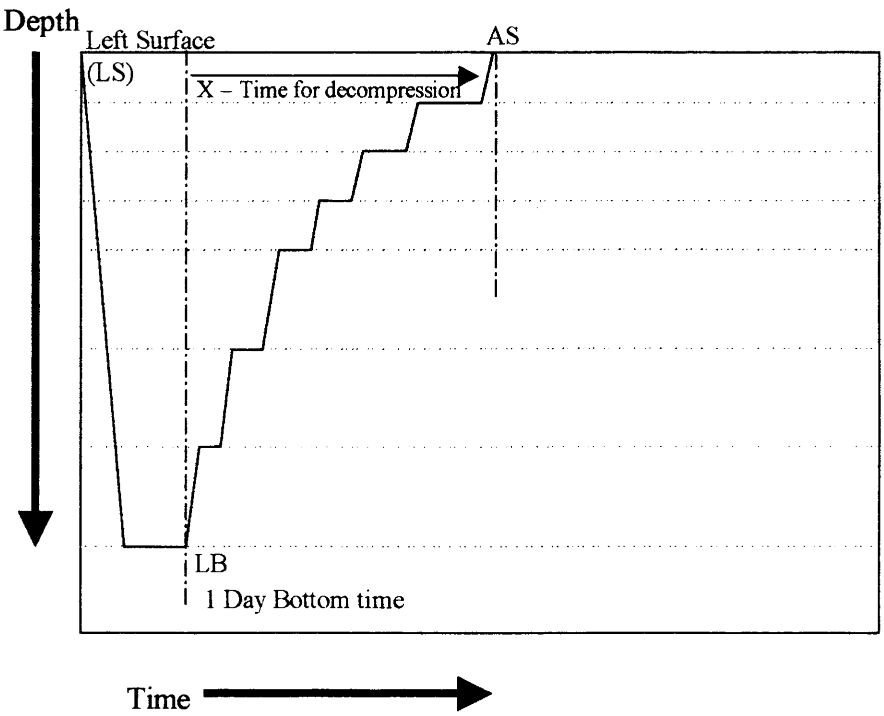


Figure 34.11 Saturation decompression after 1 day.

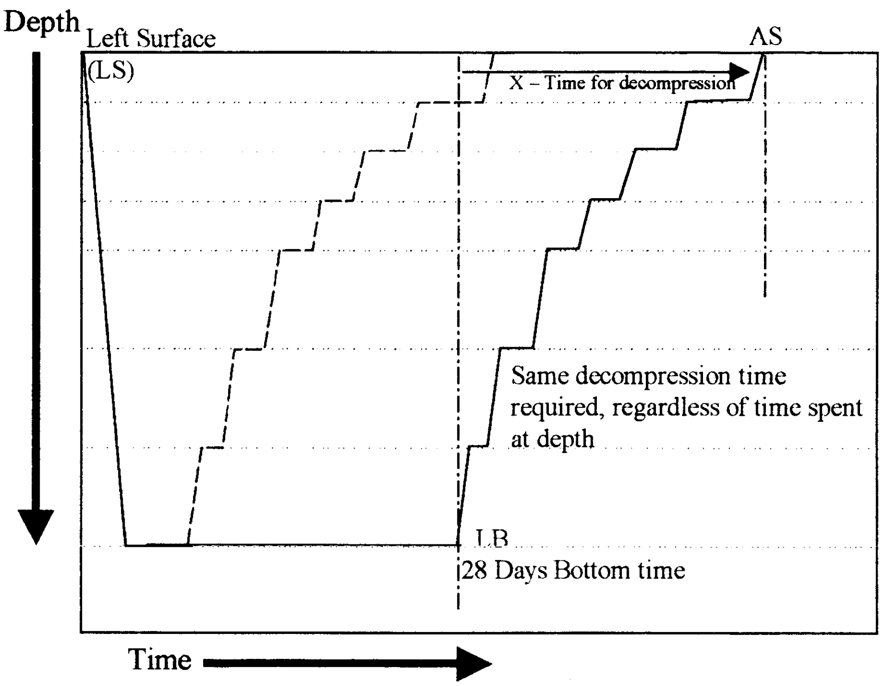


Fig 34.12 Saturation decompression after 28 days.

The negatives of using helium as the dilutant gas are that it is a very expensive gas, this means that the norm would be for the gas to be "reclaimed" and used again, and also the thermal conductivity of Helium is much greater than air (about seven times greater) and so it is harder to keep the divers temperature within acceptable limits. Helium may be expensive but if there is a need for divers to be at depth for a long time i.e. there is a lot of work to be done, then this system of diving is very cost effective and so is widely used.

The main advantage of saturation diving then is relating to decompression and the added time advantage, it is quite common for divers in saturation to do 8 hour bell runs (time from the bell leaving the deck to returning), this will mean the divers will be on the bottom for at least 7 hours, of which the 2 divers would spend probably 3 hours each in the water.

The diver will have all the advantages of the air diver in that he has his other senses, brain on site, can give on the spot assessments and colour vision with him as well provided that he has a light source. The disadvantages are less in that there is no time limit, allowing the inspection to be less hurried, there is virtually no depth limit and the decompression is only carried out at the end of the saturation period and not after every dive.

During saturation, the divers will be "stored" in a chamber on deck at a given pressure or depth, this depth is normally one bar shallower than the expected working depth. The diver can be asked to work both shallower and deeper than this depth if required, these variations to the depth will be termed **"excursions".** If the diver needs to carry out some work at a shallower depth than the storage depth, this will be termed an **"upward excursion".**

Upward excursions are possible although the diver will be subjected to some decompression in order to get to the work site. The maximum upward excursion normally allowed would be to depths where the pressure will fall by less than one bar (10 metres of seawater), so for instance a diver stored at 60 metres could have a maximum upward excursion of 10 metres, to allow him to work at 50 metres but no shallower. If the work is deeper than the storage depth then this is a **"downward excursion"**, there is normally less of a limitation on downward excursions than there would be on the upward excursions.

If a diver has to carry out some work at two depths during one dive, and these depths are both shallower and deeper than the storage depth, then he will always carry out the upward excursion first, once this work is complete he will still be able to descend to carry out the work at the deeper level.

The following is a sketch showing the method of deploying the divers using a closed bell, such as will be carried out during saturation diving.

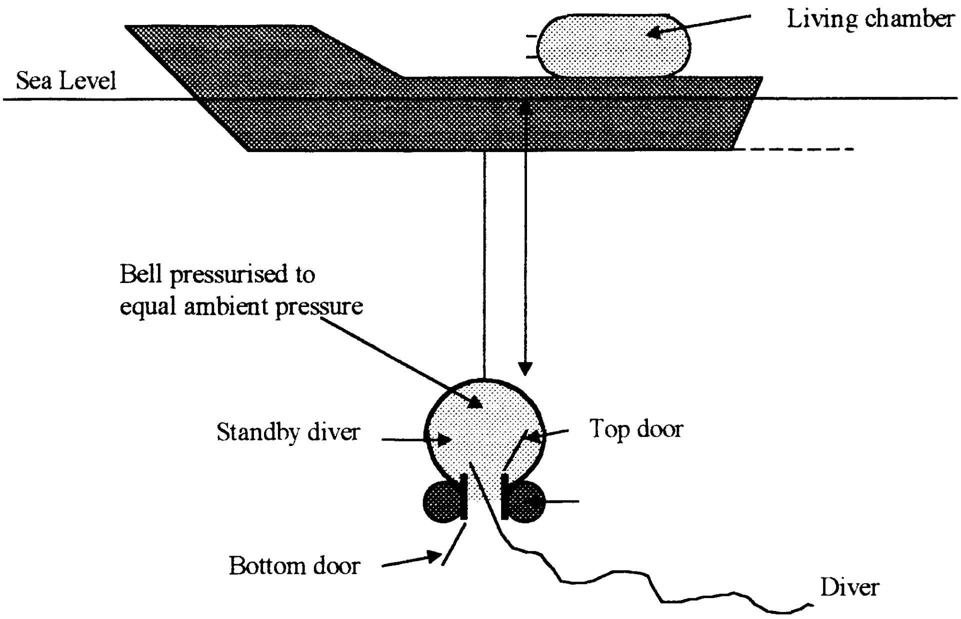


Fig 34.13 Closed bell arrangement

The disadvantages are the costs, extra equipment and the size of the crew required to carry out this type of diving and also there will be a problem with distortion of the divers voice as well as a greater thermal drain on the diver as the thermal conductivity of Helium is about 7 times that of air, this being the case the divers will need to be supplied with heating. The law in the UK states the following:

Diver heating requirements:

Diving depth less than 50 metres	-	No requirement
Diving depth between 50 to 150 metres	-	Suit heating must be supplied
Diving deeper than 150 metres	-	Suit and gas heating must be supplied

Deployment of divers in tidal flow or current:

Divers cannot be deployed when there is a high current of tidal flow, by law divers cannot be deployed when the flow of water is greater than **1.5 Knots** however air divers cannot be deployed when the flow is greater than 0.8 Knots and normally a bell diver (Saturation) would not normally be deployed above a flow of 1.2 Knots and even then only at the divers discretion.

REMOTE OPERATED VEHICLES (ROV):

Vehicles will be normally tethered via an umbilical either directly to the surface or a Tether Management System (TMS) and will be powered to the job by using thrusters, which allow the vehicle "swim". The main advantage of a tether management system is that it will normally allow a greater operating footprint for the vehicle, as the ROV will have only a light tether running back to the TMS, this would not be heavy enough to allow recovery of the vehicle on its own. Recovery and launch will be carried out with the vehicle stowed in the TMS which will itself have a much larger umbilical to the surface, this will allow the vehicle to be deployed in much higher sea states than would otherwise have been possible.

