# CHAPTER 16

# UNDERWATER CUTTING AND WELDING

There are at least ten general techniques in current use for cutting underwater. Choosing the most suitable technique for a job, whether it be construction, maintenance or demolition, is more a consideration of operating conditions and the quality of the cut required, than anything else, although cost is a very relavent factor. Similarly, with welding underwater, there are two basic methods, known as "wet" and "dry" welding, both of which have their respective merits.

This chapter will deal only with the three basic cutting methods employed underwater, namely gas cutting, oxy-arc and thermic cable, which are the skills normally practised during diver training. The principles, methods of operation and safety precautions of underwater electric arc "wet" welding are also covered, with some reference to habitat or "dry" welding, but it is stressed that it takes years of practice to become proficient in this skill.

## UNDERWATER CUTTING

## GAS TORCH CUTTING

The basic principle of cutting metal underwater by means of a gas torch, is essentially the same as that employed on the surface, except that the equipment has to be modified, and hydrogen gas substituted for acetylene as the "fuel". Oxy-acetylene can be used underwater, but only at very shallow depths, ie. a maximum of 7m, since acetylene cannot be compressed to overcome the water pressure deeper than 7m. Instability of an acetylene flame underwater is a further disadvantage, whereas oxy-hydrogen cutting equipment can be used down to 37m.

## OXY-HYDROGEN CUTTING

With this method, a special torch allows a mixture of oxygen ($O^2$) and hydrogen (H) to burn, generating sufficient heat to melt the material to be cut. This flame is directed at the metal until a small molten puddle is obtained known as the "hot-spot", after which the diver causes a jet of pure oxygen to be directed into the puddle, causing the metal to oxidise or burn. The pressure of oxygen in this jet is then sufficient for the oxidised metal to be blown out of the cut, sometimes known as the "kerf", after which it falls to the bottom as globules.

If the diver now moves the head of the torch, at a slow uniform rate in the direction of the desired cut, the continuous process of heating, oxidisation and blowing away of metal, will achieve the desired result. In most cases, divers under training will have some difficulty in obtaining a "hot-spot" or else maintaining a uniform cut without "bridging", but this is only a matter of practice and experience.

Although underwater gas torch cutting is seldom used in the offshore industries, the equipment has many advantages over other methods, particularly regarding portability and the very neat, clean cut obtained.

The cutting torch most commonly used in this country is the Kirkham Sea Vixen Mk 2, which was designed specially for underwater use, and requires only a two-hose supply of oxygen and hydrogen, with a single core electrical cable as an addition, if the torch is required to be lit underwater. This torch originated as the Kirkham Seafire, designed in 1945, which has been in use by the Ministry of Defence almost to the present day. Technical changes modified the original design, after which it became known as the Vixen Mk 1 and Mk 2, the latter sometimes being known as the Vixen Salvage torch, simply because it was capable of cutting steel up to 150mm thick. The Sea Vixen Mk 2 is designed to have a maximum cutting capability of 100mm(4in), but will in fact cut metal much thicker.

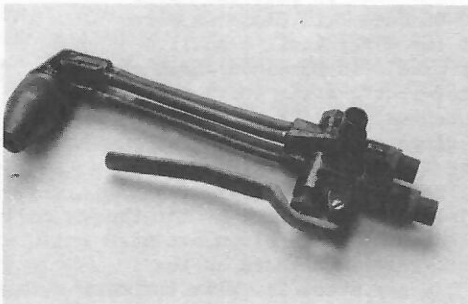


Fig 16.1 Sea Vixen Mk 2 oxygen-hydrogen underwater cutting torch

Setting up procedure

To avoid blockages due to grit or small particles entering the torch jets, it is important that the complete system is flushed through with high-pressure gas before connection. The following is the standard procedure:

1 Clear the cylinder connections of any foreign matter by briefly opening and closing the valves of both the oxygen and hydrogen cylinders, known as "cracking" the cylinders.

2 Fit the oxygen ($O^2$) regulator; this is usually colour coded black, and the hose connections will be right-handed.

3 Connect the blue or black hose, with right-handed threads, to the regulator, and open the cylider valve. Adjust the regulator control to flush gas through the system, then return control to the point where the gas flow ceases.

4 Fit the hydrogen (H) regulator; this is usually colour coded red, and the hose connections will be left-handed.

5 Connect the red hose, with left-hand threads to the regulator, and carry out the flushing operation detailed in (3) as for the oxygen.

6 Fit a 'blow-back' preventer non-return valve at the torch end of each hose.

7 Connect the blue/black and red hoses to their appropriate fittings on the torch, and then tighten all connections with a spanner.

8 Close the torch valves; open the regulator controls, increasing the pressure reading on both regulator output gauges to the maximum anticipated working pressures and check for leaks. The torch can be submerged in a bucket of water, or lowered over the side of the craft as convenient for this operation.

9 Fit the striker plate and connect the leads to the torch frame, and the battery.

The torch is now ready to be lit.

<u>Ignition procedure</u>

Turning 'ON':

a. First turn on the oxygen ($O^2$), black regulator, to give a suitable gas pressure for shallow cutting.

b. Next turn on the hydrogen (H), red regulator, to give a suitable gas pressure for shallow cutting.

c. Turn on the oxygen knob (black) of the torch - 2 full turns

d. Turn on the hydrogen knob(red) on the torch - a ½ to 1 turn

e. Light the torch

Turning 'OFF':

a. Turn off the hydrogen (red) knob, on the torch

b. Turn off the oxygen (black) knob, on the torch

c. Turn the two regulator controls

"off", hence cutting off the gas supply

It is important  to note that hydrogen is a highly inflammable gas and as such very dangerous, and must be turned on AFTER the oxygen, and off BEFORE the oxygen.

STRIKER PLATE

The purpose of the striker plate is to enable the diver to light the torch underwater. This is of considerable advantage, since it allows the operator to light or extinguish the torch at will as work progresses, and be a considerable saving on gas consumption. The alternative is to light the torch on the surface each time, and either lower it to the diver, who may not easily locate it in bad visibility, or for the diver to return to the surface and collect the torch.

The striker plate consists of a serrated brass plate casting, connected through a water-tight lever switch, to the positive (+) terminal of a 12v DC source on deck. The negative terminal is connected to the body of the torch itself.

To light the torch underwater, the diver opens up his torch gas valves the correct number of turns, and in the correct sequence. He then closes the striker plate swith with one hand, whilst drawing the cutting nozzle of the torch itself across the serrated plate with the other. As the negative polarity torch rubs across the positive plate, the voltage will allow current to flow, and violent sparking will result in the gas being ignited.

The diver must remember to push the torch away from his body across the plate, in order to protect his diving suit from the somewhat violent ignition which will result. It is also advisable that the diver should wear gloves, to prevent any accidental burning of the skin. As soon as the torch has been lit, the diver can release the striker plate switch, which should isolate the positive (+) 12v connection from the plate.

In practice, the striker plate switch and electrical connections require frequent servicing, to renew seals, remove corrosion etc, otherwise the switch will short out due to water ingress and the plate will remain at 12v positive potential for the duration of the dive. This will cause a permanent short-circuit, with the result that the voltage source, assuming it to be battery, will quickly drain to zero volts as the current flows from the torch, through the water, to the plate.

Transfer of a Lit Torch

If a striker plate is not being used, or it has become unserviceable, then the torch must be surface lit and passed to the diver within a maximum of 5 seconds, otherwise the copper shield will be burnt due to the excessive heat without cooling.

For testing or demonstration purposes, provided the outer gas shield is unscrewed and removed, then the torch can be surface lit and allowed to burn for as long as is necessary, even being used to carry out cutting work. However, once the shield is fitted, it must immediately be immersed in water.

Transfer of an Unlit Torch

If a striker plate is being used, it is essential that no water is allowed to enter the torch body before it is lit.

Before the torch is allowed to enter the water, the diver must be instructed that the surface have opened the torch oxygen valve about half a turn. This should be sufficient to allow a steady escape of gas from the torch nozzle. If, due to depth, the flow of oxygen is obviously insufficient, then the attendant must increase the flow by valve adjustment.

This trickle of gas should continue until the torch is lit, and should the diver extinguish the flame underwater, he must leave sufficient flow of oxygen to prevent water from entering the torch chambers or hose.

## Cutting Nozzles

The copper alloy cutting nozzles used with the Sea Vixen torch, are precision made, complex and costly units, consisting of a series of concentric cylinders, each with accurately drill gas metering holes at both ends. For this reason, they demand careful attention, and a nozzle should never be used with which to hammer or knock an obstacle, and the nozzle jets will require frequent cleaning with special wire 'prickers'.

Nozzles are available in 4 grades, and the size ( 1 - 4) will be stamped on the side.

No 1 For mild-steel plate up to 19mm(3/4in) thick

No 2 For plate up to 38mm(1½in) thick

No 3 For plate from 38 to 51mm (1½ to 2in) thick

No 4 For plate from 51 to 102mm(2 to 4in) thick

## Cutting Procedure

Fig 16-2 is a Table of Pressures indicating the pressure of both hydrogen and oxygen required with regard to both depth, and the size of nozzle fitted to the torch. For example, if a No 4 nozzle were fitted, the left hand arrow shows that this will cut metal from 2 to 4in thick. If the diver anticipates cutting 3in metal, then the gas pressures required would be 35lb per sq ins, to which must be added the depth allowance of an additional 1lb of gas pressure for every 2ft of water depth. If in this case, the diver was working at a depth of 60ft(18m), then the depth allowance would be an extra 30psi, so that 30 + 35 = 65psi gas pressure necessary of both oxygen and hydrogen.

The diver, having lit the torch, or having it passed down in a lit condition, places the cutting shield in contact with the metal at the point where cutting is to commence, which can be an edge, or the middle of a piece of plate. There is no necessity to put any pressure on the head, but merely to hold the "tubular" section of the torch in one hand, and the base and cutting lever with the other.

Before cutting can commence, the metal must be pre-heated to the point whereby combustion can start. This should only take some 2-3 secs, after which white oxide sparks should be evident below the shield. As soon as these are seen, the diver should gently depress the cutting lever, and at the same time, commence to draw the torch at a slow, steady and uniform pace across the work in the required direction. If the torch is moved too fast, the cut will be broken and result in gaps, which are difficult to remove. If the cutting speed is too slow, this will only result in a wastage of gas.

The speed of cutting will vary accordingly with the thickness of the steel being cut. Material up to 1in thick can safely be cut at a rate of about 1in per 5 seconds, but only after some practice.

As penetration is achieved, so the sparking and volume of gas bubbles will reduce, since they will now be passing down and out through the cut. If during use, the flame and bubbles increase, and a loud "banging" noise is heard when not actually cutting, this is an indication that the torch is alight inside itself, and the hydrogen valve should immediately be closed, which will extinguish the flame. If this situation arose in cutting equipment not fitted with "blow-back" preventers, it is possible for the flame to travel back up the hose to the surface, and possibly cause a major explosion.

## After Use Maintenance

Following use, the torch should be washed off in fresh water, warm if available, Before being disconnected, oxygen should be flushed through the system, after which the torch is removed and dried.

The shield should then be unscrewed, the nozzle removed by unscrewing its locking ring, and all three components wire brushed with great care. Any obstructions in the nozzle holes should be removed only with the correct size pricker tool. The torch should then be re-assembled, but with the various components removed left only finger tight.

Accessories

For safe and efficient cutting underwater, the following additional equipment should be considered:

A pair of gloves, and of choice those with a gauntlet 'sleeve' which offer some protection to the wrist seals of suits

Diving helmet or full-face mask

Diver communication

Staging or similar platform on which the diver can stand or sit to work

Underwater lighting, where possible

Safety Precautions

No oil or grease should be use on the regulators, hose fittings, cylinders or cutting torch

Surface attendant to monitor gas pressures and consumption

Beware of a build up of hydrogen gas in 'pockets' in a confined space

Follow the recommended procedure for turning a torch "ON" and "OFF"

Fault Table for Sea Vixen Operation

Torch will not light:

Insufficient electrical supply voltage; poor electrical connections; blocked jets in the cutting nozzle; leaks in the hose connections.

Torch lights, but diver unable to obtain a "hot-spot":

Incorrect technique; wrong supply pressures; jets blocked; wrong nozzle; diver holding cutting lever depressed before a "hot-spot" can be achieved.

Hot-spot achieved, but torch will not cut:

KIRKHAM
VIXEN Mk2. TABLE OF PRESSURES

Table of Surface Pressures to cut steel up to a recommended thickness of 4″. Add 1 lb pressure for each 2′ depth of water.

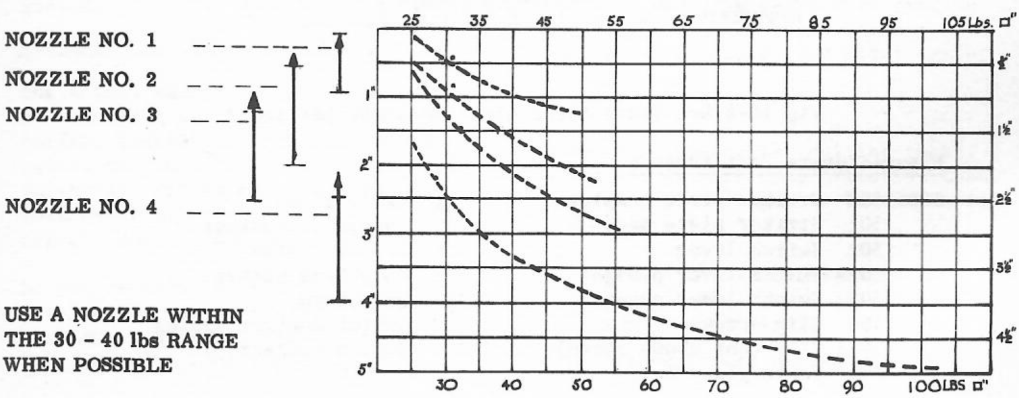



Fig 16-2 Table of nozzle sizes and gus cutting pressures

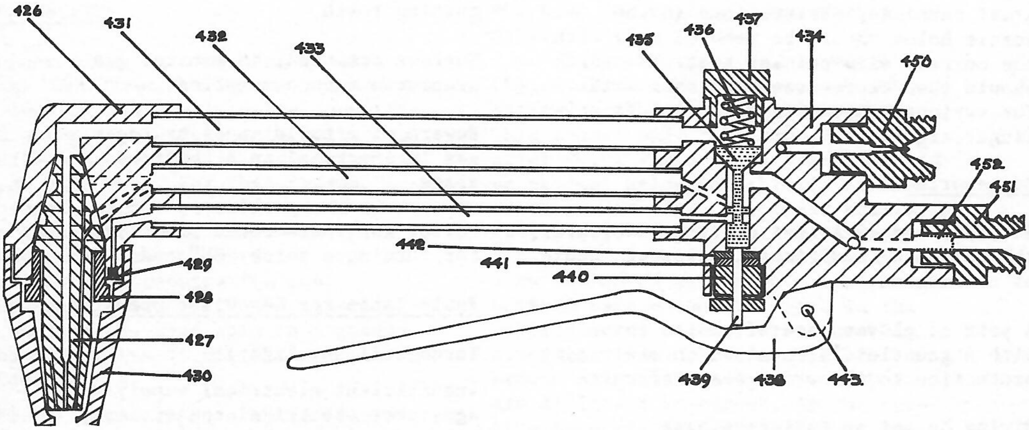



Fig 16-3 Cross section of a Sea Vixen torch, with part numbers

<u>Manufacturers Part Numbers</u>

| | | | |
|---|---|---|---|
| 50425 | Vixen torch complete | 429 | Shield feed restricter screw |
| 426 | Head casting | 430 | Shield nozzle |
| 427 | Nozzle | 431 | Oxygen cutting supply pipe |
| 428 | Nozzle retaining nut | 432 | Heating oxygen or hydrogen pipe |