ADVANTAGES

1. No human in the water
2. Exceptional endurance compared to divers
3. No decompression Requirements
4. Very high power availability
5. Safety feature for divers
6. Can be deployed when divers may not be able to
7. Large number of sophisticated sensing devices easily deployed concurrently

DISADVANTAGES

1. Access will be restricted compared to divers
2. Normally will only have a 2 dimensional viewpoint
3. The operator will not be at the job site (no brain on the job)
4. No other senses to back up visual inspection.
5. The vehicles are complex and can be difficult to repair.
6. ROV may not be as effective as divers when the diving depth is shallow.

MANNED SUBMERSIBLES:

These can be split into two main groups:

i) Autonomous, not tethered to the mother ship on the surface:

Vehicles such as diver lock out submersibles where the pilot is at 1 atmosphere but divers are carried in a separate compartment under saturation conditions, normally this will mean that the divers can "lock out" (leave) of the submersible to work. The problem has been access to structures and a lack of power principally in keeping the divers warm.

Also in this class are deep diving submarines such as Alvin, which is used principally for scientific purposes.

ii) Tethered:

Tethered submersibles could be either flying bells, these are used to place divers close to their work site; again the pilot will be at 1 atmosphere while the divers are held under saturation conditions, or small one-man hard diving suits such as Wasp, Jim, Mantis, Hornet and the Newtsuit, amongst others, these are all vehicles in which one man can go to depth while staying at 1 atmosphere. The pressure is taken by the hull of the vehicle.

Advantages

1. The human is on the job so allowing better on site assessment
2. No decompression is required
3. Good endurance maybe 6 or 8 hours (typically up to 48 - 72 hours in an emergency).

Disadvantages

1. Human is in the water and so safety is compromised
2. May not have as much power so station keeping capability will be reduced by comparison to an ROV

CHAPTER 35

Abilities And Limitations Of ROV/Submersibles For The Collection Of NDT Data

MANNED SUBMERSIBLES

The main advantage of submarines over divers will be endurance and depth capability with reduction of safety problems due to decompression, the main disadvantage is access to parts of the structure and additionally there will be no back up for the inspection from the other senses such as touch.

REMOTE OPERATED VEHICLES

The main advantages of ROV over divers is that they can carry a lot of sophisticated equipment and the information can be displayed constantly on a video screen. The information that can be displayed will include the likes of date, time, depth, heading, inclination of cameras, cathodic potential readings and sonar information, all of this can be complemented by the use of a video typewriter which will be able to include more or less any information on the screen at the same time. The main disadvantages will be that they are not able to make decisions for themselves so things can be missed easily due to the remote vehicles operator having only two-dimensional information via a video camera.

EQUIPMENT COMMONLY CARRIED

Sonar
Various electronic sensing equipment
Flooded member detection devices (UT, Radiographic and Thermal)
Cathodic Potential probes and Current Density
Still cameras
Photogrammetry
Pan and tilt video cameras both colour and black and white (sit)
Lights and strobes
Cleaning equipment
Sampling equipment
Current meters
Gyrocompasses
Depth sensors

Temperature sensors
Hydrophones
Location pinger and flasher
Distance monitor (kilometre marker)
Manipulative arms and grabbers
Suction pads
Odometers (Distance measuring device utilising wheels in contact with the pipe)
Pipetrackers
Accelerometers
Laser Range finders
Scanning Ultrasound
Zip Pumps

TASKS SUITABLE FOR ROV

i) General survey (using video)
ii) Close survey (using video)
iii) Riser inspections
iv) Flow line pipeline inspections
v) Scour surveys
vi) Debris surveys
vii) Photographic surveys
viii) Cathodic potential surveys
ix) Construction
x) Flooded Member Detection

LOADING AND UNLOADING OF FILM, PRE-SETTING CAMERAS

Pre-setting:

Some cameras will be pre-set for "f" stop, and shutter speed, if it is not possible to change them while the camera is in the water such as in the scoones housing.

Points to consider for pre-dive checks:

1. Distance to the subject
2. Guide number of the strobe
3. Film requirements
4. Type of lens
5. Seals and sealing faces
6. Battery charge state
7. Film selection

In addition the camera may have some form of "data back" or data chamber in which case the details of the film and date etc can be printed onto the film and this would have to be set prior to the dive.

Calibration of cameras:

Mostly done at the shore base or at a specialist facility in the case of Photogrammetry cameras.

In the case of a stereo camera set up, the calibration is carried out by means of bench set in water with a series of rods of known different lengths protruding vertically up towards the camera set, the cameras will take some exposures of this known arrangement, the results can then be used to assimilate any future results gained from the calibrated pair of cameras. The cameras will be calibrated in pairs and then must be kept together (there will normally be a number on a glass plate the "Reseau plate" which will identify the individual camera, this plate will lie between the lens and the film). There will also perhaps be a need to include a block of known dimensions into the photographs; this "calibration block" will be used as a comparison by the computer when assessing the size of other objects in the frame.

Charging Batteries For Cameras And Strobes And The Keeping Of Charging Logs

Much of the failure of equipment offshore is due to the batteries being insufficiently charged, as soon as a piece of equipment comes back aboard it should be charged.

Batteries should not be charged for more than their maximum which is usually 14 -16 hours **(12 hours for a Hydroscan camera)** from completely discharged, if they are over charged then there can be production of hydrogen gas and of course this is explosive.

In addition the batteries should be cycled which means that they should be charged and discharged in cycles, as if this is not done properly the Nickel Cadmium batteries may not accept a charge, batteries should always be stored charged.

1 So the batteries should be properly charged 14-16 hrs
2 If the machine is used then the percentage of the charge used should be noted (this means that if a fully charged strobe can do 400 flashes and it only does 100 then it is 1/4 discharged)
3 Always store fully charged
4 Ensure that the area of charging is well ventilated to ensure no build up of hydrogen gas, and that no over charging will occur.
5 Always maintain a charging log for all batteries

Charging log:

Equipment type & Serial number:		Location:	
Date	**Time on charge**	**Time off charge**	**Time in use**

SAFE USE OF ELECTRICAL EQUIPMENT UNDERWATER

1 Always check the electrical insulation of the umbilicals and connectors every time the equipment goes in the water, test line insulation monitors (LIM).
2 Check connectors are free from foreign bodies every time the equipment goes in the water.
3 Check all circuit breakers at the very least daily.
4 All equipment used in water must have a means of isolation, and should be provided with an isolation transformer.
5 All fuses must be of the correct rating.
6 Always visually inspect equipment prior to use.
7 Proper certification of equipment.
8. Permit to work (hazardous areas).

CHAPTER 36

Hydrodynamic Forces Acting On Vehicles And How This Can Affect The Operation Of Vehicles

Hydrodynamic forces can be largely grouped into the following categories:

i) Wave action
ii) Tide
iii) Current
iv) Wind when being launched and recovered

All of the above will have very definite effects on the vehicle; wave action will reduce with depth making vehicles more effective at depth. Tide and current, some vehicles share power between the forward thrusters and vertical thrusters and this may mean that the vehicle cannot be accurately positioned.

THE CONTROL MARGIN

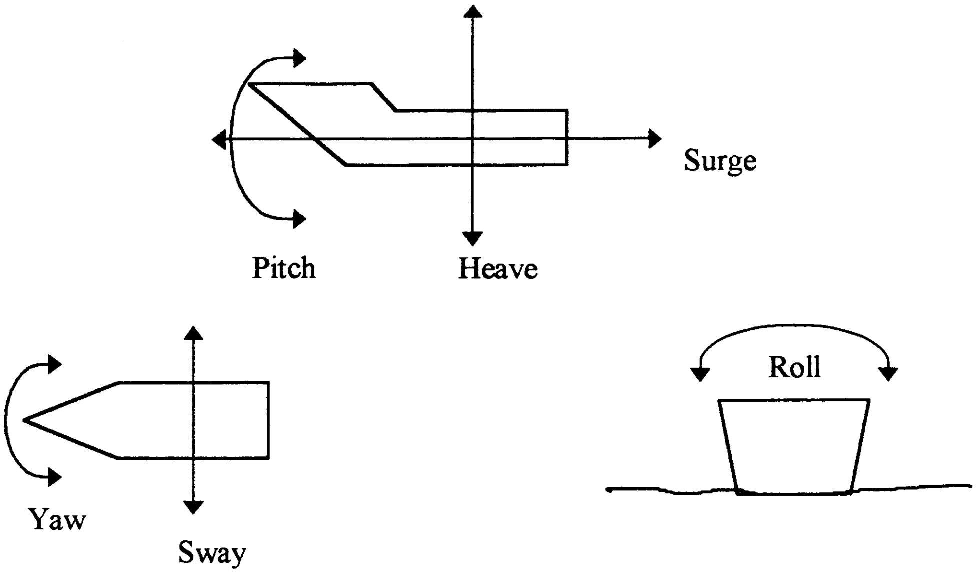
The control margin is the term applied to the difference between the power necessary to maintain position and the vehicles maximum power.

MANOEUVRABILITY

Will be affected by a number of things:

i) Drag and hydrodynamic forces on the vehicle
ii) Whether the vehicle is deployed "heavy" or "buoyant"
iii) Individual dynamics of the vehicles
iv) Operator skill

The following is a representation of the differing movement, which a vehicle may experience:



CAPABILITIES AND LIMITATIONS OF REMOTE VEHICLES

The most important factor when thinking of capabilities and limitations is **PLANNING**.

Assess the following:

1 What is required?
2 What is the best equipment for the job?
3 Expected weather in the area
4 Tide
5 Access for the vehicle

Factors affecting capabilities:

1 Size of vehicle (drag, power, weight, manipulators)
2 Environmental (tide, heave, wind)
3 Access
4 Type of equipment carried
5 Endurance (batteries, film)
6 Power at the vehicle (light, thrust, hydraulic)
7 Tether management system used
8 Launch method
9 Personnel
10 Location (DSV, platform, supply boat)

11 Type of task
12 Service periods

FACTORS AFFECTING THE DEPLOYMENT OF VEHICLES AND LAUNCH METHODS (TETHER MANAGEMENT SYSTEMS)

There are several factors affecting the deployment of vehicles they are as follows:

1 Weather conditions (During weather bulletins the word "Imminent" will mean the weather will be expected within the next six hours)
2 Swell
3 Tidal surge
4 Type of vessel
5 Location of the dive spread
6 Handling system involved

LAUNCH METHODS

There are generally four methods of launching vehicles they are as follows:

1 Articulated HIAB type crane
2 A-frame
3 Fixed deployment cursor/guide wire system
4 Line and quick release hook

With the HIAB crane we can fit a docking mechanism which will allow a reasonably smooth launch/recovery of the vehicle, the HIAB will not take up much deck space, it will allow easy access to the vehicle for maintenance and repair and to an extent it could be used to place the vehicle in a convenient place on deck which can be varied according to other tasks being carried out on deck.

A-frame is similar to the above in that there can also be a docking mechanism the A-frame should have a reasonable reach over the stern or side of the vessel. The A-frame may be able to carry bigger loads and so the vehicle and TMS can be larger, it may also be easier to operate than a HIAB. However the A-frame may limit the access to the vehicle when it is on deck making maintenance of the vehicle somewhat more difficult, A-frames may take up more deck space than HIAB deployment devices and will not allow positioning of the vehicle on deck in another location easily.

Fixed deployment cursor/guide wire systems are usually utilised with a moonpool, this will extend the weather window and allow the deployment of the vehicle in poorer weather conditions than the above two methods, this system can handle large vehicle and TMS combinations. This system may be more costly than the above and will not be as flexible as to where the vehicle can be deployed, the vehicle may need to be removed from the cursor when carrying out maintenance. A dead vehicle may cause more problems though as the vehicle will come up outside the ship provided the vehicle is buoyant, this will mean the vehicle has to be hooked from an inflatable and pulled aboard the ship, then the umbilical will have to be disconnected and pulled back through the moonpool.

Line and quick release hook, this will involve the vehicle being lifted over the side by means of a crane or some winch and cable other than the umbilical, when the vehicle is in the water the hook would be released with a line thus releasing the vehicle, recovery can be difficult, it will involve manoeuvring the vehicle along side the ship and hooking a line on with a long pole, or the deployment line will be secured to the umbilical and will be removed when the vehicle comes back to a safe depth. This system is however very cheap and does not tie up deck space, it can only be used with small vehicles.

UMBILICAL OR TETHER MANAGEMENT SYSTEMS (TMS)

There are basically two types of umbilical management these are:

1 Top hat system
2 Garage system

The top hat systems are perhaps the best where the recovery of a dead vehicle is concerned as the other two can cause problems.

The TMS can give good back up to the operation as follows:

1 Additional lifting or winching capacity
2 Sonar capability can be increased
3 Additional lighting can be supplied
4 Tool carrying carousels can be attached to the TMS
5 There will be less drag from the umbilical, which could affect the vehicle
6 Increased operating footprint
7 Increased weather window of operation
8 Less likelihood of vehicle tether becoming entangled in vessel thrusters
9 Less "jerking" of the vehicle tether due to ship movements

The tether will be smaller than the umbilical of a surface supplied vehicle thus creating lower drag and allowing much greater operating footprints and freedom.

If working on a pipeline, a TMS will allow the vehicle to be effectively isolated from the rise and fall (Heave) of the surface vessel, it will also allow the surface vessel to be positioned in the most advantageous position relative to the vehicle and the tide or wind, this will ensure that the vehicle can stay on the pipeline and does not get pulled off.

When working on a structure, a TMS will allow greater penetration of the structure by the vehicle. The TMS will be positioned at the elevation along which the work is to be carried out, the vehicle will then be released and can travel horizontally into the structure, this will remove most of the drag from the vehicle and also will ensure that the tether is not being dragged under braces more than is absolutely necessary. If the vehicle were to be deployed from the surface, the vehicle would need to pull the heavy lift umbilical into the structure, this may cause fouling or extra drag thus reducing the vehicles manoeuvrability within the structure.

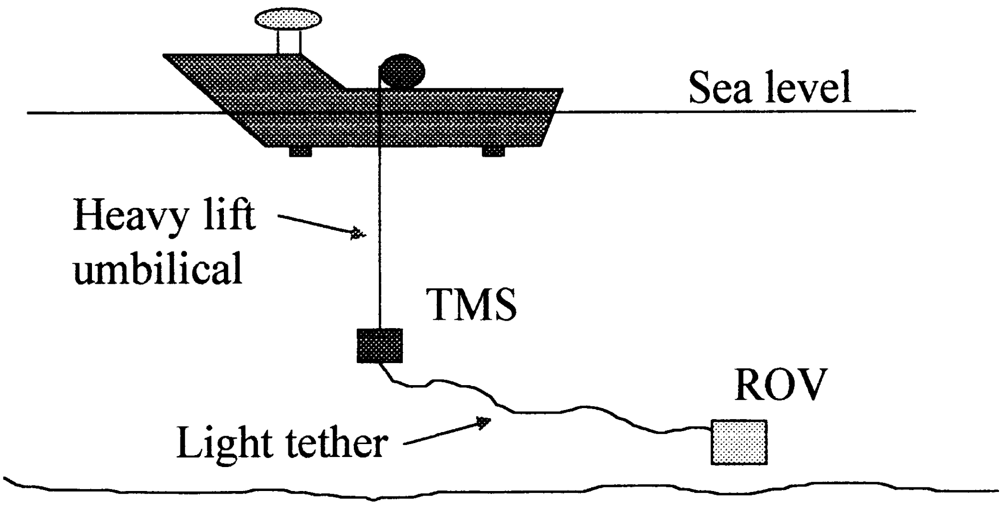


Figure 36.1: ROV deployed using a Tether Management System (TMS).

MANOEUVRABILITY

This will be affected similarly to speed but in addition the following will affect manoeuvrability:

1 Drag and hydrodynamic forces on the vehicle
2 Whether the vehicle is deployed "heavy" or "buoyant"
3 Individual dynamics of the vehicles
4 Pilots lack of experience
5 Negotiating a structure or template,
6 Access
7 High payload

8 Task (tooling packages)
9 Thruster power sharing (vertical thrust may automatically take some power from forward thrust and so on)

Size:

There are several different classifications of vehicle; this is because they have been developed to deal with a variety of tasks the most common in offshore terms are as follows:

1 PURE OBSERVATION (Class I)

Pure observation vehicles are physically limited to simple video observation. They cannot undertake any other task without considerable modification.

Examples are: Mini rover, Phantom & Super "C" Cat

2 OBSERVATION WITH PAYLOAD OPTION (Class II)

These are vehicles capable of carrying additional sensor such as still colour cameras, cathodic protection measurement systems, additional video cameras, sonar systems and flooded member detection systems. A class II vehicle should be capable of operating without loss of its original function when carrying at least two additional sensors.

Examples are: Dart, UFO, Sea Hawk, Scorpi, Sprint, Sea Owl, RCV 225, RCV 150, Sea Eye 600

3 WORKCLASS VEHICLES (Class III)

These vehicles are large enough to be fitted with additional sensors and/or special tools for manipulative tasks. Class III vehicles should have multiplexing capability allowing additional sensors and tools to be operated without being "hard-wired" through the umbilical system. The umbilical should, however, have spare conductors to allow operation of payload equipment. Workclass vehicles should have sufficient propulsive power to operate at least one thruster in each of the longitudinal, lateral and vertical directions.

Examples are: Scorpio & Super Scorpio, Pioneer, Trojan, Challenger, Hydra, Hysub, Recon & Explorer etc.

4 TOWED OR BOTTOM CRAWLING VEHICLES (Class IV)

Towed vehicles have no propulsive power although they may be capable of limited manoeuvrability. They travel through the water by the hauling action of a surface craft or winch. Bottom crawling vehicles move primarily by exerting ground pressure on the sea floor via a wheel or track system although some may be able to "swim" limited distances.

Examples are:	1	Towed vehicles:	Ocean surveyor, Benigraph
	2	Crawlers:	Sea dog, Seabug

5 PROTOTYPE OR DEVELOPMENT VEHICLES (Class V)

Vehicles in this group include those still being developed or regarded as prototype and special purpose vehicles which do not fit into one of the other four categories.

Examples are: Solo, DAVID & Portunis.

The sizes of some of these vehicles can be as follows:

Mini rover	: 26" x 18.5" x 12.5"
RCV 225	: 20" x 26" x 20"
RCV 150	: 52" x 47" x 43"
Hydra	: 5.83' x 3.83' x 4.17'
Scorpio	: 7'3" x 5'8" x 5'3"
Super Scorpio	: 7'6" x 4'5" x 4'8"

POWER AT THE VEHICLE, MANIPULATORS, RANGE OF FUNCTIONS, AND SENSORY FEEDBACK

1 POWER AT THE VEHICLE

This is obviously going to vary considerably with the type and size of ROV and the tasks required, in the past ROVs have not had much power to spare after thruster drains, but now with the advanced vehicle that is set to change.

Examples:

Scorpio	:25 HP or 40 HP
Rigworker	:50 HP
Challenger	:100 HP (could be increased to 150 HP)
NHD	:230 HP (Noordhoek diving)

The task will to an extent dictate the type of vehicle and so the power needed hence the categories, light insp. work, work class etc.

MANIPULATORS

These are the "hands" of the ROV and as such are a very important part of the vehicle, again the type and size of manipulators will largely be dependent on the task to be performed, some common ones are as follows:

Perry five function
Kraft five function master/slave arm
Kraft nine function force feedback arm
Slingsby five function grabber/claw arm
Slingsby nine function master/slave arm
Schilling nine function computer aided arm
Slingsby TSC nine function computer aided arm

The functions refer to the number of axis of movement possible with the arm; therefore a nine-function arm will be capable of movement in nine definite axes.