( Part Numbers continued on page 16.7)

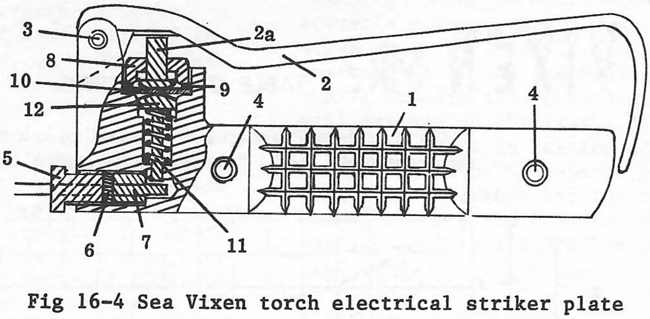



Fig 16-4 Sea Vixen torch electrical striker plate

<u>Manufacturers Part Numbers</u>

| | | | |
|---|---|---|---|
| 02962500 | Striker plate complete | 506 | Cable gland |
| 501 | Striker plate body | 507 | Insulated contact |
| 502 | Switch lever | 508 | Cap nut guide |
| 502a | Switch lever plunger | 509 | Diaphragm washer |
| 503 | Switch lever screw | 510 | Diaphragm |
| 504 | Clip screw | 511 | Switch contact spring |
| 504a | Clip (not shown above) | 512 | Switch contact |
| 505 | Cable gland nut | | |

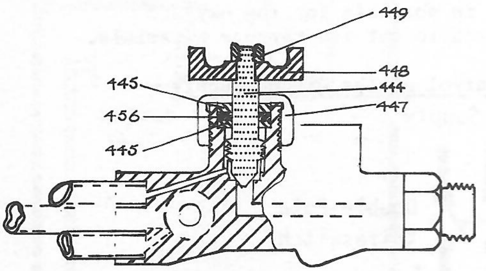



Fig 16-5 Sea Vixen valve assembly

Manufacturers Part Numbers (cont'd):

433 Shield supply pipe
434 Body casting
435 Oxygen chamber valve
436 Oxygen chamber valve spring
437 Spring cap nut
438 Cutting lever
439 Cutting lever plunger
440 Cutting gland nut
441 Cutting plunger gland
442 Cutting plunger washer
443 Cutting lever screw
444 Supply valve (oxygen or hydrogen)
445 Supply valve washer
446 Supply valve gland
447 Supply valve gland nut
448 Supply valve control wheel
449 Control wheel nut
450 Hydrogen inlet nipple
451 Oxygen inlet nipple
452 Oxygen filter

Metal unsuitable for cutting using a Sea Vixen torch; incorrect gas pressures; blocked centre jet; shield jet blocked; incorrect technique.

Torch stops cutting:

Tilting the torch on work; rough surface causes loss of hot-spot; falling gas supply pressures; lever not depressed; general blockage; nozzle burnt out.

When fully serviceable, the torch is very reliable, but any of the faults listed can usually readily be eliminated.

General Notes on Operation

The actual amount of gas being passed by the torch is controlled by the surface regulators, not the control valves on the torch itself. The torch valves are fitted only to allow gas metered by other means to reach the nozzle, and to shut off the flame.

Do not depress the cutting lever until pre-heating has been achieved, otherwise the additional flow of oxygen will only serve to cool the area.

The pressure readings on the surface will fall slightly when actually cutting, due to the additional gas consumption. This fall should not be corrected.

It is impossible to cut heavily rusted plate, or that covered with barnacles or other marine growth. In such cases, pre-cleaning must be undertaken.

Non-ferrous metals and stainless steel cannot be cut with a Sea Vixen torch.

If the cut is "lost", move over to one side of the original line, as close as possible, and start again.

OXY-ARC CUTTING

For most underwater cutting tasks, oxy-arc is more cost effective than gas-torch cutting, for the following reasons:

1 Less skill is required on the part of the diver, to achieve the same results.

2 Although more oxygen will be

consumed, this will not cost as much as the hydrogen content of gas cutting.

3 Greater thicknesses can be cut for the same effort.

4 Oxy-arc does not require the same degree of surface cleanliness as does gas cutting.

There are, however, disadvantages, as follows:

1 A considerable bank of oxygen cylinders will be necessary for prolonged tasks, or even the provision of a bulk oxygen supply.

2 The high amperage necessary, which must be "direct current" and not "alternating current" which can generally only be produced by a diesel driven generator, hence the power source is bulky and heavy.

3 The quality of the cut obtained is such that grinding may be necessary, if the remaining surface is to be flat. In gas cutting, by comparison, a very clean surface would remain.

The principle of the oxy-arc underwater cutting process is the utilisation of the intense heat created by an electric arc between the work, and a hollow steel or carbon electrode passing a current in the order of 200 amps, whilst at the same time, the arc is supplied with an oxygen flow.

The oxygen is supplied to a specially designed and fully insulated torch holder, and allowed to flow through a hollow electrode to emerge at its tip. Once an arc has been struck between the work and the tip of the electrode, the diver opens the oxygen control valve, by means of a lever, and the resultant flow of high pressure gas causes the base metal to oxidise, which is then blown clear of the cut. Since no pre-heating is required, the cutting process is instantaneous.

The heating energy available in an arc is much greater than that of any gas generated flame, hence it is possible for the oxy-arc torch to cut non-ferrous materials.

Control of the Oxygen Supply

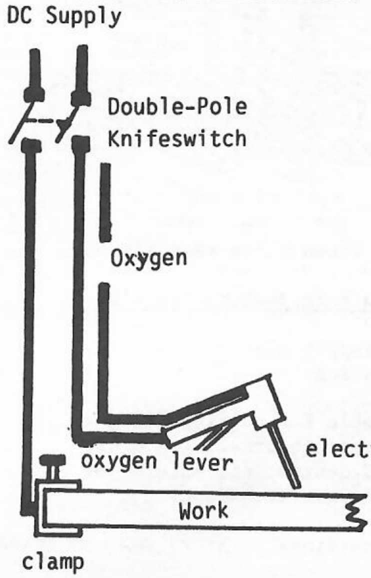



Fig 16-6 Manual oxygen control

With manual oxygen control, the necessary gas pressure is set up under "flow conditions", ie. with the torch cutting lever fully operated. For the duration of the task, the diver then has full manual control, and has only to press or release the cutting lever to start, or stop work.

An alternative method of oxygen control is illustrated in Fig 16-7, solenoid valve control of the cutting gas. Although possibly less economical that manual control, this method has the advantage of being almost trouble free.

With solenoid oxygen control, the cutting torch has no control lever, and relies purely on the current flow created by the arc, to energise a solenoid valve, which in turn opens, and allows gas to flow.

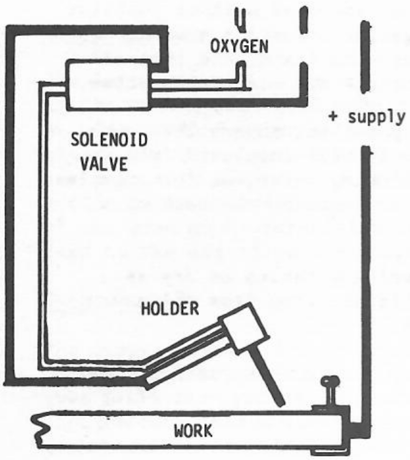



Fig 16-7 Solenoid valve control

As soon as the diver ceases work, with no current flowing, the solenoid valve de-energises, and the oxygen flow is cut-off. This method allows the diver greater concentration on the job, but otherwise its advantages are minimal.

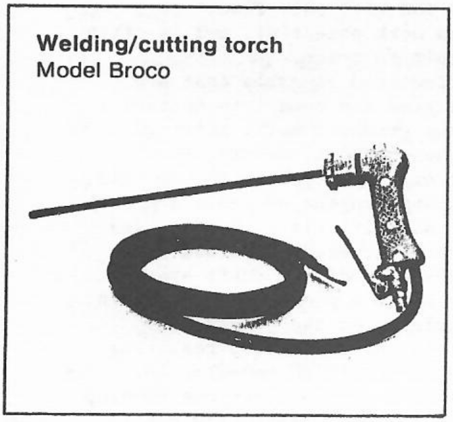



Fig 16.8 Broco model combined under-water welding and cutting torch

## Power Supply

It has already been mentioned that the power sourse must be DC (direct current), and a diesel driven machine producing 80v, 300 to 400amperes is ideal. Such generators are bulky and not readily available on a hire contract basis, other than from specialist suppliers. On no account should an AC (alternating current) generator be considered, or even tried as an experiment, since the diver will experience severe electric shocks which could well prove fatal.

An oxy-arc cutting torch will operate as low as 150amps, but as the current falls, so the cut will become rough, and more difficult to maintain, and the higher current levels are recommended.

## Polarity Switch

With oxy-arc cutting, the work is almost always maintained as the positive (+) electrode, and the actual cutting electrode/torch as the negative (-). A polarity switch which is a normal feature of most DC generators, will allow the polarity to be reversed if necessary.

## Polarity Testing

If there is an uncertainty as to which output cable from a generator is positive polarity, the following test can be carried out, assuming that a DC voltmeter is not available.

Connect a small metal plate to one cable, and immerse the plate in a bucket of water. Insert a cutting electrode in the torch holder, and attach the other cable to the torch connection. Place the tip of the cutting rod about 2in from the plate whilst both are still submerged.

With the current supply turned on, a heavy stream of bubbles should rise from the electrode tip if the torch is negative, and the plate positive. If this result is not achieved, then reverse the leads and repeat the test.

Having determined the polarity, the ground clamp should then be attached to the positive (+) lead, suitably marked, whilst the negative lead is attached to the electrode holder. The connection of the latter should be well insulated.

Safety Switch

A quick-acting, double-pole 'knife-switch' must be included in any circuit for oxy/thermal-arc cutting or welding in order to safeguard the diver, surface operator, and the equipment. This switch must break both positive & negative leads. Only by this means can a diver have complete confidence that the electrical power is "ON" when he requires ir, and "OFF" at all other times.

Operation of the switch can be the task of the surface diving tender, who should be aware of the hazards involved, and instructed only to operate the switch on receipt of instructions from the diver.

For this reason, it is almost impossible to work satisfactorily with oxy-arc cutting equipment without a full communication system, since the diver will need to instruct the surface support to "make it hot", ie. close the switch, and provide current into the circuit; or "make it cold", ie. open the switch, and break the supply.

The attendant controlling the switch then takes the necessary action, and acknowledges with the reply "torch is hot", or, "torch is cold", as appropriate.

Since the diver should have stopped cutting before the switch is broken, and should not restart until it has been made, there should be no arcing across the terminals of the knife switch. Nevertheless, the surface operator should be aware that arcing can occur, and that he should not look directly at the switch as it is changed over, to avoid the possibility of "arc-eye".

General Power Supply Notes

The following precautions should be taken when operating a high amperage power source, as would be required for underwater cutting:

1 Ensure the machine frame is well earthed, and that neither positive or negative terminals are allowed to touch the frame, and that all connections are clean and secure.

2 Where possible, ensure the power source is well insulated from any free flowing water, as for example might be found on the deck of a ship.

3 Keep welding cables as dry as possible and free from oil and grease.

4 Where possible, hang cables clear of any steel decking, but offer them support since when drawing heavy current, they will commence to sag as the copper conductors heat up.

Welding Cables

The cutting torch and "earth" lead must be completely insulated over their entire length, both on the surface and underwater. Current leakage underwater due to cracked or cut insulation will only result in a reduced work potential, and is often difficult to trace.

Sections of cable that are uninsulated and come into contact with any grounded metal fittings will cause arcing, melting the conductor, and breaking the circuit.

Long lengths of cable are both heavy and difficult to handle, and when being lowered or raised over the side of a diving craft are subjected to a great deal of strain, particularly at the joints. Any damage to the insulation resulting, should be rectified immediately.

For cutting operations in deep water, loss of current flow due to the increased resistance of the cable can only be overcome by using cable with a larger cross-sectional area.

All joints must be insulated with proper sleeves, and these can be given some support by taping the length of welding cable to a length of rope, rather like an unbilical.

Earth Clamp

The earth clamp must be well secured to the work task, which should first be wire brushed or scraped "shiny" clean. The cable should have sufficient slack to ensure that it is not accidentally pulled free, and must be of the same gauge material as the lead to the actual cutting torch.

Oxygen Supply

The oxygen consumption is not critical, and satisfactory results can be achieved over a wide range of pressures. Fig 16-9 shows a recommended range of oxygen gas pressures, but is intended purely as a guide only:

Cutting Electrodes

In oxy-arc cutting, work is performed at the expense of the cutting electrode, which is slowly consumed. Depending on the current setting, a steel electrode will last for about 40 to 60 seconds. The most common commercially available oxy-arc cutting or burning rod is made from 5/16in diameter steel tube, with a 1/8in bore, some 14in in length.

Another common type of oxy-arc cutting electrode is the copper coated, carbon graphite rod. Shorter in length, but greater in diameter, these maintain an arc far easier than steel rods, but are very brittle and break easily. They also require a higher amperage, in the order of 400amps.