Some of the newer arms are used in conjunction with computers; this may allow them to be used to assess distance from datum on welds. This is made possible by touching the manipulator onto the 12 O'clock position and then onto the 3 O'clock position, the diameter of both members is then input to the computer and the computer maps the weld. Once this has been done, if the manipulator is touched onto the weld at any point the computer can give the distance from the datum in millimetres. The computer aided arms may also give a smooth enough scanning motion along a weld to allow the use of ACFM or Eddy Current probes, they will definitely be capable of placing Electromagnetic Arrays which are automated ways of deploying either ACFM or Eddy Current in order to locate small surface breaking defects, and once found these can be assessed for length and depth of penetration into the metal. This can be achieved through paint coatings provided they do not conduct electricity and are in reasonable condition.

The size of the arm and manipulator may well greatly affect the speed and manoeuvrability of the vehicle.

FORCE FEEDBACK

This is the ability of the arm to transmit some kind of feel back to the operator, it has not been widely introduced and indeed some operators would say that it makes the arm needlessly complex and so maybe less reliable.

In practice approximately ninety per cent of the tasks undertaken by ROVs do not need force feedback, with the increase in reliability of the vehicles and also the increase in the demand for complex tasks to be carried out by ROV then force feedback may become essential in the future.

Manned submersibles, both autonomous and tethered:

Autonomous vehicles are not tethered to the surface and as such can be used only for the periods that their power and limited life support will allow.

RANGE:

This will be dependant on the type and size of the battery pack, the size of the vehicle and the environmental conditions (tide and current) all of these will affect the range, and lastly the payload, which it will be expected to carry.

ENDURANCE:

This will again be directly dependent on the capacity of the submersibles batteries, there are several types, which have differing power outputs, and some of these are as follows:

i) Lead/acid
ii) Nickel/Cadmium
iii) Silver/Zinc
iv) Hydrogen/Nickel

All of the above are commonly used; in addition there are several more types currently under development. It has been suggested that nuclear packages may be the way to go but there are obvious disadvantages to this type of power plant.

Some submersibles can dive for a total of 8 to 10 hours if the conditions are favourable.

PAYLOADS:

This relates to the type of work being carried out, and would be directly related to the type and size of vehicle.

If the submersible is to be used to ferry divers to a work site then some other factors must be taken into account:

Heating of the divers tends to be the most likely limiting factor to the endurance of a diver lock out submersible. As has been discussed previously water will conduct heat away 27 times faster than air will and if the diver is also breathing helium then this will also increase his heat loss, this being the case the amount of power needed for heating the divers will be a major limiting factor, as a rule of thumb 6 hours has been achieved but this will not be nearly enough to make this type of vehicle widely used (note that in Norway the submersible must have at least 48 hours reserve life support for use in the event of accident).

Access to the structure will be limited as the vehicle will have to be quite large in order to accommodate the divers and pilot, the normal way in which a diver lockout submersible will operate is to penetrate the structure and then "settle" on one of the members in order to remain stationary while the diver is outside, this may well not be acceptable to many clients who may already be worried about damage and loadings.

Attachment to structures would perhaps be achieved by the use of suction pads, of the type now fitted to ROV's.

TETHERED VEHICLES (ATMOSPHERIC DIVING SUITS)

Over the past few years there have been a number of one man diving submersibles, most have remained tethered to the surface so that they can have the benefit of virtually unlimited power and light. They all make use of some kind of articulated arms in order to achieve the desired work,

Advantages:

i) The divers brain is on the job site
ii) Relatively good access to structures
iii) Cheap to run
iv) Easily deployed
v) Versatile
vi) No decompression

Disadvantages:

i) Limited mobility
ii) Limited dexterity
iii) Man in the water (up to now though they have 100% record of safety)

There are several types of "ADS" currently available for use offshore these are as follows:

1 - ADS "JIM" Mk 1

This is a one-man suit for use on the seabed or a specially constructed walkway; the hull is constructed of Magnesium with all of the accompanying corrosion problems. The following is a list of some of its statistics:

Hull material	-	Magnesium
Depth rating	-	457 metres (1500 ft)
Life support	-	30 hours
Limbs	-	Fluid supported articulated aluminium

2 - ADS "SAM"

Sam is very similar to the Jim suit in that it is designed to be used in a walking mode, Sam is however a much smaller suit which has been a limiting factor as only relatively small persons can fit in to it, the following list relates to its statistics:

Hull material	-	Fabricated aluminium
Depth rating	-	305 metres (1000 ft)
Life support	-	20 Hours
Limbs	-	Fluid supported articulated aluminium

3 - ADS "JIM" Mk 2

Again this is a suit designed for use as a walker, this is of course a limiting factor in its self, as such it is an evolution of the original "Jim" suit, it has the following statistics:

Hull material	-	Glass reinforced plastic
Depth rating	-	610 metres (2000 ft)
Life support	-	40 hours
Limbs	-	Fluid supported articulated aluminium

All of the above are as has been said designed as walking bi-ped suits, but in order to make them more versatile some have been fitted with a thruster pack which enables them to be used mid water, this derivative has been termed "Jet Jim".

4 - "NEWTSUIT"

The Newtsuit is a new generation one atmosphere suit which makes use of up to date technology, the main advance is in the joint technology used in the arms and legs which is similar to that used in the NASA hard space suit, this uses a rotating fluid supported "knife edge" joint thus cutting down friction. The suit is again designed to work in the walking mode but can be deployed in the "neutral" mode, the statistics are as follows:

Hull material	-	Aluminium (T60)
Depth rating	-	375 metres (1230 ft) soon to be 450 metres (1476 ft)
Life support	-	54 hours
Limbs	-	Aluminium fluid supported rotating knife-edge

5 - "WASP" Mk 1

This is a "flying" suit, as such it is designed to be used mid water, this suit has largely been phased out as it suffered with a real shortage of thrust, the statistics are as follows:

Hull material	-	Laminated GRP and aluminium
Depth rating	-	610 metres (2000 ft)
Life support	-	40 hours
Limbs	-	Fluid supported articulated aluminium

6 - "WASP" Mk 2

As has been said the Mk 1 wasp was underpowered this being the case the Mk 2 has more thrusters, this gives it a better capability for working in tide or current, it will also allow a greater work capability, the statistics are as follows:

Hull material	-	Laminated GRP and aluminium
Depth rating	-	610 metres (2000 ft)
Life support	-	72 hours
Limbs	-	Fluid supported articulated aluminium

7 - "HORNET"

The Hornet is a more powerful version of the Wasp Mk 2; it has been generally uprated to make it more versatile, the statistics are as follows:

Hull material	-	Laminated GRP and aluminium
Depth rating	-	850 metres (2788 ft)
Life support	-	72 hours
Limbs	-	Fluid supported articulated aluminium

All of the above will use the strength of the operator's own arms to operate the limbs.

8 - "MANTIS"

This is again a "flying" submersible designed to work midwater, the operator would lie horizontal in the mantis as opposed to upright in the other suits. It will also make use of seawater hydraulics in the arms making them able to exert more strength than the above suits albeit they may suffer some decrease in dexterity, the statistics are as follows:

Hull material	-	Laminated GRP and aluminium
Depth rating	-	915 metres (3001 ft)
Life support	-	150 hours
Limbs	-	Seawater hydraulic articulated aluminium

9 - "MANTIS DUPLUS"

This is a bit of a hybrid in that it can be operated either as a manned or unmanned submersible, it never really caught on as it was not able to perform as an ROV can because of the need to have a hull big enough to accommodate a man, this will reduce its effectiveness in side currents, the statistics are as follows:

Hull material	-	Laminated GRP and aluminium
Depth rating	-	1000 metres (3280 ft)
Life support	-	150 hours
Limbs	-	Seawater hydraulic articulated aluminium

It should be noted that although the above statistics and information is correct when the suit leaves the manufacturer, each and every suit would be subject to modification to suit the individual needs of the operating company.

Even though the vehicles can stay underwater for the given life support, this would mean that the carbon dioxide absorbent or the oxygen supply would be totally exhausted, this may be necessary in an emergency but normally most companies would limit the dives to 6 hours only.

Seabed crawler vehicles, towed units and diver support vehicles

Crawlers:

Normally seabed crawlers are used in conjunction with cable laying/burial or specialist applications, for instance a vehicle named Portunis has been built for use on the coast of Holland, a crawler was used because of the strong tides and currents which exist in that area, the system has been successful for the inspection of seabed mattresses which are positioned around the base of the barrier.

Structure crawlers could also have a good advantage in that the current or tide will not make any difference to the vehicle, removing these factors from the equation will allow the vehicle to use all of its power for the operation in hand, the problem with structure crawlers are going to be anodes and structure geometry, this has meant that to date there are not really any viable units used offshore.

Towed units:

There are a very large number of towed units in use they have been successful for pipeline survey and location of sunken shipping as well as seabed survey etc. Most of the vehicles can be towed at a speed of between 0.5 k to 4 knots and they will normally be able to control their depth and lateral movement.

The towed units can deploy the following:

Xenon flasher
Compass
Speed meter
Depth sensor
Photo strobe
Still camera
Lights
Pan and tilt
SIT CCTV camera
Sidescan survey
Sub bottom profiler
Trench profiler
Scanning sonar
Echo sounder and altimeter
Transponder
Temperature sensor
Salinity sensor
Pinger

As well as a large number of other specialist tools.

DIVER SUPPORT ROV'S

This can be split into two groups as follows:

1 Small inspection class vehicles:

These will give the diver additional safety and productivity; they can be used to enhance the following:

i) Location of the job site, this will allow a considerable saving of time and thus increase productivity.
ii) Can provide the topside crew with a detailed observation of the divers work.
iii) Will provide good lighting for the diver to work with.
iv) Safety for the diver will be much improved when a small ROV is on site.

2 The "David" diver support ROV :

This is a purpose built ROV which is designed to be used by the diver as a physical support platform for him to stand on, also it will supply light and power for tools,

Endurance, human risk, manning levels, spatial awareness, human contact and dexterity

ENDURANCE

This will vary according to the vehicle and crew involved, as we have said manned submersibles would normally be limited to 6-hour dives, even though they may well be capable of much greater time underwater.

In the case of ROV's it is not uncommon for the vehicle to be in the water for 100 hours at a time, this is obviously going to lead to good continuity with the work the vehicle.

HUMAN RISK

Electricity is of course a killer, all ROV and submersibles use quite high voltages and of course this means that each facility will have to be properly protected, it is also advisable for all personnel to have training in dealing with electrocution.

Physical risk, by this we mean the risk of using cranes and lifting apparatus for the movement of sometimes quite heavy loads on a ship which may be somewhat less than stable.

Diver safety, divers are safer if there is a vehicle on site provided that the vehicle is being flown by an experienced pilot and that proper procedures are followed, however all vehicles must be fitted with propeller guards to prevent injury. Note that the ROV can only be deployed or recovered with the permission of the diving supervisor.

MANNING LEVELS

These will vary depending on the type system and the task workload; in general the following is a good guide:

Inspection ROV	-	2 men per 12 hour shift
Work class ROV	-	3 or 4 men per shift
Manned submersible	-	2 operators, 1 supervisor, and 3 air divers per shift

REAL TIME DATA ACQUISITION

If real time data acquisition is in use then it will allow remedial work and anomaly mapping to be carried out quickly and effectively, possibly without the vessel leaving the site. An example of this would be when the following are in use:

CP Probe
CCTV
Dual scanning profiler
Surface navigation, Easting, Northing and kilometre post (KP) information etc.

SPATIAL AWARENESS

This is the awareness of ones place in space, as such when using an ROV care must be taken to identify all likely locations where problems could occur such as snagging, this would mean taking into account the path to the job, obstacles, guide wires, anodes and valves etc. Also it will be important to decide whether the ROV will be able to turn or not, maybe it will have to reverse out.

HUMAN CONTACT

This is related to the above in that we can only find our place in space by the information which we receive, when this information comes only from a 2 dimensional image on a television screen we will have only a very limited appreciation of where we are (especially if the visibility is not good), this can be a limiting factor, it must be said that some pilots can overcome this to a point with experience of structures and flying the machines but they will always have only the information from the Television screen to use. In the future we will have stereo television all around the vehicle, which will greatly increase the spatial awareness of the pilot.

DEXTERITY

This will of course be greatly affected by the type of manipulators in use; also the manned submersible has an advantage in that the divers brain is also on site thus allowing greater appreciation of the task. At present most manipulators fitted to ROV's are straightforward hydraulic units which do not give any feel, this can to an extent be enhanced by the use of "force feedback" which means that as the ROV's arm comes up against an object so the operator will notice a pressure on the master arm which he is using, this allows a greater level of control to be given, most operators feel that at this time the greater complexity of a force feedback system is not worth the gains.

CHAPTER 37

Pipelines And Pipeline Features

GENERAL BACKGROUND TO SUBSEA PIPELINES

Pipelines are the arteries of the offshore industry; they are used for the import and export of oil and gas to and from the structures and the shore base.

All pipelines on the seabed are at risk from physical damage and corrosion as well as seabed scour which will cause the pipe to become suspended, this will put the pipe under extra stress.

PIPELINE FEATURES

The following are features of pipelines and their support structures:

Risers Used to carry oil or gas vertically up or down a platform.

Riser clamps Clamps used to attach risers to structures and to provide support of the pipework.

Conductors Pipes through which the oil or gas is produced, in effect an extension of the well bringing the oil or gas up onto the rig floor.

"J" tubes & Tube turns A point where flowlines and risers change direction.

PLEM Pipeline End Manifold this will be the end of a Subsea pipeline normally below an export buoy (SBM) this item may now be termed a "FTA" or Field Termination Assembly.

Valves & Flanges Valves will be used to control the flow of oil or gas through a pipeline and flanges will be used to connect two pipes or a pipe to a valve etc.

Weightcoat Weightcoat is used for three purposes:

i) The protection of the pipe from physical damage
ii) Protect the pipe from corrosion by passivation.
ii) To give weight to an otherwise buoyant pipe.

Burial trenches Pipelines are often buried in trenches in order to afford them protection from physical damage and to keep the located firmly.

Rock dumping Rock dumping is used as an alternative or as well as putting the pipe into a trench, both will protect the pipeline.

Pipeline crossover Any point where a pipeline crosses another will be termed a crossover point; there are a number of ways of protecting the pipes at this point such as grout bags and bituminous mats. The pipes must not be allowed to move at the joint and will be kept apart from one another.

Anodes & retrofit Anodes Anodes will afford corrosion protection to the pipeline, when the original anodes are exhausted then new ones will be fitted, these will be termed Retrofit anodes

Kilometre posts & Field joints Kilometre posts are points marked onto the pipeline which can be used to locate the vehicle on the pipeline, Field joints are points where the pipe was welded in the field during installation they are normally at a distance of 12 metres apart, the exact location of these points will be on the drawings and so can easily be found enabling good location of the vehicle or defects, debris etc.

Saddle Blocks & Mechanical anchors These are devices designed to ensure that the pipeline stays in location and is not moved by tides, wave action and currents etc.

Expansion Loops Expansion loops are loops laid on the seabed in order to allow some movement of a flowline, this will allow for some expansion and contraction with varying temperatures.

Tie In A tie in is where flowlines are brought into and connected to a riser system.

ROV PIPELINE INSPECTION TECHNIQUES

Rov's will be used for almost all levels of inspection concerned with pipelines, this will span from the initial inspection of the pipeline route looking for the substrata, through to surveying the trench profile, pipe placement and finally in service inspection of the pipe.

A class three or "Workclass ROV" will normally be used for pipeline inspection as the array of sensors needed will be quite wide, there is also a requirement for the ROV to be able to inspect the whole of the exposed pipe with only one "pass", thus there will be boom cameras fitted so that both sides of the pipe and also the top of the pipe can be video taped simultaneously. The following sketches show typical system requirements:

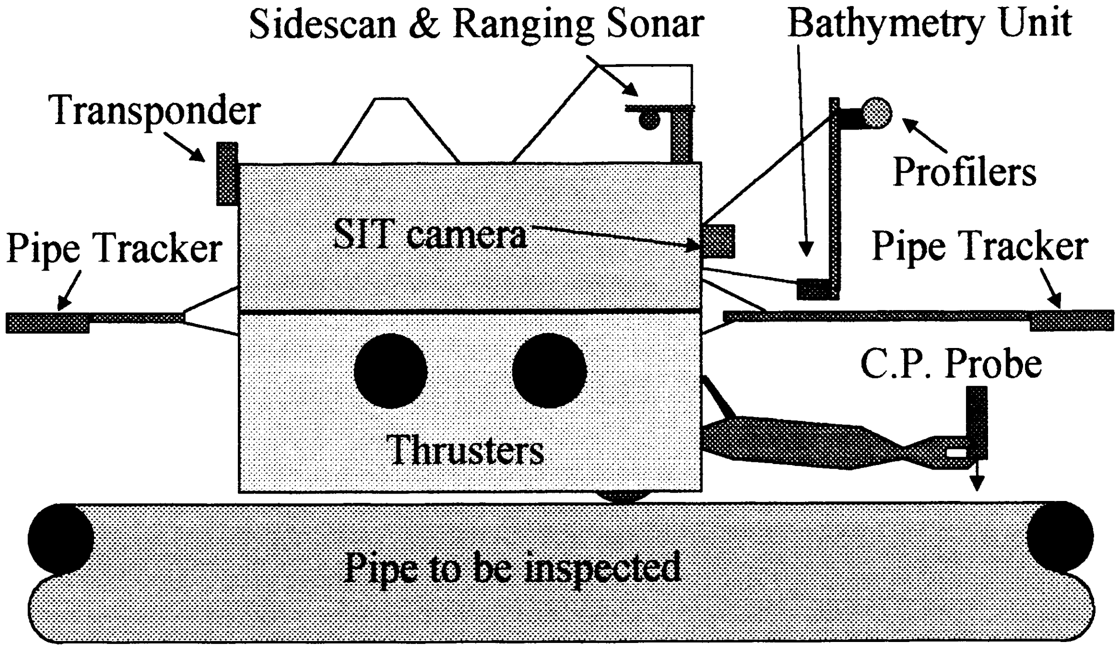


Figure 36.1 Side view of class 3 vehicle with pipeline inspection system

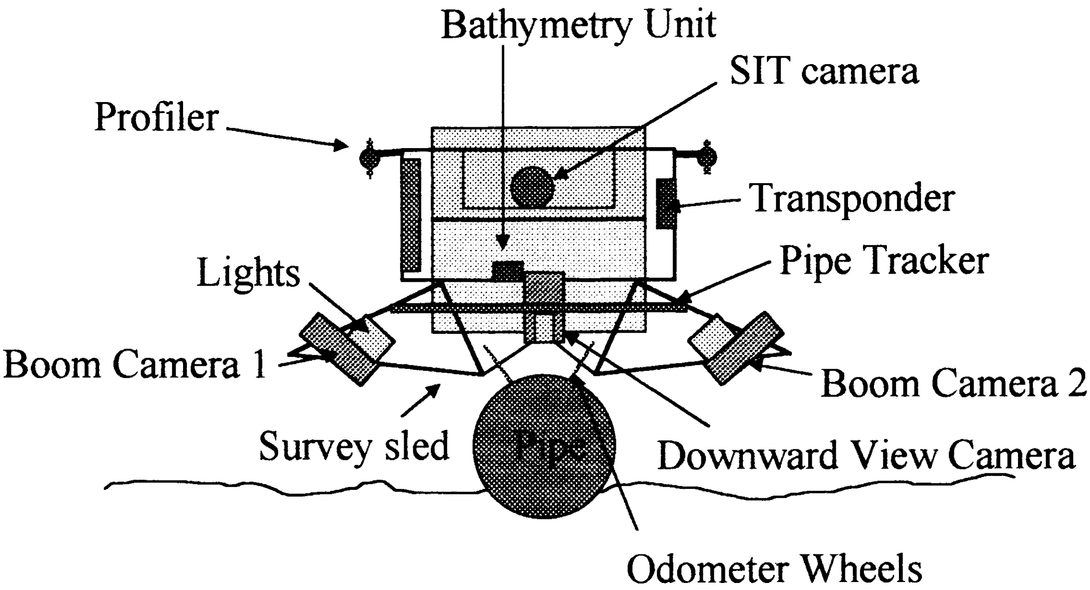


Figure 36.2 Frontal view of pipeline inspection class 3 vehicle

For pipeline inspection the ROV will use a very wide range of sensing apparatus, some of the sensors available are listed:

1 Bathymetric measurement (depth and altitude, can be linked to thrusters for auto depth).

2 Sub bottom profiling (will give a section through the strata at the angle of the sensor, ROV will have to fly high [5-6m] above the seabed).