Electrodes are covered with a flux which produces a gas bubble at the point of contact with the work, within which the arc burns. This bubble stabilises the arc, and prevents the heat generated from dissipating too rapidly into the surrounding water. Electrodes are also waterproofed, to protect the

Fig 16-9 Table of operating values for oxy-arc cutting

| Depth in Feet | Current in Amps | 1/8" | 1/4" | 3/8" | 1/2" | 5/8" | 3/4" | 7/8" | 1" | 1⅛" | 1¼" | 1⅜" | 1½" | 1⅝" | 1¾" | 1⅞" | 2" |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | OXYGEN PRESSURE FOR PLATE THICKNESS | | | | | | | | | | | | | | | |
| 10 | 350 | 30 | 33 | 35 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | | | | | |
| | 470 | 20 | 22 | 24 | 30 | 40 | 50 | 60 | 70 | 78 | 87 | 98 | 107 | 115 | 120 | 125 | 130 |
| 20 | 350 | 34 | 36 | 38 | 43 | 53 | 63 | 73 | 83 | 93 | 103 | 113 | | | | | |
| | 470 | 23 | 25 | 27 | 33 | 43 | 53 | 63 | 73 | 81 | 91 | 101 | 110 | 118 | 123 | 128 | 133 |
| 30 | 350 | 38 | 40 | 42 | 47 | 57 | 67 | 77 | 87 | 97 | 107 | 117 | | | | | |
| | 470 | 27 | 29 | 31 | 37 | 47 | 57 | 67 | 77 | 85 | 94 | 105 | 114 | 122 | 127 | 132 | 137 |
| 40 | 350 | 43 | 45 | 47 | 52 | 62 | 72 | 82 | 92 | 102 | 112 | 122 | | | | | |
| | 470 | 32 | 34 | 36 | 42 | 52 | 62 | 72 | 82 | 90 | 99 | 110 | 119 | 127 | 134 | 137 | 142 |
| 50 | 350 | 48 | 50 | 52 | 59 | 68 | 78 | 88 | 98 | 108 | 118 | 128 | | | | | |
| | 470 | 38 | 40 | 42 | 49 | 58 | 68 | 78 | 88 | 96 | 105 | 116 | 125 | 133 | 138 | 143 | 148 |
| 60 | 350 | 55 | 57 | 59 | 66 | 75 | 85 | 95 | 105 | 115 | 125 | 135 | | | | | |
| | 470 | 45 | 47 | 49 | 56 | 65 | 75 | 85 | 95 | 103 | 112 | 123 | 132 | 140 | 145 | 150 | 155 |
| 70 | 350 | 63 | 65 | 67 | 74 | 83 | 93 | 103 | 113 | 121 | 132 | 143 | | | | | |
| | 470 | 53 | 55 | 57 | 64 | 73 | 83 | 93 | 103 | 111 | 120 | 131 | 140 | 148 | 153 | 158 | 163 |
| 80 | 350 | 72 | 74 | 76 | 83 | 92 | 102 | 112 | 122 | 130 | 139 | 152 | | | | | |
| | 470 | 62 | 64 | 66 | 73 | 82 | 92 | 102 | 112 | 120 | 129 | 140 | 149 | 157 | 162 | 167 | 172 |
| 90 | 350 | 82 | 84 | 86 | 93 | 102 | 112 | 122 | 132 | 140 | 149 | 162 | | | | | |
| | 470 | 72 | 74 | 76 | 83 | 92 | 102 | 112 | 122 | 130 | 139 | 150 | 159 | 167 | 172 | 177 | 182 |
| 100 | 350 | 93 | 95 | 97 | 104 | 113 | 123 | 133 | 143 | 151 | 160 | 173 | | | | | |
| | 470 | 83 | 85 | 87 | 94 | 103 | 113 | 123 | 133 | 141 | 150 | 161 | 170 | 178 | 183 | 188 | 193 |

flux material from becoming soft and falling off. It also serves to insulate the rod itself from current leakage..

Since the flux coating is both thin and brittle, if the cutting task is likely to require the rods to suffer some rough handling, it is well worth the time and effort to wrap them with one layer of pvc tape. Should the flux become badly chipped whilst working in a deep cut, the diver will notice the rod commencing to arc out sideways.

Damaged rods can also be over wrapped with tape, but it should be remembered that the steel rod will burn down quicker than the pvc coating, and will leave a tape sleeve in its wake.

Cutting rods should be checked before being taken underwater to ensure that the centre hole is not blocked, and that the uninsulated end to be gripped in the collet is both clean and free from burrs. Of all the problems likely to be encountered whilst cutting underwater, the most frustrating is the number of stub ends of rods that 'stick' in the electrode holder. For this reason alone, it is recommended that divers should carry a pair of pliers whilst cutting, which will at least save the time it would otherwise take to pull the torch to the surface, to have the collet cleared.

Technique of Oxy-Arc Cutting

The diver can either take down the cutting torch, ground cable and clamp, plus a supply of rods, or else they can be lowered after he has made bottom. On reaching the work site, the first task is to clean the point of contact for the ground clamp, then make a secure connection ensuring that good electrical contact is achieved. The clamp should be positioned so that it is in front of the diver when he is cutting. If it were placed in such a position that the diver was positioned between the ground point and the work, then his body and all his equipment would act as an anode from the electrolytic point of view. In such a situation, even after only a short period of time, extensive damage will be caused to helmets and fittings. It may even be necessary for the diver to move the ground clamp from time to time, to ensure that this situation does not arise.

Using carbon-graphite rods:

1 To start the cut, hold the electrode perpendicular to the surface to be cut, at the same time allowing the tip to touch the work. If manual control is employed, the diver then opens the oxygen valve, calls to the surface to "Make it hot", and withdraws the rod slightly from the contact to start the arcing process. After that it is only a case of maintaining a slow steady arc as the cut progresses.

2 To advance the cut once started, drag the electrode along the desired line of cut, keeping the rod either perpendicular or else with a slight leading angle in the direction of travel. The tip of the electrode should continue to lightly touch the working surface, the diver maintaining pressure inward to compensate for electrode consumption, and forward to advance the cut. With graphite rods, only the minimum amount of contact with the work is necessary.

3 Should the cut be incomplete at some stage, due to a fault, or control of the torch, this will generally be indicated by a "back flare", which will be visible even in the worst of underwater visibility conditions. Should this situation arise, the diver should lift the electrode out of the present area, go back along the cut a few inches, and renew the cutting process.

When the cutting electrode reaches the point at which it has been used to within about 2in of the holder head, cease cutting, call for the torch to be "Made Cold", then remove the stub, and fit a new electrode. Since some rods are not insulated, it is most important that the torch is held in the cutting position until the surface acknowledges that the current has in fact been disconnected from the circuit.

Failure to observe this simple safety precaution can result in the diver receiving a severe, even fatal shock, as his body conducts current through to ground.

Using Tubular Steel Rods

The following technique is for the cutting of steel plate over 6mm in thickness.

1 Commence the cut in the same manner as for carbon/graphite rods.

2 Advance the cut in the same manner, except that the electrode is maintained in contact with the work without attempting to hold an arc, and always perpendicular to the work surface.

3 An incomplete cut will be indicated in the same manner as for carbon electrodes, and should be treated exactly the same.

4 The same safety precaution to avoid unecessary electrical shocks to the diver should be observed.

Technique for Cutting Steel Plate Less than 6mm Thickness

A slightly different technique is employed in the cutting of thin steel plate from that already described, which is for thicker material.

Instead of maintaining the electrode tip in the cut, and pressing against the lip of the advancing work, the end of the rod should barely touch the work surface as it progresses forward.

An alternative technique, to be used where underwater visibility is poor, is to increase the effective thickness of the plate. This requires the electrode to be held angled towards the operator , in the direction of the cut at an angle of approximately 45°. The electrode thus "sees" the work as being of greater thickness, and normal pressure can be applied.

Technique for Piercing Holes in Steel Plate

Piercing a hole in steel plate, to accommodate a wire strop, to fit a shackle or a "strong-back", is readily accomplished using oxy-arc equipment.

The technique is as follows:

1 Touch the rod lightly on the steel plate at the desired position of the hole. The oxygen supply is turned "on" and the current applied to the electrode.

2 The diver holds the electrode stationery, withdrawing it momentarily if necessary to permit melting of the steel rod back inside its covering.

3 Ease the electrode slowly inwards into the hole until the plate has been pierced. Steel up to 75mm thick can be pierced by this method without any real difficulty.

Technique for Cutting Cast-Iron and Non-Ferrous Materials

Cast-iron and non-ferrous metals are not readily oxidised, so that underwater cutting of these is more of a melting process.

In such instances, no benefit is derived from the oxygen supply except that it physically blows the molten metal out of the cut. It is recommended that compressed air should be substituted for oxygen when cutting these metals, and the technique requires a different approach.

The diver should manipulate the tip of the electrode in and out of the cut, since melting will only take place in the immediate vicinity of the arc.

For thin materials, such manipulation may not be necessary, and it may cut as if it were thin steel.

Since successful cutting is a pure function of the amount of heat in the arc, it is recommended that 400 amps current is used, or at least the maximum available if less than that figure.

Safety Precuations

Since the use of electricity underwater can be extremely hazardous, it is important that precautions are taken to provide adequate protection for the diving personnel. The following are considered the basic minimum precautions which should be observed:

1 The welding power source must be grounded to the parent vessel on which it is mounted.

2 No part of the electrode holder or submerged lengths of power cable, including joints, should be left uninsulated.

3 A spring-loaded, quick action knife switch should be incorporated into the circuit, connected such that its operation will 'make' or 'break' the current to the electrode holder held by the diver.

4 The position of the diver in relation to the "grounded" work clamp should be such, that at no time does he or his equipment become part of a secondary circuit.

5 If cutting inside a compartment or a similar confined space, adequate provision must be made to ensure ventilation, to prevent hydrogen gas released by the cutting action from accumulating in a pocket.

6 Avoid the use of any grease or lubricants in areas where they may come in contact with high-pressure oxygen.

7 The diver should never hold a cutting torch in such a manner that the rod or electrode is pointing at either himself, or snother diver.

8 The diver should always wear a pair of gloves made of an insulating material.

9 No attempt should be made to remove or change the used stub of a cutting electrode, until confirmation has been received from the surface that the supply current is "OFF".

ULTRA THERMIC CUTTING

The limitations of oxy-arc cutting, already outlined, but summarised, include:

Requirement for a bulky, heavy duty, DC welding generator.

Limitations with regard to the thickness of steel that can be cut, and that other metals may cause some difficulties.

Inability to cut concrete, rock or protective coatings.

Requirement for the frequent replacement of the cutting electrode.

Electrical hazards generally.

A development which overcomes most, if not all of these limitations, is the use of "thermal lance" equipment underwater, and a more recent improvement from a diving point of view, the "thermal arc".

The thermal lance has been in use in industry for a very long time, but its use underwater was not fully appreciated until the late 1960's. It works on the principle that a special mild steel electrode, fed with a continuous supply of oxygen, will generate an arc of sufficient intensity (some manufacturers have claimed temperatures as high as 5000°C) that it will burn almost any substance.

A thermal lance consists of a length of mild steel tube, usually in the order of 3.2m and of some 9mm diameter, fitted at one end with a screw threaded connection. To this is attached the oxygen supply hose. The interior of the tube is filled with a series of small diameter, solid metal rods, tightly packed but with sufficient space between them to allow the passage of high pressure oxygen gas. The rods used to fill the tube of a thermal lance may be mild steel, a steel alloy, aluminium, magnesium or other materials, depending on the nature of the task.

The lance must be ignited by a secondary source of heat, which can be a gas burning torch, blow-lamp, or oxy-arc equipment. Once ignited, the thermal lance can only be extinguished by depriving it of its oxygen supply; even after removing the oxygen flow, it will continue to burn for several seconds. Hence a lance must be turned "OFF" when at least 300mm of tube is left, otherwise it will continue to burn back through the threaded holder connection, into the oxygen supply hose.

Because of the physical problems of handling long lengths of thermal lance underwater, the high consumption rate of oxygen, and the obvious hazards involved, its use by divers is limited. It is, however, of particular value in the cutting of reinforced concrete, or steel of considerable thickness, which no other cutting equipment can handle.

A thermal lance will cut through almost anything, including all steels, non-ferrous metals, rock, and all forms of concrete. With heavy shafting, such as propeller shafts on wrecks, a thermal lance will cut through 300mm of steel per minute, consuming some 200 to 300mm of lance. A complete 3.2m length of lance will therefore probably last some 6 minutes. The quality of the cut is very rough compared with oxy-arc, and less skill is required, but no diver should attempt to use a thermal lance underwater, without considerable surface practice.

The risk of explosions "in the hole" when cutting non-ferrous materials in particular, are very real, causing serious "blow-backs".

## Thermal Arc Equipment

Many of the problems associated with the thermal lance underwater were resolved by the development of a flexible version of the rigid thermal lance, by Clucas Engineering Ltd, a British company based at Hull.

Known as Kerie cable, the thermal arc equipment can be likened to a conventional 6 or 7 stranded length of wire rope, which has had the "heart" core removed, and the outside sheathed in a pvc material. In this manner a flexible "lance" has been produced, which allows oxygen to fed through the centre, the strands of the wire rope taking the place of the wire rods packing a lance.

Supplied in 30m rolls, and available in both 6 and 12mm diameters, Kerie cable burns at an average rate of 27m per hour, or about 0.5m per minute. The burning temperature is in the order of 2700°C, which is sufficient to cut non-ferrous metals. The cut produced is still much wider and rough compared with oxy-arc, but not so rough as with the thermic lance. The same basic safety precautions should be observed as for oxy-arc cutting underwater, except that greater attention must be paid to safety clothing, and protection of diving suits.

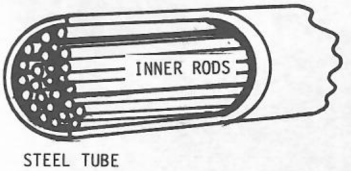



Fig 16-10 Cross section of a typical thermic lance rod

## Equipment for Thermal-arc Cutting

A complete system, as purchased, although it is stressed that the surface control panel could be of local manufacture, consists of:

Oxygen reducer; a flexible manifold for 3 oxygen cylinders; a 30m length of electrical cable; a 30m length of oxygen hose; Kerie cable; a pair of heavy duty cable cutters; insulating sleeves and spares.

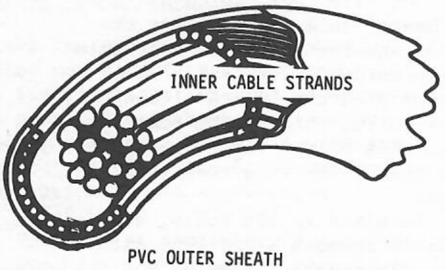



Fig 16-11 Cross section of Kerie thermal arc cable

Fig 16-12 Clucas thermal-arc control panel, showing supply and reduced oxygen pressure gauges, ammeter, knife switch and control valve

## Preparation for Use

Connect 3 full oxygen cylinders to the HP manifold supplied, and the common connection to one end of the 3m length of oxygen hose. The other end of this hose connects to the position marked "HP $O^2$ IN".

Connect one end of the 30m electrical cable to the terminal marked " -NEG AMPS OUT TO CUTTING CABLE",amd the 30m length of oxygen hose to the position "LP CUTTING $O^2$ OUT".

Two 12v lead acid batteries of at least 20AH each should then be connected in series (ie. the +ve terminal of one, to the -ve terminal of the other). Then connect the main battery negative (-ve) terminal to the control panel position " NEG AMPS IN", and the positive side (+ve) to the work task with a ground clamp.

The other end of both the oxygen hose and the electrical cable are then connected to the Kerie cutting cable. The Kerie cable is supplied in individual coils, tightly wound and should be unpacked and recoiled in large loops on the deck, similar to the manner in which a diving umbilical is stowed to prevent kinking. Make sure than one of the red, double insulating sleeves provided, is slipped over the joint at the cable end of the oxygen hose.

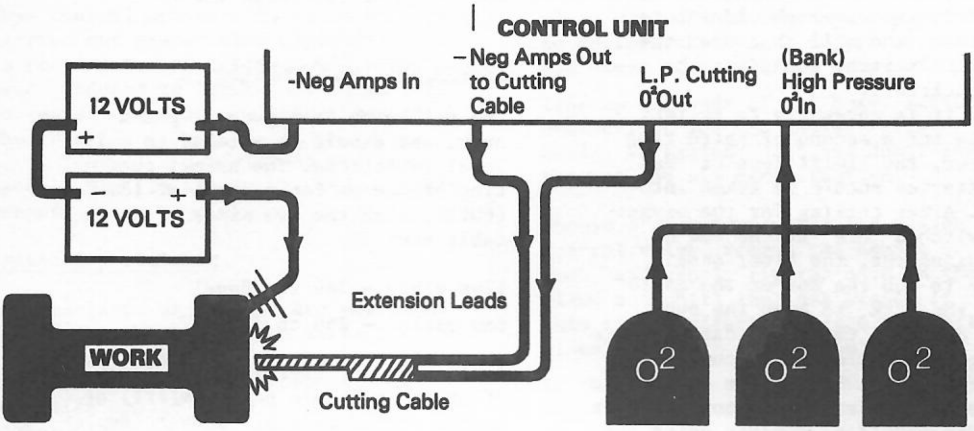
The equipment is now ready for surface testing.