3 Parametric sub bottom profiler (similar to the above but uses an array of transducers [sensors] to scan the sea bed to give a real time sub bottom profile).

4 3d mapping tool (sonar mapping either in 3d or as a contour map).

5 Scanning sonar (gives continuous map of objects in the path of the vehicle).

6 Avoidance sonar (gives a peak or ping with the bearing and range to the object).

7 Sidescan sonar (object location along the sides of the vehicle, pipe will normally be visually inspected with CCTV and the sidescan will look off to either side for debris etc).

8 Ultrasonic trench profiling, a real time image can be produced of the trench profile.

9 Spot scan trench profiler (uses high frequency emissions to profile trench either laterally or longitudinal).

10 Spot scan profiler (uses laser scanning 10 scans/second can give a full profile of pipe very quick and accurate).

11 Pipetracking, this can be achieved by magnetometer or maybe by the use of sub bottom profilers, to track a pipe which is submerged.

12 Laser sizing and range finding, lasers can be used to size accurately any defect on a pipe or to assess the distance to an object. This can be especially useful in the assessment of pipe spans (length of unsupported pipe).

13 SIT video camera (low light navigation camera).

14 CCTV colour and monochrome video (Videogrammetry is now available for effective sizing and ranging quickly and is user friendly).

15 Photography and Photogrammetry (Photogrammetry is now available as a quick easy and user friendly system available for size and range measurement ± 7mm easily).

16 Cathodic potential measurements.

17 Ultrasonic thickness measurement of metal pipes.

As far as the surveying of the seabed is concerned we will cover this in the next section, "Geophysical survey methods".

Once the pipeline is in service it will need the following inspection:

1 Assessment of pipe burial or rock dump profile.

For this we will use 3d sonar scanning to give us a 3d image of the area in question, this type of scan can also give us a contour type presentation of the area (similar to that given on an ordinance survey map), and ultrasonic profiling which can give us a profile across or along the pipe or mound.

2 Span assessment.

If the pipe is not buried then it must be supported along its entire length in order to spread the weight evenly, if there is a span detected then it must be measured accurately, this can be achieved by the use of Laser sizing and ranging as well as by visual methods such as CCTV and photography, or by use of the D.E.I. (company name) Span monitor (ROV sits on the pipe over the span and the DEI unit will assess vertical and lateral movement of the pipe, uses accelerometers). From time to time there may well be a need to re-assess the pipe burial, this may be necessary after storms have gone through a region.

3 Weight coat assessment.

Weight coat is a concrete coating, which will have been sprayed on to the pipe prior to installation, this coating is designed to give adequate protection from the elements and physical damage from anchors or fishing gear etc, it will also add stability to the pipeline. If the weight coat is damaged then the pipeline will tend to corrode more than before and will obviously not be as well protected, we will assess the weight coat by the use of CCTV, photography and LASER sizing and ranging.

4 Physical damage.

Physical damage assessment will normally start with the initial video done on the pipe as the vehicle tracks along it, if an item is found then further assessment will be carried out as necessary, this may involve photography, Photogrammetry, close video inspection and CP readings.

5 Cathodic potential readings, assessment of the corrosion protection system.

This will give an idea as to the structures ability to withstand corrosion at a given point; this will be achieved by video inspection of the anodes and cathodic potential readings at intervals along the pipe. These can be achieved by the employment of either a Contacting measurement device or a Proximity Probe, or perhaps Current Density systems, which measure the current flow around the pipe.

6 Visual assessment of features (flanges and valves etc).

This will be achieved by the use of video, videogrammetry, photography and Photogrammetry of the component.

GEOPHYSICAL SURVEY METHODS

Geophysical survey relates to the assessment of the seabed and physical environment into which the pipeline is placed, this will involve the following:

1 Seismic profiling:

This will show the profile of the seabed surface and sometimes sub-bottom profile, surface scanning is often termed topographic survey and will show the shape and contours of the seabed in the area of the transducer, this can then be illustrated by means of a 3 dimensional display or by contoured printout.

2 Sub-bottom profiling:

Will show the sub strata on which the pipe or structure will be located, this can commonly penetrate the seabed to a depth of 100 metres, and will allow the detection of buried pipelines as well as giving a depth of burial, the system can also be used to detect shallow gas pockets, hydrographic cable reconnaissance and deep water alluvial mining.

3 Trench profiling:

As a pipe is laid in a trench it will be important that the depth is controlled, this can be achieved by altering the attitude of the plough laying the pipe, but it can only be achieved if there is accurate information as to the placement of the pipe in the trench. This can be achieved by the use of a high-speed echo sounder capable of obtaining real time video displays. Normally this will involve employment of dual scanning head transducers which simultaneously view both sides of the pipe, this method will provide a hard copy of the pipeline or cable and the trench in which it is located, in addition the information can be displayed on the pilots monitor thus allowing alteration of the vehicles attitude immediately.

INSPECTION DATABASE

All of the above will be referenced to an **inspection database**, this will reference the inspection to the previous years inspection to a point that if damage is re-located next year then a single still frame of it can be superimposed on to a computer impression of what it was like the previous year. This is very good for trend analysis such as span migration etc.

In general all of the inspection results will be presented on an AutoCAD system.

VEHICLE POSITIONING

With all of the above methods positioning of the vehicle will be of paramount importance, this can be achieved by the use of accurate positioning reference systems, both the ship carrying the surface support and the ROV will need to be accurately placed and this can be achieved by the following methods:

SURFACE SHIPPING.

1 Global positioning systems or Differential Global Positioning System (GPS or DGPS)

In order to achieve an accurate position there have been placed in Tundral stationary orbit several satellites, with the aid of some relatively simple ship based electronics the satellites can be used to triangulate the ships position on the surface of the globe relative to the satellites, this method can be extremely accurate. Ships using this method will periodically contact a shore-based station in order to calculate any error that may be evident in the information given by the satellites

2 Artemis

Artemis is a line of sight method, incorporating a mobile antenna on the ship, and a fixed antenna on the platform. Shipping, cranes and helicopters etc passing between the two antennas, can cause the ship to loose its Dynamic Positioning (DP) capabilities, as it is line of sight only.

3 Hydroacoustic position reference systems (HPR)

This technique involves placing several transponders on the seabed, each will inform the ship of its location and the ship can then work out its position relative to them, the transponders should be placed upwind and upstream (current) of the ship. The transponders can be placed on the vehicle and this will then allow the ship to follow the vehicle as it progresses along a pipeline etc.

4 Taut wire

This will involve deployment of a weight on a wire, the weight will keep the wire taut and the ship will assess the angle of the wire, and can thus keep the ship on station. The maximum angle a taut wire can be allowed to stray from the vertical is 15°. It should be noted that at all times when diving operations are taking place-involving divers there must be a taut wire deployed.

5. Inertial Navigation Systems (INS)

INS is a system, which uses gyros, and accelerometers to position the ship and sense any movement, once set this system can sense any movement of the ship including a change in heading. If the system uses traditional gyros it will not be all that stable and so will need to be referenced to another system and updated at intervals, however if laser gyros are being used any drift caused by the earths movement can be compensated for using electronics and so the system becomes very reliable.

Positioning of the Underwater Vehicle.

During inspections and surveys there is obviously a great need for accurate positioning of the vehicle underwater, this is normally achieved by the use of **Hydro Acoustic Position Referencing systems (HPR)**. This method relies on the placement of a beacon on the vehicle which will be mobile relative to the ship, there is another transducer placed in the water from the ship which will be effectively fixed relative to the ship, by assessing the range between the two transducers and also calculating the bearing from one to the other the vehicles position can be accurately plotted. The vehicles depth will also be monitored by a bathymetric device, thus the vehicles position can easily be fixed in three dimensions.

Once on a pipeline the vehicle will be placed by the use of Kilometre posts and field joints both of which are known positions and can be easily located on maps and drawings. They will be used to reference anomalies and features, with the aid of Odometer wheels on the bottom of the vehicle, this method will only be accurate over a relatively small distance.

ROLES AND RESPONSIBILITIES OF PIPELINE SURVEY PERSONNEL

There are several persons involved in a pipeline survey these are as follows:

Pilot

The pilot will be responsible for flying the vehicle to the correct location and keeping the vehicle on site for the desired period.

Data logger (3.3U)

Will be responsible for the immediate gathering of the information from the ROV, such as CP readings etc, in addition he will be expected to put a commentary on to the video as and when necessary.