## Testing the Equipment

First turn "ON" the oxygen cylinder valves, then set the control to give a gauge reading on the panel of 200psi output pressure. Turn the control valve marked "ON/OFF/VENT" to "ON", close the knife switch on the panel, and touch the tip of the Kerie cable on the work test piece.

Provided there is sufficient bared metal to make contact the cable should immediately ignite. Break the knife switch the moment that ignition takes place.

Proceed to cut the test piece




Fif 16-13 Connections and lay out of Thermal Arc cutting equipment

from one edge. To stop the process, the Clucas system offers a choice of methods, either by turning the oxygen control valve to the "CUTTING $O^2$ OFF" position, or to the "CUTTING $O^2$ OFF AND VENT" position.

In the first of these, the cable will continue to burn until all the oxygen in the line has been consumed, which may take some 5 seconds, or in the alternative position, not only is the oxygen supply cut off, but the hose is vented to atmosphere, hence extinguishing the flame almost immediately. This latter method is far safer, but is very wasteful on oxygen, and should be considered as an emergency procedure only. Should this method be employed whilst the equipment is still underwater, the entire remaining length of cable will become flooded, and cannot be relit until blown clear by the oxygen flow.

It is important to use the special 3m length of hose joining the panel and the cylinder manifold. This is an electrically "insulated" length of hose, designed to prevent the cylinder bank from become "alive".

<u>Cutting Underwater</u>

The cutting cable should be passed to the diver, and taken down with a sufficient oxygen flow to exclude water from entering the bore. The pressure of gas need only be that necessary to compensate for depth, (ie. at 30m, about 60 - 70psi).

On reaching the place of work, the diver, when ready, should signal or call for the oxygen pressure to be increased before attempting ignition. This is most important, since should ignition take place with the oxygen pressure too low, the cable will commence to burn inside itself. When full pressure is then applied, it will cause the flame to burn out sideways along the length of the cable in a series of "blow-holes", which can be very dangerous.

The surface operator should be made aware of this danger, and can assist by delaying the closing of the knife-switch for some 20 seconds after the application of full cutting-gas pressure. This will give time for the oxygen pressure to build up along the full length of the cutting cable.

The panel ammeter will give a reading as the diver attempts ignition, which will then fall back to zero as the burning cable retreats back inside its pvc coating. Once it is obvious that ignition has been successful, the diver should inform the surface, who will then open the panel knife switch, isolating the ignition circuit.

If it is necessary to relight the cable for a second or third time underwater, the limitations of lead acid batteries should be taken into account. After calling for the oxygen to be switched "OFF" at the end of the previous cut, the diver should continue to rub the end of the cable against the work, to keep the pvc coating clear of the inner cable, hence ensuring a good electrical contact when re-lighting. Should the end of the cable be badly burnt or distorted, then some 150mm should be removed using the cable cutters and discarded. If cable cutters are not available, beating the end with a hammer will often break up the burnt pvc, and expose sufficient bare wire to complete the circuit and allow re-ignition.

Although lead acid batteries are the accepted source of ignition, the output from a DC welding generator can be substituted, in which case, with a much higher current source available, re-ignition can be achieved merely by rubbing the pvc fused end on a rough surface.

In the event of neither a DC generator nor batteries being available, or the battery bank has been 'flattened', Kerie cable can be surface lit and taken down burning, but great care is necessary. Force a small plug of fine wire wool, about the size of a finger tip, down the end of the cable. Apply oxygen pressure of about 5psi, and set light to the wire wool with a match or lighter. Then hold the end of the cable against a block of wood, and increase the oxygen pressure to about 50psi, allowing the cable to reach a satisfactory burning temperature.

The cable is then passed to the diver, who calls for full cutting gas pressure as soon as he has full control of the situation, and before he leaves the surface. If full pressure is not applied until he reaches his task on the bottom, water pressure may cause the cable to burn back inside itself.

## Oxygen Cutting Pressures

The following is a general guide only, and should be altered to suit local conditions. The normal cutting pressures for a depth of 18m (60ft), with the two sizes of Kerie cable are:

12mm cable - 340 to 380psi

6mm cable - 250 to 300psi

An increase of approximately 11psi of oxygen pressure per 0.3m(1ft) of depth, should be applied over 18m.

As a general guide, 3 x 240 cubic ft cylinders of oxygen will cut approximately 1.8m length of 50mm thick (6ft x 2in) plate at that depth.

Thermal arc equipment will not cut concrete or rock, either above or below the surface. It should not be used on non-ferrous materials, as experience has shown that this can result in a very violent explosion, which could be fatal.

## Cutting Very Thick Steel

The cutting of thick sections of steel should be carried out working around the circumference, withdrawing the cable from the cut every 2 or 3 seconds, to allow water to enter.

A brushing or stroking action in the direction of the cut should be employed, and under no circumstances should the work be allowed to become a deep seated inferno, since it is this situation that can lead to an explosion. The 12mm Kerie cable is recommended for cutting thick metal; the 6mm for thin material, wire rope or cable and general light work. 6mm cable is supplied in 15.25m lengths instead of the 30m lengths for 12mm, due to the restriction in oxygen flow.

Using Kerie cable deeper than 43m

When thermal arc cutting is to be carried out deeper than 43m(150ft), it is recommended that 12mm cable only is used, reduced to lengths of 15.2m(50ft) to assist the flow of oxygen through the core.

Thermal arc equipment has been used at 91m (300ft) depth, and possibly deeper.

Protective clothing

Thermal lance or thermal arc equipment should not be used on the surface without special attention to the protection of the operator. Fire proof material coveralls should be worn, with any pocket flaps done up, and the suit closed up to the neck. Asbestos or leather gauntlet gloves are essential for the hands, and a protective helmet with a full visor for the head and face. Footwear should be industrial boots, and care taken that sparks or globules of molten metal are unable to fall inside or get "stuck" to socks.

Underwater, similar consideration must be afforded the diver. It is strongly recommended that only rigid helmet equipment is used; that thick, gauntlet type gloves are worn, with thick rubber bands around the tops to prevent slag from falling inside. The helmet faceplate should be protected by a clear plexiglass or perspex screen, to prevent slag pitting.

The cutting arc is not so bright that glass filters are necessary to protect the eyes, neither is there the danger of electric "arc-eye".

Maintenance

Very little maintenance is required, but the following points should be observed:

Break all the electrical connections after use, clean, dry and coat them with a silicone compound.

Treat all the oxygen connections in a similar manner, ensuring that no oil or grease it used.

If the "blades" of the knife-switch show signs of arcing or corrosion, clean well with a fine emery paper to restore the bright copper surface, and smear with silicone compound.

Tape up the ends of all hose, manifold connections and the unused Kerie cable, to exclude dirt and dust. and prevent any oil contamination.

Should a leak develop on the oxygen control valve, remove the handle or knob, and gently tighten down on the gland nut until the leak stops. If this has no effect, replace the entire gland seal with a new item.

If the seat of the nylon valve in the oxygen reducer should develop a leak, the LP cutting pressure will continue to build up until the safety valve blows off at 500psi. To change this seating, unscrew the control panel, remove it from its box and turn over. Remove the hexagon cap nut from the reducer, and fit a new seat with the recessed brass ring uppermost. Replace the piston, spring and cap nut, and refit the panel back in the control box.

The manufacturers of the Clucas Thermal Arc Cutting Equipment are:

Clucas Diving and Marine Eng Ltd
Sandiacre
Dunswell Road
Cottingham
North Humberside

USA agents for the equipment are:

Taylor Diving and Salvage Co Inc
795 Engineers Road
Belle Chasse
Los Angeles 70037
California

BROCO ULTRA- THERMIC CUTTING RODS

The American Company "Broco" have miniaturised the thermic lance, in such a manner that it can be used as conventional oxy-arc cutting equipment.

Slightly longer than the

conventional oxy-arc cutting rods, the Broco electrodes are 460mm in length and available in a range of diameters, the most commonly used being 9.5mm. Since the normal oxy-arc cutting electrode is 7.5mm, a special collet will be required to adapt the standard torcch.

Broco rods are ultra-high temperature melting (1600 to 2500°C) and will cut or melt most conventional materials such as steels, non-ferrous, rock and concrete.
As with conventional thermic lance rods, the Broco version is a steel tube packed with steel rods, some of which are high-tensile material, the outer tube being pvc tape wrapped for insulation purposes.

These rods can be lit in the same manner as thermic-cable, or when striking an arc with oxy-arc, but will of course consume a far greater quantity of oxygen than conventional oxy-arc cutting. For this reason, the manufacturers recommend that any sealing washers inside the electrode holder should have a central hole of at least 7mm diameter, to assist the flow of oxygen.

Field experience with Broco rods has shown that the most common difficulties are directly related to:

a) Current setting too high
b) Insufficient or blocked oxygen flow

**POWER SETTING**

| Length Of Power Cable Ft. | M | Cable (Double Length) Amperage Setting 1/0 | 2/0 | 3/0 |
|---|---|---|---|---|
| 150 | 46 | 155 | 152 | 150 |
| 200 | 61 | 157 | 154 | 152 |
| 250 | 76 | 159 | 156 | 154 |
| 300 | 91 | 161 | 158 | 156 |
| 350 | 107 | 163 | 160 | 158 |
| 400 | 122 | 165 | 162 | 160 |
| 450 | 137 | 167 | 164 | 162 |
| 500 | 152 | 169 | 166 | 164 |

Fig 16-14 Current requirements

**GAUGE SETTINGS FOR DEPTHS**

| Depth Ft. | M | Pressure Gauge Setting psi | atm | Depth Ft. | M | Pressure Gauge Setting psi | atm |
|---|---|---|---|---|---|---|---|
| 33 | 10 | 115 | 7.8 | 200 | 61 | 209 | 14.2 |
| 40 | 12 | 118 | 8.0 | 210 | 64 | 214 | 14.6 |
| 50 | 15 | 122 | 8.3 | 220 | 67 | 218 | 14.8 |
| 60 | 18 | 127 | 8.6 | 230 | 70 | 222 | 15.1 |
| 70 | 12 | 131 | 8.9 | 240 | 73 | 227 | 15.4 |
| 80 | 24 | 136 | 9.3 | 250 | 76 | 231 | 15.7 |
| 90 | 27 | 140 | 9.5 | 260 | 79 | 236 | 16.1 |
| 100 | 30 | 155 | 10.5 | 270 | 82 | 240 | 16.3 |
| 110 | 34 | 159 | 10.8 | 280 | 85 | 245 | 16.7 |
| 120 | 37 | 163 | 11.1 | 290 | 88 | 249 | 16.9 |
| 130 | 40 | 168 | 11.4 | 300 | 91 | 264 | 18.0 |
| 140 | 43 | 172 | 11.7 | 310 | 94 | 268 | 18.2 |
| 150 | 46 | 177 | 12.0 | 320 | 98 | 272 | 18.5 |
| 160 | 49 | 181 | 12.3 | 330 | 101 | 277 | 18.8 |
| 170 | 52 | 186 | 12.7 | 340 | 104 | 281 | 19.1 |
| 180 | 55 | 190 | 12.9 | 350 | 107 | 285 | 19.4 |
| 190 | 58 | 195 | 13.3 | | | | |

Fig 16-15 Oxygen pressure settings for various depths

When the equipment is to be used at depths in excess of 106m(350ft), oxygen gauge pressure can be calculated as follows:

For every 30m(100ft) required, add 10psi to the 90psi necessary at the rod tip. In addition, add 10psi for every 100ft of depth of hose.

Example: Assume a working dive of 170m(560ft); what would be the pressure of oxygen required ?

Requirement = 90psi above ambient pressure

Ambient pressure = 560ft x 0.445psi

= 249.2psi + 90psi

= <u>339.2psi</u>

Plus 560ft of hose x 10psi for each 100ft length used= 56psi

<u>Answer</u>: Pressure = 395.2 psi

## Precautions

Cutting with Broco rods requires little skill or practice. Divers qualified and experienced in either underwater oxy-arc cutting or arc welding, will experience little difficulty in its operation. Surface practice is recommended for those not familiar with either techniques.

Protective clothing should be worn as recommended for both surface and underwater operation of thermic lance and thermal arc equipment, plus the need for a welding visor, with at least a No 10 protective lens fitted.

Broco rods, as with other thermal arc type equipment, can only be extinguished by cutting off the supply of oxygen. It is therefore recommended that rods should not be allowed to burn down to less than 75 - 90mm length, to protect the holder, and avoid a "blow-back" situation.

UNDERWATER WELDING

Until some 10 years ago, all underwater welding was "wet" welding, in which the diver/welder took all the necessary equipment to the task, and carried out the work completely in a submerged, wet situation. Since then the technique of "dry" or habitat welding has been introduced, a number of companies and diving contractors have made a speciality of the art, and "wet" welding has become accepted more as a "first-aid" treatment, than a reliable repair.

With "dry" welding underwater, the diver is provided with either a special welding "habitat" or "box", within which the water is evacuated by pressure of an inert gas which removes the risk of an explosion, which would otherwise result from an oxygen rich atmpsphere. The complexity and cost of dry, habitat or as it is sometimes known, "hyperbaric" welding, is such that this will normally only be carried out by divers who are also coded welders, in order that the insurance companies involved can have total confidence in the work performed.

Wet welding is an accepted and simple approach to a great many types of underwater repair, but has the disadvantage that due to the instantaneous quenching of the deposited metal by the surrounding water, the weld must be inferior to dry welding. Wet welds are therefore of less impact strength, with increased porosity and hardness, even when carried out by a skilled welder. It is therefore important that divers should attempt to acquire as much surface welding practice as possible, in order to better equip themselves for "wet" welding, but, at the same time accept that it takes years of work experience to become proficient, and longer to become "coded" by one of the inspection authorities. Only in recent years has the practice of "wet" welding become generally accepted by Lloyds, DNV and American authororities, and then only within certain boundaries.

The following terms, techniques and equipment details, are intended only to give the diver who may be unfamiliar with welding practice, a basic appreciation of the equipment.

The Welding Arc

An electric arc is nothing more than a prolonged spark, maintained between two terminals of an electrical circuit. The arc, or spark, which creates a temperature of some 4000 to 6000°C, is concentrated in a relatively small area, and is sufficient to instantly melt a small area of the work surface and the tip of the metallic rod or electrode.

As the tip of the electrode melts due to the intense heat, small globules of metal are formed, which are forced across the arc and deposited into the molton pool on the work side.