Inspection controller (3.4U)

Will be responsible for the overall inspection and as such may be involved in more than one inspection at a given time (there may be a diving program under way simultaneously), he will program the inspection and will handle the data, videos and photographs etc which have been collected, he will be responsible for the transmission of this data to the shore base in the proper manner, and he will ensure that all data is correctly referenced and logged. The controller will be familiar with the criteria of non-conformance and so will be assessing anomalies with regard to their importance.

Client's representative

The client's rep will be responsible for the initial acceptance of data, video and photographs, it is his responsibility to either accept or reject results, in addition he may well be able to authorise additional examination with regards anomalies found during the routine inspection. In all cases he will be the link between the offshore operation and the shore base of the operating oil company.

Shore based engineering department

All of the inspection program will be generated by the engineering dept taking into account all previous inspections and the damage register, the engineers will dictate the criteria of non conformance and will assess any anomalies as and when they are found offshore, they will indicate the need for repair and the modification of future inspections to be carried out on the structure.

CHAPTER 38

Floating Production Storage & Offloading Units (FPSO)

FPSO's have been in use since 1977 the first was installed off the coast of Spain in the Castellon field. There are several reasons why FPSO's make good economical sense the main ones are as follows:

1. The water depth is too great for conventional structures.
2. In shallow water locations where the size of the hydrocarbon accumulations is too small to make conventional platforms viable.
3. In areas where export pipelines are too expensive.
4. Where the hydrocarbon accumulations are too far apart to be drilled from one platform and the cost of more than one platform is prohibitive.
5. Where weather conditions are extreme, FPSO's can in some instances be disconnected and removed before bad weather arrives.

Normally FPSO's are not used to store gas, rather if gas is involved it will be used as fuel or maybe it will be re-injected downhole. Most FPSO's will be used as storage vessels for oil only.

There are a very large number of variations in the design of FPSO's some are converted monohull vessels such as tankers and in one case an ex Russian submarine support vessel (Foinaven), some are purpose built vessels. Some may be self-propelled while others are effectively "dumb barges" without any propulsive power at all. Most FPSO's use a turret system, which allows the FPSO to "weathervane" (vessel can rotate, head to wind or tide), but some are moored and have risers running up to the side of the vessel.

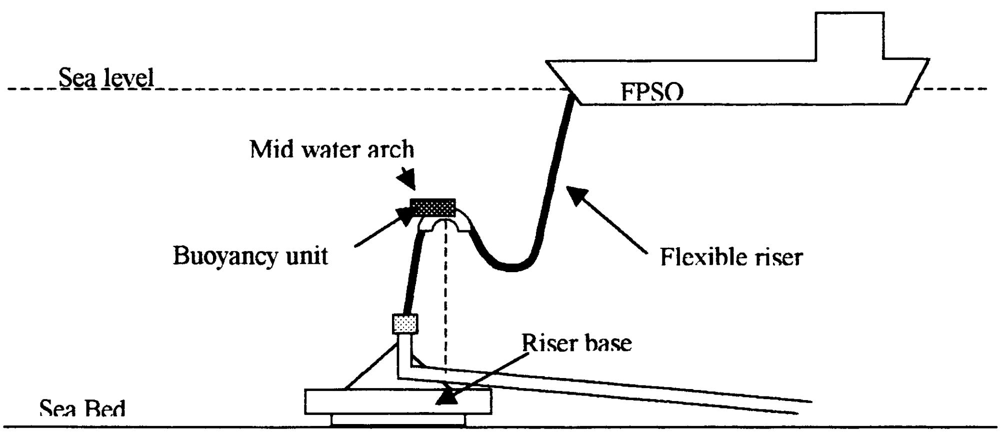


Figure 38.1 Floating Production Storage and Offloading unit (FPSO)

The typical components of an FPSO system are as follows:

Turret

Some Turrets are internal of the vessel whereas some are external. Internal turrets will normally be positioned close to one end of the vessel in order to reduce the mooring loads; internal turrets tend to be used where mooring loads will be high i.e. in exposed locations. External turrets are suitable where the mooring loads are lower (in shallower water depths). Some turrets can be locked to allow work on the turret without risk of the turret moving, it should be noted that when the turret is locked the ship would not be able to "weathervane".

Flexible Riser Systems

Some FPSO's use risers that can be disconnected this means that the FPSO can leave the field for bad weather and disconnectable risers will make replacement of damaged Subsea hoses easier. Riser systems will not normally hang vertically from the vessel, they will normally have catenaries in the form of the "wave" or "S" type. With both of these systems there will be a requirement for the riser to be supported midwater using buoyancy of some sort, this may be a large single buoy which will be tethered to a "deadman" anchor on the seabed or alternatively it will be supported by a series of smaller buoys, these do not need a "deadman" anchor, rather they will be restrained by the riser itself. The risers will be separated to avoid any contact with the buoyancy midwater. The buoyancy will pull the riser up to a high point with the riser rising to this point and then falling away into a loop once over the buoyancy this is normally referred to as the "arch".

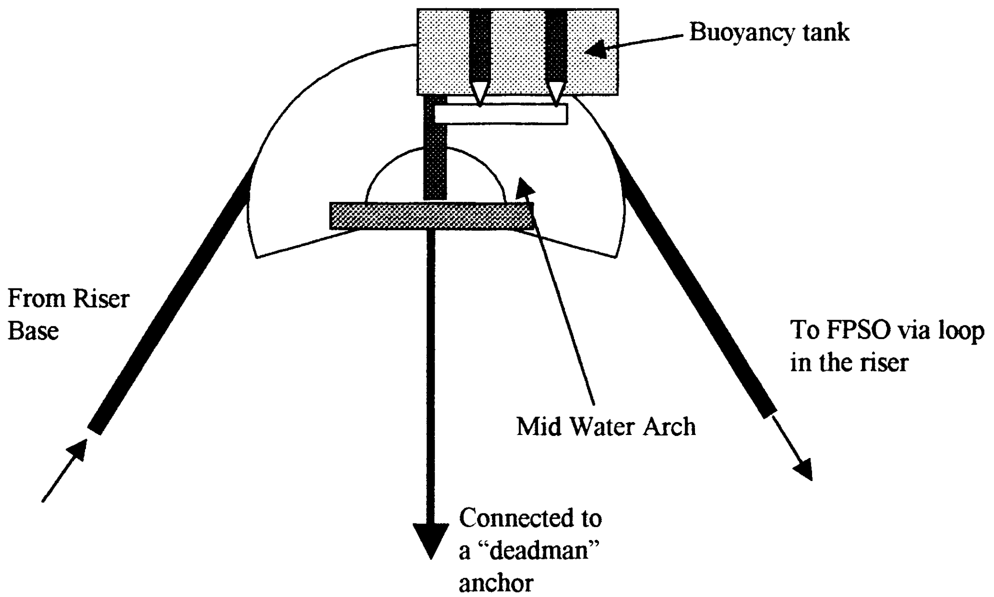


Figure 38.2 Mid water arch.

Buoyancy is used in order to ensure that any rise or fall of the vessel is taken up by the flexible riser and not by laying the pipe onto the seabed repeatedly; this will protect the riser and give a longer life to the system.

In the case of the single large buoy being used there will be a CP system used to protect it from corrosion, however with the smaller buoys there are normally no metal parts and so CP is not required.

Subsea Pipeline and Wellhead systems

These will be very similar to those found in conventional fields, there may be flexible or rigid flowlines used. In some fields there may be a requirement for Subsea manifolds to collect the oil before sending it to the FPSO.

Offloading system

Offloading will normally be carried out using a hose passed from the FPSO to the transfer tanker. This hose may be left floating when not in use and care should be taken in order to avoid getting fouled with it when moving around the FPSO.

Mooring system

There will normally be a set of mooring lines radiating from the FPSO; in some cases these mooring lines are attached to piles driven into the seabed. However they may be connected to anchors in some cases. There may be a requirement to inspect the mooring lines/chains and this may be done in some cases by divers or ROV, care should be taken when working at the touchdown point as the vessel could pull the mooring thus lifting the line only to put it down onto a divers umbilical. The chains will have no CP protection and will wear, inspection may be needed to check the wear and this can be done again by diver or ROV, there are some sophisticated optical video systems that allow this to be carried out to a very high standard by ROV.

Inspection of FPSO systems

It should be noted that FPSO's are prone to "weathervane" and this could be a safety hazard when working close to the vessel, it may be better to dive from the FPSO or to moor directly to the FPSO and allow both vessels to move together.

Mooring and Riser Inspection

Mooring and riser systems are probably best inspected using ROV due to the fairly extreme depths involved; this work should be carried out in flat calm conditions with the ROV support vessel having a planned escape route in case of emergency. Generally mooring inspection will include the following:

1 ROV visual survey
2 Measurement of individual links for wear
3 Possibly removal of sections of chain for assessment on the surface

Some companies carry out a rolling programme of chain renewal and refurbishment to reduce the possibility of a mooring parting.

Hull Inspection

Marine growth will make inspection of the hull impossible it will depend on where the FPSO is located in the world as to the amount of growth likely and thus the cleaning regime necessary. The hull may require a full GVI inspection and thus it may be necessary to carry this out when the FPSO is fully loaded in order to have access to as much of the hull as possible. Seachests/inlets will need to be cleaned and close inspection carried out as this is normally a requirement by ABS and Lloyds, and divers would normally carry out these tasks.

Turret Inspection

The turret will need to be inspected at regular intervals, some turrets can be immobilised to ensure a safe environment for inspection and divers will normally carry this out. Specific information will need to be recorded depending on the particular design being inspected.

Detailed Inspection

Detailed inspection of Subsea components will normally be carried out during dry-dock or refit, this may involve wall thickness measurements or lamination checks may be required at certain points on the hull, however if the hull is single thickness some of this could be carried out from inside the hull while the ship is on station. MPI may be required on particular welds on the hull or on external turret buoys or riser systems. ACFM has been used to assess a weld on a "deadman" anchor in very deep water using ROV.