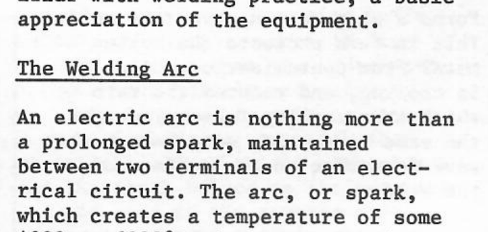



Fig 16-16 Metal arc welding

It is important to appreciate that these globules do not just fall or drop due to gravity, but are forced by current flow, hence making overhead welding possible.

Electrodes

The electrode or rod supplies the metal which will join the two surfaces together, and to a large extent, the strength and quality of the weld will depend on the composition of the wire rod material, and its "flux" coating.

The all important coating performs the following functions:

a) Stabilises the arc, and allows an AC (alternating current) to be used.

b) Causes impurities present on the surface of the work area to be "fluxed" away.

c) Forms a slag coating over the weld. This in turn protects the molten metal from contamination whilst it is cooling, and reduces the rate at which this cooling takes place. At the same time, slag smooths out the wave formation on the surface of the weld.

Welding electrodes are available in lengths of 9; 12; 14 and 18in, with 14in being the most common. The size of the electrode refers to its core diameter, ignoring the flux coating.

Diameters can range from 1/16 to 1/4in and are usually expressed in SWG (Standard Wire Gauge), or else in millimetres.

Almost any welding electrode can be used underwater, but without waterproofing the flux coating will quickly become saturated and flake off. Should this happen to an electrode, it must be discarded, and certainly not used for welding purposes. To waterproof an electrode, they can be given two coats of paint, a coat of plastic spray covering, dipped twice in molten paraffin wax, or any combination of these. Where possible, welding electrodes manufactured specifically for underwater use are recommended, since these will have been specially coated, but when not available, a diver should be prepared to coat and waterproof his own surface electrodes.

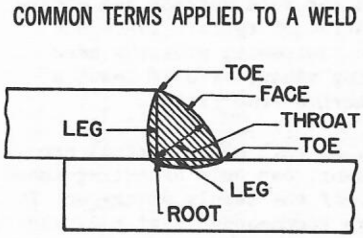



Fig 16-17 Weld terminology

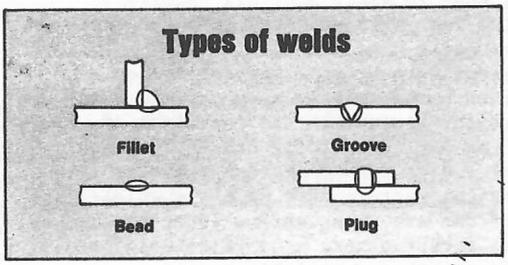



Fig 16-18 The four basic welds

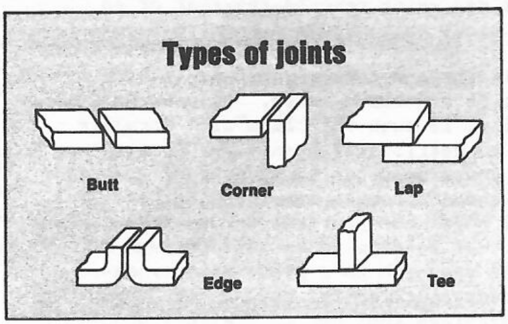



Fig 16-19 Basic welding joints

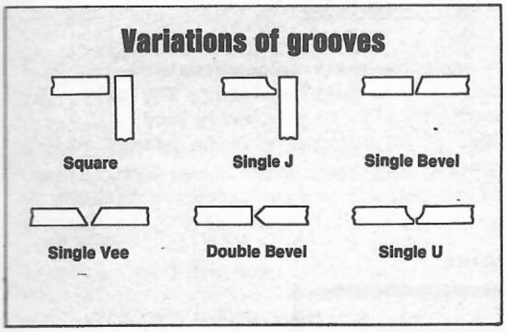



Fig 16-20 Preparation of joint faces

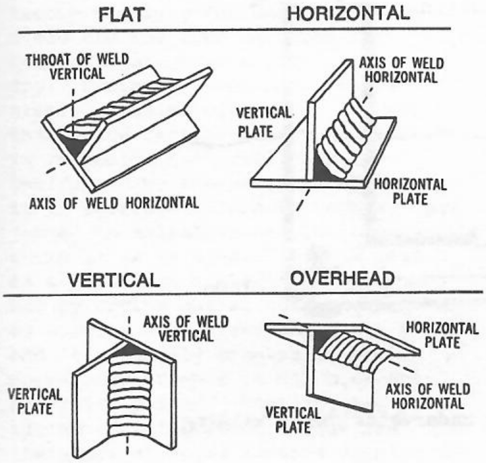



Fig 16-21 The four basic welding positions

Electrode Holders

Electrode holders for underwater use differ only from their surface counterparts in their element of insulation, and the method of holding the rod.

Underwater holders are designed with a simple "twist-grip" action to remove and fit new rods, which can be located in the one position only, ie. at 90° to the axis of the handle.

Surface holders are usually spring loaded, and allow for both a 45° and a 90° position for rods.

Holders designed for underwater use should never be used for surface work, since they are designed to be cooled by the surrounding water, and would otherwise quickly overheat. Some oxy-arc cutting torches can also be used as welding holders, after the collet has been changed for the correct size rods. In general, these are somewhat heavy for welding purposes, and most operators prefer the light-weight, underwater "stinger" as it is sometimes called.

Power Sources

A DC welding generator or rectifier with a 300 amp output capacity, is sufficient for all underwater welding tasks. It should be fitted with a polarity switch if possible, in order that the work connection can be reversed if necessary.

External to the generator, there must be a quick-action knife switch, which can connect or disconnect current from the underwater circuit both quickly and safely.

It is usual to connect the output of the generator with the positive (+) lead to the work clamp, and the torch holder as the negative (-). If used in the reverse mode, electrolysis will quickly eat into the metal parts of the electrode holder and the diver's equipment, particularly his helmet.

Protective Clothing and equipment

Rubber gloves for the diver are essential, but apart from an anti-glare shield fitted to the helmet or mask, no other items are essential.

The shield offers the diver protection from the glare of the welding arc, although the water between the diver's eyes and the work task will already have cut down on the harmful ultraviolet rays radiated from the point of electrical contact.

Such welding shields are normally hinged, so that the diver can swing it up out of the way, or down prior to striking an arc. Welding glasses are normally rated from No 1 to 12, with 10 the most common for diving purposes, which should be changed for a No 12 in conditions of very poor underwater visibility.

## Safety Precautions

All the safety precautions for oxy-arc cutting apply to underwater electric arc "wet" welding. The only observation is that a much lower level of DC current will be used, normally about 180 amps.

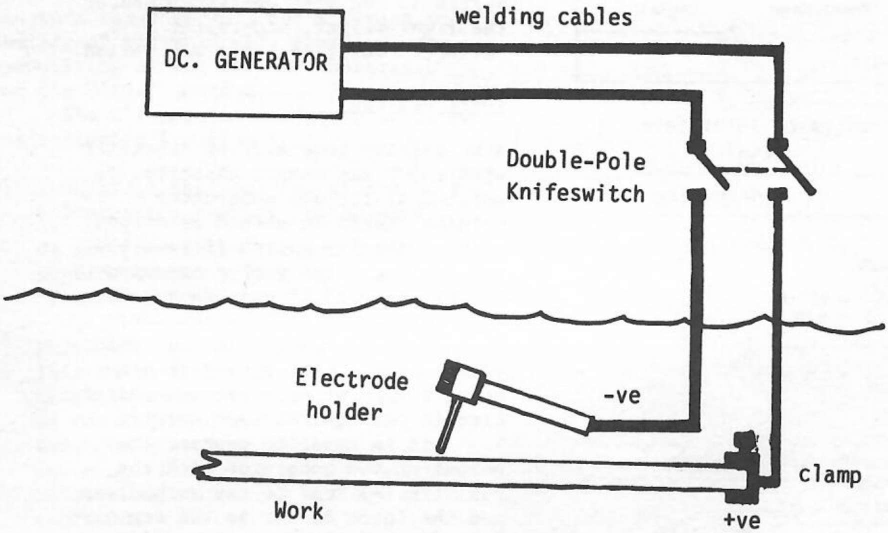



**Fig 16-22 Circuit and connections for underwater "wet" welding**

CHAPTER 17

# UNDERWATER CONCRETING

There are two basic approaches to the problem of forming concrete underwater either the concrete is mixed in the conventional manner and then placed by special methods, or the special process of grouted aggregate is used. In addition, concrete bagwork is still used for small jobs and special purposes but its applications are relatively restricted. It is discussed separately after the more important basic methods.

In many respects the rules and recommendations for underwater concrete are the same as those for conventionalconcrete placed in the dry. Properly mixed concrete is a stable material with a density more than twice that of water. Once it is in position it will remain unaffected by the water in which it is immersed unless it is subjected to agitation or other movement while it is setting. Cement sets as a result of a chemical reaction-not by drying out-so concrete hardens as quickly underwater as in the dry and it generally behaves in a normal manner once it has been successfully placed. Most of the recommendations which follow are therefore directed towards solving the problem of placing concrete in these conditions without damage.

Mass concrete can be placed successfully underwater in most circumstances where de-watering is either impracticable or uneconomic. Reinforced concrete can also be formed underwater but there are substantial difficulties in ensuring sound results.

Inspection is more difficult on underwater work than it is on work in the dry and the same applies to the repair of defective work.

Partly for these reasons and partly because of the characteristics of the mix and the conditions of placing. It is unwise to design for high compressive strengths in concrete that it to beplaced underwater. The highest strength normally specified is about 22.5 $MN/m^2$ (3000lbf/$in^2$).

## CONCRETE PLACED UNDERWATER

When a mass of fresh concrete moves through the water, or when water flows over the surface of fresh concrete, some of the cement is washed out from that part of the mix which comes into direct contact with the water. Thus the aim, when placing concrete underwater, should be to keep as much as possible of the concrete out of direct contact with the water and to avoid any rapid movement or agitation of the exposed surfaces.

The principal methods of placing concrete underwater are:

(a) by tremie

(b) by skip or similar device

## PLACING THE TREMIE

The tremie is a steel tube, suspended vertically in the water, with a hopper fixed to the upper end to receive the fresh concrete. The tube or pipe must be watertight and joints, where necessary, should have watertight meeting faces. It should be smooth-bored and have adequate cross section for the size of aggregate to be used. A diameter of 150mm (6") is commonly regarded as the minimum for 20mm (¾") aggregates and 200mm (8") as the lower limit for 40mm (1½") aggregates. The hopper acts as a reservoir to convert an intermittent supply of concrete into a steady flow down the pipe, and

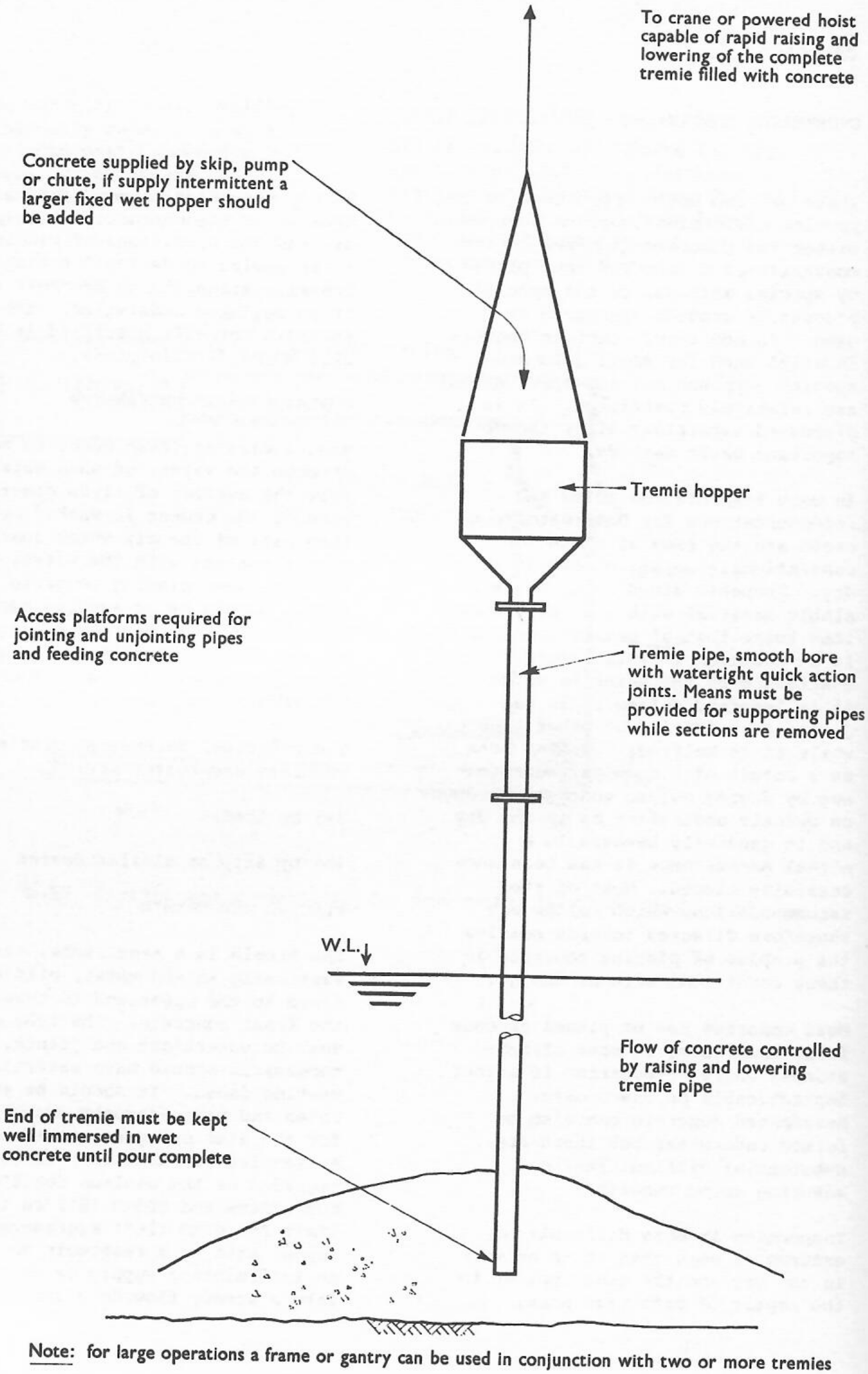



Fig 17.1 Typical arrangement of tremie concreting unit

it should be of such a size that will enable the level of concrete to be maintained generally within its depth. The assemble pipe and hopper must be provided with a means of rapid raising and lowering when charged with wet concrete. Simple blocks and tackle, unless power assisted, are generally inadequate for this purpose.

CHARGING THE TREMIE

The tremie is erected vertically over the area to be concreted with the lower end of the pipe resting on the bottom. Various methods can be used for sealing the bottom of the pipe to keep out water and to enable the pipe to be filled in the dry, but it is difficult to provide a means of opening the bottom which is reliable and at the same time does not obstruct the flow of concrete or the removal of the pipe after use. Furthermore the flotation of an empty pipe can be a nuisance when the assembly is being placed in position. For these reasons, it is now common practice to place a travelling plug in the top of the pipe as a barrier between the concrete and the water. The water in the pipe is then displaced as the weight of concrete forces the plug to the bottom. Cement bags or sacks, folded into shape, are most commonly used for the travelling plug, but foamed plastic plugs and inflated balls have made an appearance in recent years. Purpose-made buoyant plugs are expected to extricate themselves from the concrete and rise to the surface, otherwise plugs are generally not recovered and if they are buried in the depths of the concrete normally placed by tremie, their effect is insignificant. More damage may be caused by attempting to remove plugs than by allowing them to remain in place.

PLACING THE CONCRETE

After the pipe has been filled with concrete it is raised a few inches off the bottom and the concrete begins to flow, quickly burying the end of the pipe.

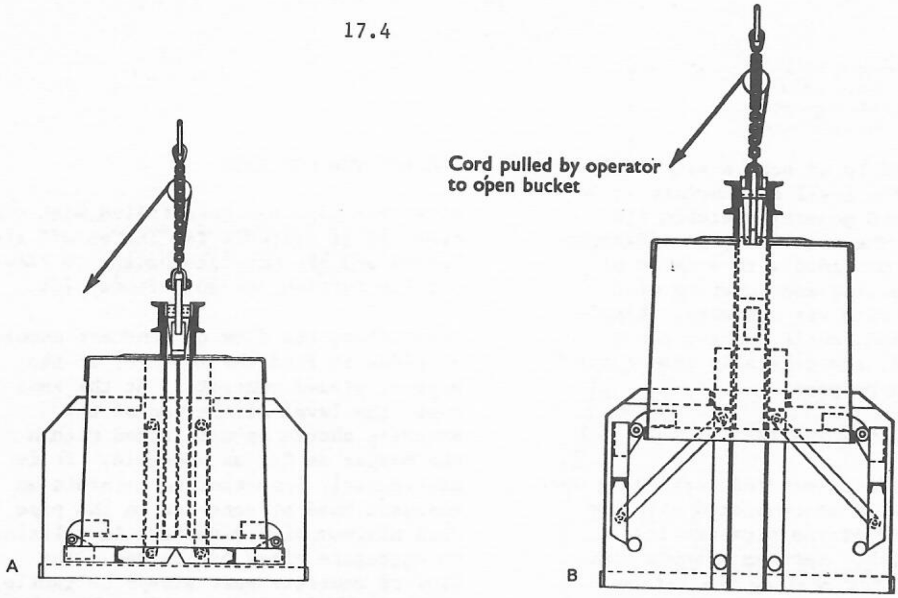
Thereafter, the flow of concrete should continue to feed the interior of the heap of placed concrete. At the same time, the level of the top of the concrete should be maintained within the hopper as far as possible. It is particularly important to maintain an adequate head of concrete in the pipe when minimum pipe diameters in relation to aggregate sizes are in use. The flow of concrete must always be gentle so that air is not trapped within the concrete in the pipe.

When it is necessary to reduce or increase the length of the tremie pipe during concreting, the joint used should be of a simple type with a fit accurate enough to preserve the smooth bore of the pipe and make watertight meeting faces. When the pipe lengths are being removed or added, the concrete must be allowed to fall to just below the level of the joint being broken.

BROKEN SEALS

If the bottom of the tremie pipe ceases to be immersed in the body of wet concrete the seal will be broken, allowing the concrete in the pipe to rush out and in its passage through the water it will almost certainly segregate and lose its cement. Such concrete is worthless and may have to be removed completely before the tremie is recharged and work resumed. In addition, the rapid discharge of the concrete will often cause serious disturbance of unset concrete already in place and this concrete, too, may have to be removed before placing is resumed.

It is emphasised that the best insurance against such mishaps is to produce




Bottom opening skip with skirt 'A'(above) closed 'B'(right) open

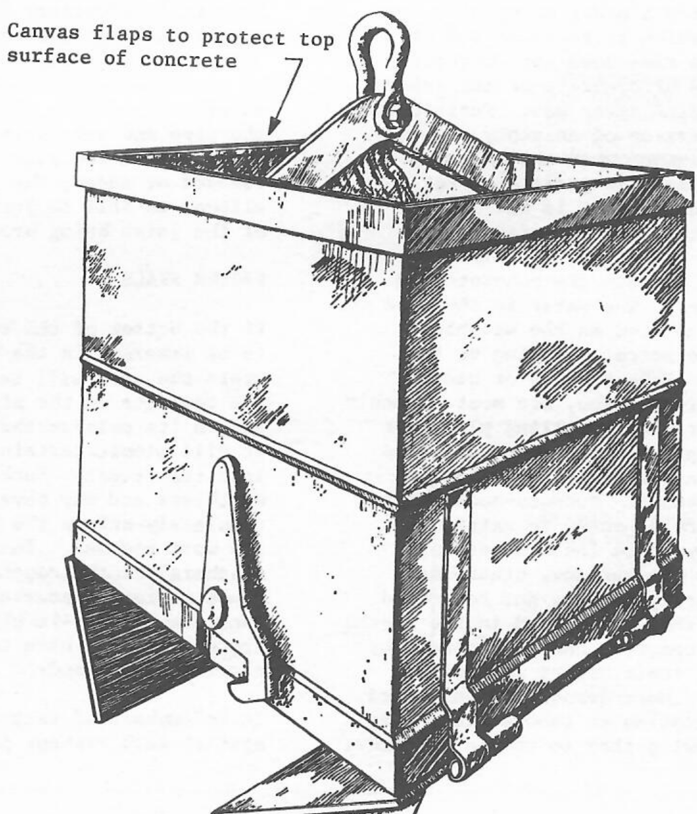



Fig 17.2 Typical bottom-opening skip

concrete which is workable enough to flow down the pipe and distribute itself in situ with the minimum of assistance. It is found that most broken seals occur when attempts are being made to clear blockages. Blockages and broken seals do occur, however, and if a large quantity of concrete has already been placed it is almost impossible to determine the extent of the damage. Attempts at this stage to remove the suspect areas can often result in further damage and the best procedure is to discontinue concreting for the day and allow the concrete to set before inspection.

## PLACING BY SKIP

### THE SKIP

The skip should be of the bottom-opening type possessing the following essential features:

a) It must have bottom-opening double doors which may be operated automatically or manually. The doors should be arranged to open with the minimum disturbance to the flow of the concrete, and so made that they cannot be opened until the weight of the skip is on the bottom or embedded in the previously placed concrete.

b) There must be no restriction of the outlet when the doors are open, the latch mechanism must be outside the skip with the hinges set so that the doors swing clear of the bottom opening.

c) It should be straight-sided, perfectly smooth and vertical inside with no taper at the bottom.

d) It should be equipped with a top cover consisting of two loose overlapping canvas flaps. The water pressure keeps these flaps in close contact with the top surface of the concrete during placing; this prevents turbulence of the water inside the skip from washing out the cement.

e) The skips should be as large as possible, consistent with the work in hand.

f) In addition, skirts are sometimes fitted at the bottom. These may be an advantage in some circumstances by confining the concrete while it is being deposited.

### PLACING THE CONCRETE

Skips must be completely filled before the top covers are placed. They must be lowered slowly, particularly when entering the water, to avoid disturbance of the concrete under the top cover, and again when nearing the bottom, to avoid excessive disturbance of the previously placed concrete.

After it settles on the bottom the skip must be lifted gently and slowly so that the released concrete causes no turbulence in the water around it. The aim is to deposit fresh concrete from the skip into the body of previously placed concrete and to displace the existing sloping surface of the mass forward in the formwork.

Except for pours in very confined spaces it is desirable to have a diver to control the placing of the skips, even when the release mechanism is automatic.

### CHOICE BETWEEN TREMIE AND SKIP

The choice between placing by tremie or skip is usually based on economics and on the plant and skills available.

Placing by skip is slower, so the tremie is usually preferred for large pours. The tremie may also be preferred where there are obstructions underwater. Skips are more practicable for thin pours and for work requiring a screeded finish. They are also useful for handling small volumes of concrete; but if the job is small and there is little repetition it is often cheaper to rig up a tremie than to provide an expensive bottom-opening skip. The intermittent nature of skipwork and the way in which the pour is built up from a number of individual discharges must subject a greater proportion of the concrete to the risk of local washing out and the chance of trapping silt or slurry is more likely than would be the case in properly executed tremie work. However, such defects as may occur are likely to be small in extent and acceptable in relation to the total volume. Properly executed tremie concrete is more homogeneous and therefore better but on the other hand, the effect of a single badly executed deposit from a skip is usually much less disastrous than that of a single broken seal with a tremie pipe.

Successful operation of both methods requires a continuous supply of concrete at the correct consistency; delays in delivery of over 10 minutes are undesirable.

## OTHER METHODS OF PLACING

### TOGGLE BAGS

Re-usable, bottom-opening canvas bags, sealed at the top, sometimes known as toggle bags, can be used for small pours and for depositing small, discrete quantities of concrete. The bags are lowered into the water mouth downwards with the open ends tied by a chain or rope and secured by a toggle. Exactly the same principles apply for placing with toggle bags as for using bottom-opening skips.

### PUMPING

Recent improvements in the design of concrete pumps have made it possible to consider them for the direct placing of concrete underwater. Experience to date is limited and the following observations are based on the filling of bored-pile shafts underwater. It may well be that with experience, pumps will be more widely used in future.

Pumping the concrete under pressure directly into the mass cuts out the necessity for frequent lifting of the pipe and ensures the desirable constant flow of concrete into the mass. Before pumping commences the pipe should be adjusted to give a few inches clearance above formation, and a sponge rubber ball, or other suitable plug, inserted in the pipeline adjacent to the pump.

This plug travels in front of the concrete and stops it dropping freely down the vertical pipe. Concreting should proceed at a fast rate, especially during the initial stages when the bottom of the pipe is being buried. It is desirable to pump for as long as possible at a time, lifting the pipe only when necessary. The depth of concrete which can be placed between lifting operations will be a matter of experiment, because it depends on the area of the pour, the characteristics of the concrete being used, the size of the pipe, and the pressure which it is possible for the pump to generate. Caution must be exercised however, as excessive lengths of buried pipe in the mass, coupled with a slow rate of pour, can result in new concrete being pushed up underneath concrete that has already begun to stiffen.

The more workable concretes suitable for pumping can be used for pumping directly into the mass, or for tremie work, but the converse is not necessarily true. The concrete will need to have a slump in the region of 125 mm (5"), but the slump test, while a good test for workability, does not indicate the other desirable qualities required. Good flowability and cohesion without stickiness are also necessary. These qualities are common requirements for both tremie and pump concretes.

BAGWORK

Although formerly used extensively for both permanent works and repairs, bagwork is now rapidly being relegated to use for temporary works such as sealing, expendable formwork and miscellaneous work where high structural standards are not required.

The bags are usually made of hessian and are half-filled with a very plastic concrete mix. Full bags tend towards a cylindrical shape which are difficult to bed down properly, but half-filled bags can be well trodden down into position to give a large area of contact. Adhesion of the concrete takes place between the weave of the hessian. The bags, which are laid in typical brick bond fashion should interlock to form a sound structure. Dry mixes should be avoided and the aggregate sizes should be reasonably small.

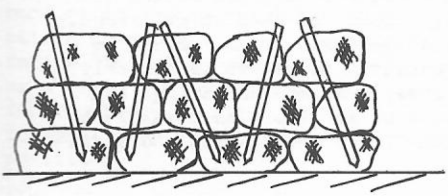


Fig 17.3 A method of bagging

MIXING CEMENT

Ordinary Portland cement is normally used, and the decision to use sulphate resisting or other special cements should be based on the same criteria that would apply to any concrete in the same environment.

AGGREGATES

The usual rules and standards apply to the selection of aggregates but it must be remembered that an especially high workability is required. Thus, where there is a choice between rounded gravel and crushed stone, the decision should be based on the same criteria that would apply if concrete with high workability were being produced for ordinary purposes. Crushed rock fine aggregates should generally be avoided because the gradings are usually poor and the particle shape unsuitable. Where their use is necessary, as in areas devoid of suitable natural sand, or where the natural sand is poorly graded, it may be necessary to supplement the 'fines' by addition of imported material. Increasing the proportion of fine material and/or the cement content can often help the situation and should be checked first.

MIXING WATER

Fresh water is normally used for mixing, but there is usually no objection to the use of seawater for mass concrete, provided that it is free from contamination by organic or other deleterious matter.

ADMIXTURES

These are not normally necessary but in certain circumstances can be used with advantage to change the flow properties, cohesion and rate of setting and hardening. In deciding whether admixtures should be used and in choosing the type, the same criteria should apply as for concreting in the dry. (see 'The Concrete Society Technical.

Report Admixtures for Concrete' TRCS 1-52.015.)

MIX DESIGN

The mix design should be carried out in the same way as it would be for work in the dry, while bearing in mind the following special requirements.

(i) Aggregates generally should not be larger than about 40mm (1½") for normal tremie work because of possible arching in the pipe, but where large concrete pours are being placed underwater and especially large diameter pipes are contemplated, aggregates should then be chosen in relation to the pipe diameter and the workability of the mix.

(ii) Especially high workability is required and the concrete should be wet by normal standards - when the concrete is tested in the dry slump exceeding 125mm (5") is essential. Underwater concrete of the proper consistency is unlikely to stand at a slope greater than 5$^{o}$ from the horizontal when being placed in situ, nor is it desirable that it should do so. In the interests of workability the mix should be over-sanded rather than under-sanded.

High strength concrete is not normally required and the working conditions make it very difficult to provide. Because of this, detailed mix design and trial mixes are inappropriate. A common method of arriving at the mix proportions is to take those which are known to give the required strength at the workability normally used in the dry and because of the higher workability required increase the cement content by about 25%. This is done for two reasons:

a) To produce comparable strength and durability with the increased workability and without the aid of mechanical methods of compaction.

b) To provide a margin against the loss of cement from exposed surfaces.

It should be noted that there is little scope for placing lean concrete underwater, even when working stresses are low, because the criteria is workability - not strength. Mixes containing less than 330kg of cement per $m^3$ (550lb|$yd^3$) are unlikely to be suitable. Admixtures which improve workability may be used.

TESTING

The quality of the concrete in place cannot be tested satisfactorily, so that good control during placing must be relied upon to ensure sound results. Cores may be drilled but they are not necessarily representative of the mass of concrete which, because of the nature of the placing techniques, is likely to vary considerably in quality. Concrete test cubes taken at the mixer should only be regarded as a check on the consistency of the mix, the results cannot be expected to represent the strength in situ, but only the highest theoretically attainable. It is not practicable to take satisfactory cubes underwater.

DESIGN AND CONSTRUCTION

FORMWORK

Formwork may be made of timber or steel. Steel is preferable because of its weight; if timber is used it will require to be weighted down. Forms should be robust enough to be assembled securely without fussy bracing and fixings and they should be as simple as possible to assist the divers when fixing and striking.

Sandbags are usually used to seal forms to the bottom, but where an improved seal is required a skirting of plastic sheeting round the forms and loaded with sandbags usually proves satisfactory. Corbels and similar features are undesirable in underwater concrete work and should be avoided. Foundations should be kept simple in shape and forms made in large units. Through-bolts which interfere with the pouring of concrete, should be avoided wherever possible.