CP survey

CP survey will be required at the same time as GVI/video surveys, again these are normally carried out using ROV and can be done using either contact or proximity systems, there may be both sacrificial and impressed current system on the vessel and these would need to be inspected as part of the overall programme.

CHAPTER 39

ROV Classification

The following is an extract from the IMCA guidance note 051, which relates to the safe and efficient operation of remotely operated vehicles, this guidance classifies the vehicles as follows:

1 Pure Observation (Class 1)

Pure observation vehicles are physically limited to simple video observation. They cannot undertake any other task without considerable modification.

2 Observation with Payload Option (Class 2)

These are vehicles capable of carrying additional sensors such as still colour cameras, cathodic protection measurement systems, additional video cameras, sonar systems and flooded member detection systems. A class 2 vehicle should be capable of operating without loss of its original function when carrying at least two additional sensors.

Examples: Dart, UFO, Sea Hawk, Scorpi, Sprint, Sea Owl, RCV 225 and Inspector, Sea Eye 600

3 Workclass Vehicles (Class 3)

These vehicles are large enough to be fitted with additional sensors and/or special tools or manipulative tasks. Class 3 vehicles should have a mulitplexing capability allowing additional sensors and tools to be operated without being "hard-wired" through the umbilical system. The umbilical should, however, have spare conductors to allow operation of payload equipment. Workclass vehicles should have sufficient propulsive power to operate at least one thruster in each of the longitudinal, lateral and vertical directions.

Examples: Scorpio, Pioneer, Rigworker, Trojan, Triton/Challenger, Hydra, Hysub, Duplus/Mantis and Recon

4 Towed or Bottom Crawling Vehicles (Class 4)

Towed vehicles have no propulsion power although they may be capable of limited manoeuvrability. They travel through the water by the hauling action of a surface craft or winch. Bottom crawling vehicles move primarily by exerting ground pressure on the sea floor via a wheel or track system although some may be able to "swim" limited distances.

Examples: Towed - Ocean Surveyor and benigraph
Crawling - Sea Dog and Seabug

5 Prototype or Development (Class 5)

Vehicles in this group include those still being developed or regarded as prototype and special purpose vehicles which do not fit into one of the other four classes.

Chapter 40

Personnel Responsibilities

1 Independent Verification Body

The government requires that a structure be inspected at regular intervals, however they do not certify the structure as safe, this is left to the Duty Holder. They will work with Independent Verification Bodies who are government approved. There are six currently working and these are:

1	Lloyds register -----------------------	United Kingdom
2	Germanischer Lloyd -----------------	Germany
3	Bureau Veritas ----------------------	France
4	Det Norske Veritas ------------------	Norway
5	American Bureau of Shipping -----	United States of America

These Independent Verification Bodies will work with the clients engineering department to produce an effective Inspection Repair and Maintenance program for the structure, however it will remain the responsibility of the Duty Holder to ensure that sufficient inspection is carried out to keep the structure safe to operate.

2 Client or Operator company (Duty Holder)

The client will be the party of the contract who requires the service outlined in the contract and pays for the service on completion of the contract. e.g. the Oil company which owns or operates the installation being inspected, as such they will be responsible in law for ensuring the safety of the structure.

It will be the clients engineering department which normally puts together the workscope and decides the level of inspection to be carried out on a particular platform. The client will employ an offshore representative to oversee works being carried out and to ensure the terms of the contract are adhered to. It will be the clients representative who is responsible for aspects of the job such as safety, conduct of the vessel, compliance to procedures and specifications and liaison with other field activities. The clients rep will only be allowed to request more work over and above the works initially agreed on if the contract is a day rate contract, if it is lump sum then there will have to be some re-negotiation. The offshore clients rep would be responsible for initial acceptance or rejection of accumulated data such as videos and photographs etc if a safety or contractual problem arises he could terminate a dive, but could not initiate one.

3 The Contractor

The contractor will be the party of the contract who provides the service outlined in the contract. e.g., the diving company. It will be the contractors responsibility to provide enough personnel with the correct qualifications, and sufficient equipment to carry out the works in a safe and responsible manner, he is bound by law to issue methods and procedures to ensure a safe working environment for the personnel employed.

4 Underwater Inspection Controller

The offshore inspection controller is either employed by the contractor, the client or maybe these days even by a third party, i.e. a specialist company, he is responsible for efficient management of the inspection program, reporting to all concerned the progress of the job, to plan dives (in association with the diving supervisor), brief divers, record data and report anomalies to the Clients offshore representative. He must have a good understanding of the limits and physics of the intervention techniques at his disposal and also the structural response of the platform, which will allow him to plan and program the correct method of inspection and intervention technique. The Inspection Controller should be diplomatic and knowledgeable, he will be responsible for liaison between the diving supervisor, the client rep, the master of the vessel, the OIM and the shore base representatives of the diving company and the client engineering dept.

5 Offshore Installation Manager (OIM)

The OIM is a member of the staff employed by the operator, he is the manager responsible for the safety and day to day running of the platform and all activities within a 500m radius of the platform. In the event of any incident requiring first aid then he is responsible for notification of the relevant government bodies, if there were safety aspects which the OIM did not like then he could terminate a dive.

6 Master of the Vessel

The master of the vessel is responsible for the safety of all persons on board his vessel and as such he could terminate a dive if he felt that there was a safety problem, in the event of a structure emergency the vessel is at the disposal of the OIM however the master will always ensure the safety of the personnel on board first.

7 Diving Supervisor

The diving supervisor is responsible for the safety of all persons under pressure by law, as such he is the only person legally able to initiate diving he also can terminate the diving if he feels the need. The diving supervisor will be qualified to IMCA standards and will be appointed in writing, he will have sufficient experience of the tasks involved and will be a useful ally in the planning and briefing of the divers and diving crew. Sometimes it may be necessary to explain in a diplomatic way that the whole reason for the diving team being on site is to carry out the inspection contract and so the inspection controller should try to foster a good working relationship with the supervisor.

8 The Divers

The divers will be suitably qualified to CSWIP standards and so should be familiar with the equipment and to some extent the procedures being used, however it should be remembered that a good briefing will be necessary in all but a few cases

9 ROV Supervisor and Pilots

The ROV supervisor and pilots will again be qualified to CSWIP standards but as with the divers it will be important to brief thoroughly.

CSWIP Grades

3.1U Diver

The 3.1U diver will be a qualified diver to HSE Pt one, two or three. The diver would be expected to be able to apply the following inspection techniques underwater:

1 Visual inspection, both general and close survey
2 Closed Circuit Television survey
3 Photography, both stand off and close up
4 Cathodic Potential readings, and the meaning of the readings taken
5 Ultrasonic digital thickness meter readings

3.2U Diver

The 3.2U diver would have a 3.1U and have been in the industry for at least one year. The 3.2U diver would be expected to be able to apply the following techniques underwater:

1 Magnetic Particle Inspection
2 Ultrasonic A'scan inspection (note this will for divers certified prior to 1993 only, as 3.2U divers are no longer examined practically on this technique)
3 Weld toe grinding (not an NDT technique but should be applied to welds if defects are found during MPI)

3.3U Pilot Observer

The 3.3U will have the following experience:

1 A manned submersible pilot or observer, having completed a minimum of 15 operational dives,

or

2 Be an ROV pilot or observer having completed a minimum of 100 logged hours of underwater inspection work experience as pilot or observer,

or

3 Have a qualification in a relevant engineering or science subject which should not be less than HNC level or equivalent and a minimum of 12 months subsea engineering related work, including a minimum of 60 days spent at an offshore site,

or

4 Be a current or previously approved CSWIP 3.1U or 3.2U diver inspector who has held such certification for a minimum of three years, with a minimum of 100 logged hours of underwater inspection work,

or

5 Be a surface NDT practitioner, certified under PCN/CSWIP in ultrasonic testing, magnetic particle or penetrant testing or equivalent approval accepted by the CSWIP underwater inspection management committee, who has a minimum of three years documented

experience in the application of NDT methods related to offshore facilities and to have spent a minimum of 30 days at an offshore work site gaining familiarity with underwater inspection techniques.

The 3.3U will be expected to be able to carry out inspection by means of ROV or manned submersible using the following techniques:

1 Closed Circuit Television, remotely applied
2 Photography applied by ROV
3 Cathodic potential readings taken by ROV
4 Ultrasonic methods for wall thickness
5 Flooded member detection

In addition the 3.3U would have a knowledge of data handling and processing.

3.4U Inspection Controller

The 3.4U will have the following experience:

1 Have a qualification in a relevant engineering or science subject which should not be less than HNC level or equivalent and a minimum of 12 months subsea engineering related work, including a minimum of 60 days spent at an offshore site,

or

2 Be a currently or previously approved CSWIP 3.3U ROV inspector who has held such certification for a minimum of one year, with a minimum of 300 logged hours of underwater inspection work,

or

3 Be a current or previously approved CSWIP 3.1U or 3.2U diver inspector who has held such certification for a minimum of three years, with a minimum of 100 logged hours of underwater inspection work,

or

4 Be a surface NDT practitioner, certified under PCN/CSWIP in ultrasonic testing, magnetic particle or penetrant testing or equivalent approval accepted by the CSWIP underwater inspection management committee, who has a minimum of three years documented

experience in the application of NDT methods related to offshore facilities and to have spent a minimum of 30 days at an offshore work site gaining familiarity with underwater inspection techniques.

The 3.4U will be expected to have knowledge of all aspects of the ROV inspector (3.3U) grade and of the inspection and testing methods included in the 3.2U examination. The 3.4U must have knowledge of the capabilities and limitations of diving, ROV's and submersibles, and an understanding of inspection planning and briefing, He/She must have an appreciation of the roles and responsibilities of other personnel and organisations, including Offshore Installation Manager, Master, Diving supervisor, ROV supervisor, Client's representatives, Certifying authority and Government departments.