PRESSURES ON FORMWORK

The effective pressure on the formwork is that due to the submerged weight of the concrete only. It is usual when designing formwork, however, to allow for pressures as if the concrete were being placed in the dry, and to ignore the effects of submergence. This results in practical design, robust enough to be fabricated in the large sections required and to withstand the extra demands of underwater conditions.

REINFORCEMENT

Within the obvious limitations imposed by working underwater, placing reinforcement is possible, but placing the concrete is not as certain a process as in the dry so the results obtained may often be suspect. Good results have been obtained however. If it is necessary to use reinforcement simple details are required. Congested reinforcement must be avoided because even nominal steel may impede the concrete flow, causing voids with consequent deficiencies in bond strength. Where possible the reinforcement should be assembled in the dry and lowered into position as a cage. In some cases the reinforcement may be fixed to the formwork before this is lowered into position.

TOLERANCES

If necessary, the tolerances for underwater concrete can approach those for concrete in the dry, but this can only be achieved with much greater effort and expense. It cannot be emphasised too strongly that underwater concreting work is carried out under very difficult conditions, often by divers working by touch only because lighting is ineffective in cloudy water. Tolerances must be set with due regard to the requirements of the work and the particular conditions under which it is being constructed.

PREPARATION OF BASE

The usual rules of good practice for work in the dry apply to the cleaning and preparation of the area to be concreted. When depositing concrete on a soft bottom or in silty conditions it may be necessary to arrange for the removal of silt at the far end of the forms as it becomes displaced and squeezed up by the advancing face of the concrete.

SCREEDING

Screeding widths of up to 6m (20ft) are possible in good conditions with experienced divers but a lesser width is to be preferred. The screed, which must be heavy, is manageable by two divers - it is essential to use two because they must operate clear of the concrete. The screed is usually worked off the top of the forms which should be designed with this in mind. When screeding concrete underwater it is essential to have an adequate surcharge of concrete ahead of the screed so that no slacks or hollows can form because it is difficult or impossible to place extra concrete to fill these in. Skip-placed concrete is generally more suitable for screeded work because the right amount can be delivered to the divers where they require it. A level surface must be produced in a single pass, re-working is impractical underwater because it results in the formation of laitance. It is possible for divers to achieve finishes to quite good accuracies, but whenever possible, tolerances should be generous compared with those for a similar class of work in the dry.

PREPARATION BETWEEN LIFTS

Horizontal construction joints should be avoided wherever possible but where the volume of concrete makes them necessary, the greatest care must be taken to clear laitance which forms on the top surface of the lower lift however carefully the concrete is poured. As soon as the concrete has hardened sufficiently, the laitance should be removed by means of hoses, shovels, brooms, air-lifts etc, until a clean and hard surface is reached. It is useless to attempt to grout this surface before placing the next lift.

MAKING GOOD

Satisfactory repair of underwater concrete is virtually impossible and where concrete is defective it may be necessary to cut out a relatively large section to ensure that it can be replaced properly. Alternatively, in certain circumstances, it may be possible to extend the work to achieve the equivalent result. Pneumatic tools are necessary for the removal of hardened concrete and air-lifts can be used to remove laitance or plastic concrete.

## GROUTED AGGREGATES

In the grouted aggregate process the forms are filled with coarse aggregate which is then grouted so that the voids are completely filled.

The grout is introduced at the bottom and any water present is displaced upwards as the grout rises.

Patented processes are used to achieve the necessary penetration of grout and the work is normally carried out by the proprietors or licensees of the particular process. It is important that the work should be carried out by specialist firms, or at least by operators and supervisors who have adequate experience of the particular process being used. First-class concrete will result if the work is carried out properly. Prejudice undoubtedly exists against the grouted aggregate process, at least to the extent that conventional concrete is preferred wherever it can possibly be used, but this prejudice is usually traceable to previous experience of bad results produced by indifferent operators.

WHEN TO USE GROUTED AGGREGATES

In deciding between conventional concrete and grouted aggregates the following factors should be considered:

(i) Grouted aggregate is most useful in situations where the physical conditions impede the placing of conventional concrete, as for instance in some underpinning work.

(ii) Grouted aggregate is often an advantage where flowing water is concerned. The aggregate can usually be placed in the forms without too much difficulty and without its being washed away after placing. Once it has been placed, the frictional resistance of the voids is such that the velocity of flow of the water through the aggregate is reduced to a level at which grout can be

introduced without any serious washing out.
An important property of the grouts is that they are almost twice as heavy as water and they are not easily diluted without mechanical mixing. Because of this the grout, even without the protection afforded by the coarse aggregate, has some resistance to scour by flowing water.

(iii) Grouted aggregate should not be used in conditions where silt-laden water or algae can seriously contaminate the aggregate in the interval between placing the aggregate and carrying out the grouting.

(iv) The pressures on forms from grouted aggregates are similar to those from conventional concrete. Greater attention to joints is required to ensure that they are grout-tight (though not necessarily water-tight) because seepage is not self-sealing as tends to be the case with concrete.

(v) Special plant and trained supervisors are needed for grouted aggregate work.

## MATERIALS

### COARSE AGGREGATE

For underwater work the minimum size of coarse aggregate should be over 40mm (1½in), i.e. not more than 10% passing a 37.5mm (1½in) test sieve.

The maximum size of stone is governed only by the circumstances of placing and the grading above the minimum size is important only to the extent that a reduction of voids saves grout. The shape of aggregate is not very important and even slate can be successfully grouted, although stone of the quality used for normal concrete is to be preferred. The aggregate should be clean and free from dust when it is placed because it will not be subjected to any mixing action which might otherwise remove traces of dirt.

### FINE AGGREGATE

Any clean sand which is suitable for normal concrete may be used in the grout. The maximum particle size will usually lie between one-sixth and one-sixteenth of the nominal size of the coarse aggregate. The grading of the sand is important and will depend on the particle shape of both the coarse and fine aggregates. Field tests should normally be carried out to ensure that the grouting operation runs efficiently with the selected sand.

### CEMENT

Ordinary Portland cement is normally used but blast-furnace slag or pozzolanic cements may also be used.

### ADMIXTURES

Admixtures, such as fly ash, set accelerators or retarders, water-reducing admixtures, air-entrained admixtures, expanding agents and some others, may be advantageous in some instances as determined by the nature of the work.

Fly ash (PFA) is a common admixture and when high early strength is not required it is convenient to improve the fluidity of the grout by increasing the amount used.

The quality of the fly ash is important. It should be obtained from electrostatic precipitators in power stations and should have minimum fineness of $300m^2/kg$. Fly ash with a carbon content in excess of 5% by weight increases the demand for mixing water and leads to loss of strength.

Water-reducing admixtures are frequently added to grout to improve its physical properties. Such aids help to keep the sand in suspension in the grout, to prevent bleeding of the mixing water and to produce a colloidal effect. Intrusion aids and fly ash generally reduce the laitance on the surface of the grout.

## THE GROUT

### MIX PROPORTIONS

Water/cement ratios of about 0.5 are common and for underwater work the mix proportions should be approximately 1 part of cement to 1½ parts of sand by dry weight. Where pozzolana or fly ash is used it must be considered as cement.

### MIXING

Grout must be thoroughly mixed in a special high-shear mixer so as to produce a colloidal-type fluid before pumping. It is essential to pass the grout through screens of about 6mm (¼in) mesh to remove foreign bodies or lumps which might otherwise choke the grout pipes.

## CONSTRUCTION

### FORMWORK

The formwork should be designed bearing in mind the same considerations which apply to any underwater work. The pressure from grouted aggregate concrete is the sum of the pressure from the aggregate and the fluid pressure of the grout in the submerged condition. The pressure from the aggregate is calculated using one of the well-known formulae, such as Rankine's for granular materials. This may give a pressure higher than for normal concrete but the difference is not often significant.

### CLEANING FORMS

It is necessary to ensure the complete exclusion of silt from the forms because silt chokes the voids in the aggregate and interferes with the flow of grout. If left adhering to the aggregate it may also reduce the bond between the aggregate and the grout. A 75mm (3in) layer of sand or pea gravel will usually exclude silt from the coarse aggregate if the bottom is dirty. Air lifts provide the most satisfactory means of removing silt if it is present in objectionable quantities.

Before the forms are inspected all measures should be taken to ensure that the periphery of the form is effectively sealed to prevent leakage of grout or the ingress of silt or other fine materials.

### GROUTING

The aggregate should be placed and grouted as soon as possible after inspection of the base. If any possibility of contamination exists, ungrouted stone should not be allowed to remain in the forms overnight or until the next tide.

The grout is pumped from the mixer into grout tubes which are set in the forms before the aggregate is placed. To lubricate the pipelines the first mix of the day should be a neat cement grout with a water/cement ratio of 0.45.

Depending on the area to be filled, one or more grout tubes will be necessary, and the sizes and spacing of the tubes will be related to the depth of aggregate and its size and grading. The grout generally travels through the aggregate at a slope of about 1 in 7. It is important that the tubes to be used first are at the lowest point to be grouted. This ensures that the grout works its way upwards - never downwards through the voids.

It may be necessary to raise the bottom of the grout tube to limit the maximum pressure at the pump but a reasonable pressure must be maintained to indicate that the bottom of the tube is below the level of the grout. If the bottom of the tube is raised above the surface of the placed grout, the grout will flow downwards and when this happens the stones can act like the slates on a roof, shedding the grout diagonally and leaving voids directly beneath the point of introduction.

During grouting, the level of grout should be continually checked using slotted indicator tubes, about 50mm (2in) diameter, placed about half way between the grout tubes. These should be set at the same time as the grout tubes, before the aggregate is placed. The grout level is checked by soundings, either with an electric grout level indicator, or with a simple sounding cord carrying a float/weight with a specific gravity greater than unity but less than that of the grout (about 2). One suitable material is coal which has a specific gravity of about 1½.

TEST CUBES

When making test cubes the best results are obtained by using moulds with 3mm (1/8in) thick base plates perforated by 4 holes, 15 mm (½in) diameter. Ideally the size of the cube should be about four times the nominal maximum size of the aggregate. The moulds are filled with aggregate and stacked on top of one another. Grout is then pumped in from under the lowest mould in the stack until it appears at the top. It is necessary to clamp the moulds together in the stack because they tend to float as the grout finds its way up the stack. After 25 hours the moulds can be struck and the cubes cured under water at a temperature of 20°C in the normal way.

It should be noted that both of the following procedures will produce poor crushing results:

1 Filling a 150mm (6in) cube with grout and then 'seeding' it with coarse aggregate. This destroys the point-to-point contact of the stones and as the stone is usually stronger than the grout the test cube may fail under a smaller load than it should.

2 Filling a 150mm (6in) cube mould with stone and then pouring on the grout until the cube is full. This results in voids forming under some of the stones.

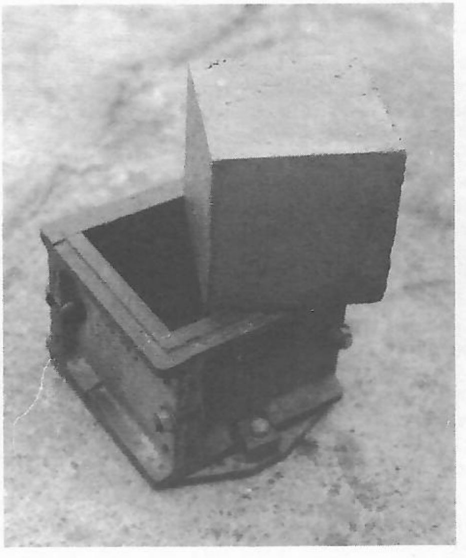


Fig 17.4 Typical concrete test cube with fabricated steel mould.

When fly ash is used in the grout, temperatures below 20°C prolong the hardening process while at 5°C hardening is practically halted. Because of this slow hardening it is customary to test cubes at the age of 90 days in addition to the 7 and 28 day tests when fly ash is used.

Quick-setting underwater cement

There are two principal proprietary brands of commercial quick-setting underwater cement, namely:

a) Speedcrete

b) Hydrotamm

These are chemically cured mixes which require no skill in mixing or in their application. They are ideal for all-ourpose bonding and patching work, but their main disadvantage is cost, since they are fairly expensive, and only small quantities can be handled easily underwater by a diver.

Speedcrete, as an example, sets underwater in 4½ - 5 minutes, has a compressive strength of 1800psi. in 24hrs, and will exceed 5000psi. in 28 days with no appreciable volume change. It has three times the normal bonding strength of Portland cement 1:2 grout. Any of these chemically cured mixes can be used at depths below 9m(30ft), and will remain effective when applied at or below freezing point in sea walls or refrigeration chambers, to show the opposite extremes.

In the event of non-availability of Speedcrete or Hydrotamm, or in emergencies, the same material can be produced by mixing together the following:

a) One bag of high-aluminia cement
b) Four bags of SRC. cement

Preparation of fast-curing cements

Specification

1. Speedcrete or its equivalent should be used as supplied, with no additives other than water, unless directed to do so.

2. Water should be clean, otherwise it can be fresh or salt.

Mixing

a) A typical mix should contain 4½-5.1 litres, or 4-4½qts. of Speedcrete to 1.1 litres(1 quart) of water.

b) The mixing should not occupy more than 1½ to 2 minutes of time.

c) Mix only quantities that can be used immediately. Speedcrete hardens in 4 - 8 minutes, and usually in less than 5 minutes.

d) Too much water will result in a weak mix. Do not add more water in an attempt to soften or thin a hardening mix.

e) Whilst the mixing water may be fresh or salt, it must be free from any polution, particularly chemicals, tannic acid, sugar or detergents.

f) The Speedcrete and water should be thoroughly mixed, until it takes on the consistency of medium/soft putty as would be used in glazing work.

g) Do not attempt to retemper a hardening mix by adding more Speedcrete powder.

Note that Speedcrete will bond to clean concrete, stone, masonry and steel. Its water absorption is 1.73% in 15 days.

Placing instructions

- All loose, scaly, oily material must be removed completely for the site.
- If to be placed above-water, the area concerned must be wetted with water immediately prior to placement.
- The diver should carry the mixture to the site in a bag, to avoid 'washing out' of the mixture prior to placement.
- Place the mix in a firm manner, tamping it well down, with no time wasting.
- Out of water a smooth finish can be achieved by hand or machine trowelling.
- Out of water, where the thickness of Speedcrete is less than 12mm(½ins),it should be cured after 16 hours with damp sand or sprayed with an approved curing compound.
- No underwater curing is required.

# CHAPTER 18

## EXPLOSIVES UNDERWATER

The use of explosives underwater has greatly increased as the technology of the offshore oil and gas industry has expanded, and explosive devices are now in common use for "constructive" purposes, whereas in the past, their use has always been associated with destruction only. Explosive charges are placed and fired deep beneath the seabed in drilling operations, to open up fissures in the rock; to cut off steel pipe or casing, to cut trenches in which flow line will be laid, to remove old structures, and countless other applications. Explosive bolts or similar shear devices can be actuated at a distance to release something as simple as a marker buoy, or control the launching of a multi-million pound platform into deep water, or shaped charges will sever wire hawsers or a 48in diameter pipe-line as easily and neatly as a knife cuts butter.

Most of these applications call for the use of pre-prepared devices, which only require connection to their triggering device, and there may be little call for a diver to actually make up a charge, fuse, place and then detonate it, except when it comes to general salvage and civil engineering contract work. These are both areas in which large quantities of explosive material may be detonated, and hence every commercial diver should have an appreciation of explosives, how they are detonated, why they detonate, how to achieve the best results from an explosive charge, handling and general safety precautions.

The subject is extremely technical, and many years' experience will be necessary before a diver could say with confidence, that he was fully competent, or "expert", but the contents of this Chapter certainly cover more than the basics.

## EXPLOSIVES AND THE LAW

### Regulations

The potential destructive power of any explosives substance, coupled with the need to ensure that it is handled only by competent, trained individuals, who have a regard for the public safety, makes it necessary for strict regulations in order that such materials can be purchased only by authorised individuals.

All users of explosives or explosive materials, or those who store explosives, other than certain government departments, must hold a valid Police Explosives Licence or Certificate appropriate to their operation.

It is the responsibility of the retailer of explosives that he does not make it available to unauthorised persons, and therefore it follows that the relevant documentation must be produced, before explosives are allowed to change hands. Co-operation in this matter between supplier and purchaser is essential, as with fire-arms licences and the purchase of ammunition, and each party in any transaction has a separate and legal responsibility, with heavy penalties for failing to observe them. Particularly at a time when explosives are the main weapon of terrorist factions, the control of explosives and their associated components and accessories, in particular high explosives and detonators, has assumed a high level of importance.

All users of explosives, other than those who purchase materials under an "Immediate Use" police certificate, must observe the regulations regarding storage, the various categories of which are as follows:

| Type of store | Quantity of explosives permitted |
|---|---|
| 1 Private use | 10lb nominally (metrication has caused the makers of explosive materials to supply in 5kg minimum packs, which represents 11.023lbs of high explosive, <u>or</u> 30lbs(14kg) blackpowder; plus up to 100 detonators, and 5 coils of safety fuze. |
| 2 Registered Premises | |
| Mode "A" | 60lbs explosives, including blackpowder and detonators, <u>or</u> 200lb blackpowder only. |
| Mode "B" | 15lbs explosives, including blackpowder and detonators, <u>or</u> 50lb blackpowder only. |
| 3 Stores | |
| Division "A" | 150lb explosives, including blackpowder and detonators |
| Division "B" | 300lb explosives, including blackpowder and detonaters |
| Division "C" | 1000lb explosives, including blackpowder and detonators |
| Division "D" | 2000lb explosives, including blackpowder and detonators |
| Division "E" | 4000lb explosives, including blackpowder and detonators |
| 4 Magazines | Varying quantities but generally in excess of those permissable under Stores Division "E", the exact quantity being dependent upon the requirements laid down by HM Inspector of Explosives, who is responsible for the examination and approval of magazines. |

NB: The explosives weight of detonators for Storage Class 2 to 4 above, should be calculated at 2.25lb per 100 detonators. The explosives weight of Cordtex and Superflex in Storage Class 1 to 4 above should be calculated at 16lb per 1000ft of Cordtex and 40lb per 1000ft for Superflex fuse.

Application to purchase explosives, and then store them in the relevant catgory of 1-3 above, should be made to the local Chief of Police. Application for permission to construct, erect or operate a magazine should be addressed to the Health and Safety Executive, HM Inspector of Explosives, who have the power to refuse an applicant a licence. The holder of a magazine licence does not also require a Police certificate or Licence.

<u>Certification</u>

Explosives certificates and licences are free, and valid for a period of 12 months from date of issue, with the obvious proviso that the Chief of Police has the power to withdraw or revoke any such authority at immediate notice, should circumstances dictate.

Police Explosives Certificate

Required to purchase any high explosives, electrical detonators and Cordtex.

Police Explosives Licence

Required for the purchase of black-powder, safety fuse and plain detonators only.

Police "Immediate Use" Certificate

Where explosives are required for immediate use in larger quantities than the existing authorisation allows, eg. a private user with an Explosives Certificate who requires 120lb of high explosive for a particular "one-off" job - or where the intending user is considered competent, but does not hold a Police certificate or Licence, the Chief of Police is authorised, at his sole discretion, to issue an "Immediate Use" Certificate.

This will be valid for the one purchase only, on a specific day, for a specific task. Should the material not be used on the day of purchase, or a quantity remains unused after, then the police issuing authority must be informed, with details of the quantity of explosives, current whereabouts, and the circumstances, plus measures being taken to ensure the safe and secure storage, whilst a decision is taken regarding their future.

It is accepted that circumstances of mechanical breakdown of craft or plant, bad weather, sickness, and other factors may bring about a situation in which explosives purchased for "Immediate Use" cannot be used as planned. Provided the circumstances are reported, then alternative arrangements can normally be made.

Application for permits

In order to be issued with any of the authorising documents mentioned, and it should be remembered that an individual person may hold both a Police Certificate and a Licence at the same time, the applicant must, in the opinion of the Chief of Police be a "fit" person to purchase, store and use explosive materials. There is no definition of the word "fit" in this context, or of a persons "fitness", either in the Explosives Act or any relevant Act of Council.

HM Inspectors of Explosive consider that that one of the conditions is that a Chief of Police must be satisfied that the applicant will take such precautions as will afford all necessary security for the public safety.

Application should be made on the appropriate form, to the Chief Constable of the applicant's home county, or Crime Prevention Officer of his home town or city, nearest to his normal place of residence. In most cases an interview will follow, at which the applicant will be expected to satisfy questions related to the intended use of the materials, where they will be stored, the type of materials likely to be purchased, and what experience or training the applicant has received.

There is normally a short delay whilst certain enquiries are made, and a visit may be necessary to see the place of storage, which may also entail the local Fire Prevention Officer. There may be other requirements, which will vary from place to place, depending on the local circumstances, and Chief Constables are free to impose such requirements as they see necessary.

In general, proof of some form of recognised training, with some subsequent practical experience under the supervision of an existing qualified Certificate or Licence holder, a character reference, proof of a permanent address and stable background, are the minimum requirements. Whilst it is not possible to be specific, applicants under the age of 18 years are unlikely to be issued with an explosives Certificate or Licence, and a criminal record or history of abnormal behaviour would be likely to debar the applicant.

Renewal

Renewal, if desired, of Certificates and Licences can take place, free of charge, on the expiry of 12 months from issue, or earlier. It is recommended that such applications be made some weeks prior to expiry of previous documents, in order to give time for any difficulties to be resolved, and in order to prevent the situation where an individual finds that his authorisation has expired, but he is now unlawfully holding a stock of explosive materials. Application for renewal will entail the completion of another application form, which should be forwarded, along with the expiring documents, to the original issuing authority. Application can be made elsewhere, since the Certificate or Licence is normally valid for use anywhere in the United Kingdom, but there may be certain restrictions or endorsements on an individual authorisations to the contrary.

STORAGE OF EXPLOSIVES

Details of the various classes of store have already been outlined, but a few notes of explanation are necessary.

There are no legal restrictions on the method in which explosives should be stored under the category of "Private Use", other than those imposed by the certification authority, but it is recommended that the maximum amount of explosive allowed under "Private Use", ie. 10lb (4.5kg) or 30lb (14kg) of blackpowder, and up to 100 detonators, should be kept in a secure, locked box, clearly marked "Explosives", and stored well clear of children, in such a place, that it could readily be removed to a safe place in the event of fire. The method of storage must satisfy the Chief of Police concerned.

Applications from individuals living in "bed-and-breakfast" type of accommodation; "shared" accommodation, or blocks of flats, are likely to be refused.

REGISTERED PREMISES - Mode A

This type of Store requires a building constructed substantially of brick, stone, concrete or iron, or a securely constructed fireproof safe, wholly detached from any dwelling house by a distance laid down in Statutory Instrument 1951, No 1163, as well as being not less than 15yds from any public place of work or thoroughfare. A registeration fee is payable, and the premises subject to inspection by the local Fire Prevention Officer.

REGISTERED PREMISES - Mode B

May consist of a properly constructed fireproof safe or other substantial container such as a locked cupboard, box or drawer, kept inside a shop, house, office or warehouse.

STORES

If the quantity of explosives and detonators to be stored exceeds 60lb (200lb if blackpowder only is to be kept), the explosives must be kept in a properly constructed building, licensed by the local authority. There will be an annual fee, and application should be made on HM Stationery Office Form No 1.

MAGAZINES

If the quantity of explosives to be stored is greater than that permissable under a Store, Division E (4000lb), and it is not convenient to erect two Stores, then an application for a Magazine must be made to HM Inspector of Explosives.

CARRIAGE OF EXPLOSIVES

The handling and conveyance of explosive materials by road is covered by the Explosives Acts of 1875 and 1923 and subsequent Statutory Orders.

Vehicles carrying explosives fall into two categories:

1 Specially constructed road vehicles

2 Motor vehicles not specially constructed.

Category 1 vehicles above are those constructed in accordance with Home Office Regulations in mind, which differ for:

a) Petrol-driven vehicles
b) Diesel-driven vehicles

The regulations should be consulted if more than 500lb of explosives is to be carried, but less than 8000lb since these are the maximum loads of both types of vehicles in Category 1.

Briefly, two men must accompany the vehicle; there must be a fire-resistant screen between the cab and the body; the fuel tank must be in front of the screen; a quick action fuel "cut-off" must be fitted in the fuel line, plus other regulations relating to fire extinguishers, the type of lamps carried, floorboard material and security.

Category 2 vehicles are required where the quantity of explosives exceeds 100lb, but is under 500lb. Again, the regulations specify the exact vehicle requirements, which include that the outer package of explosive materials must be an approved metal cylinder; all such cylinders must rest on the floor; two men must accompany the vehicle, and other requirements.

Category 2(b) vehicles can have a maximum permissible load of 100lb, and can be any mechanically driven vehicle, not carrying or plying for public passengers, provided that the conditions of O.S.S. No 11 are met, and all due precautions are taken for the prevention of accidents.

CLASSES OF EXPLOSIVES

By definition, there are three categories of explosives, which are as follows:

Low Explosives

These include non-shattering, lifting or propellant explosives, examples of which are gunpowder, blackpowder and cordite. By reason of their chemistry, or the manner in which they are used, they are incapable of detonation, neither are they affected by shock. Initiation is by flame, flash or spark only.

High Explosives

Due to the rapid chemical changes that occur, these are described as "shattering". Typical examples are dynamite, TNT, Amatol, RDX, Torpex, and all plastic explosives or those with a nitroglycerine content. These can all be initiated by shock.

Primary Explosives

Are those materials which under the stimulus of mild shock alone, will detonate easily, ie. fulminate of mercury; lead azide etc, all of which have a molecular structure which makes them unstable. Such materials are normally used in limited quantities only, and form part of what is known as the "explosives train" in providing the shock necessary to detonate high explosive materials.

Examples of explosives available to the public:

Explosives manufactured in Gt Britain will have originated from either the ICI (Nobel Division) or E & C.P Ltd (Explosives and Chemical Products). Examples of the wide range of material available include:

a) Nitroglycerine gelatines

Includes all gelatines and gelignites.

b) Nitroglycerine semi-gelatines and powders

Belex, Rockite, and dynamite

c) Non-Nytroglycerine Powders

Trimonite, Nobelite, Anobel etc.*

d) Slurried explosives

Supergel, Powerfil*

* These are trade names used by the ICI (Nobel Division) Company.

## CHEMISTRY OF DETONATION

The expression "explosives train" refers to the chain of events which once initiated will cause the detonation of an explosives substance. It might at first sight appear a matter of some simplicity to initiate an explosion, whereas in fact it is a complex process, which should be fully understood to obtain the best results, and avoid misfires.

A low explosive such as blackpowder requires only a flame, flash or spark to initiate combustion, which then consumes the powder converting the material into gas, accompanied by heat.

On the other hand, high explosive, which is purposely made insensitive, and hence difficult to detonate, requires a considerable amount of physical shock only. In the case of blackpowder, practical initiation of the "train" is by precussion, chemical or slow burning fuse. With high explosives, a small subsidiary charge of a more sensitive nature is needed, usually referred to as a "primer" which contains a "primary" explosive compound.

Exactly how shock initiates high explosive is not perfectly understood; the effect may be purely mechanical in that it secures molecular breakdown, but an alternative theory, known as the "Hot Spot" theory is equally convincing. This supposes that the necessary heat derives from the inter-crystalline friction arising from the application of a sudden shock. This makes sense if it is remembered that most high explosive materials have ingredients added in the form of particles which improve friction, and that a sensitive explosive can be made less sensitive by the addition of wax, which appears to have a lubricating effect.

### Hydrodynamic Detonation

In an explosion, the chemical reaction is one of molecular breakdown and recombination, and this reaction proceeds through the mass of material at a finite rate. Consider as an example, a small quantity of explosive material in which the reaction is developing. Now imagine it divided into a series of thin layers perpendicular to the axis along which the reaction is developing. The gas pressure resulting from the interaction will be least at the layer furthest from the initiating point, and at a maximum further back where the reaction is just completed. The gas pressure produced is achieved so suddenly, that in any layer it causes adiabatic compression of the gases in the next layer, hence raising the temperature of that layer and causing the reaction to proceed faster.

This naturally causes even greater pressure to be developed which continues to compress the gas and increase the pressure at each layer until the furthest layer is reached. The result is a shock wave known as the detonation wave. The pressure of the wave in a detonating explosive may be in the order of 150,000 to 250,000 atmospheres, which is reached in a matter of microseconds, with an average temperature increase to between 3000 and 4000°C.

In an explosion, the detonation wave travels through the explosive at a determined rate, the terminal velocity being reached when the energy produced is absorbed completely in compressing the material ahead; this rate is known as the "velocity of detonation". Typical examples of this velocity are:

| | |
|---|---|
| RDX | = 8639m/sec |
| Nitroglycerine | = 8060 " |
| PETN | = 8150 " |
| TNT | = 6480 " |
| Blasting gelatine | = 7900 " |
| Gelignite | = 6520 " |

The high pressure associated with the detonation wave has already been mentioned. Any situation which relieves this pressure will discourage the propagation, so that it is necessary to have an adequate amount of confininement. If such confinement is not possible, then an explosive material must be used that will maintain detonation under favourable conditions, ie. an HE. with a high velocity.

## EXTERNAL EFFECTS OF EXPLOSIONS

These fall into two categories, namely the shock wave, followed by the expansion of the resulting gas. The detonation wave passes through the explosive material, reaches the extremities and passes into either air, earth or water. Due to the "streaming" effect of a detonation wave, the effect is strongest at the terminal end of the cartridge of explosive. If the explosive is confined, as for example in a bomb case, or down a shot-hole drilled in rock, then far more energy is passed into the surrounding media.

## UNDERWATER EXPLOSIONS

Explosions underwater are a very special circumstance, since the surrounding water achieves full and complete confinement or "tamping" more efficiently than ever would be achieved on the surface artificially. If such an underwater explosion could be slowed down and observed, the following sequence of events would be seen to occur:

a) On detonation the shock wave is transmitted through the water, and will be seen on the surface to give an immediate "flattening" effect, followed by the noise of detonation.
b) A rapidly expanding bubble of gas is produced, which in effect does the actual "work".
c) This gas bubble expands until its maximum diameter is achieved, which will be governed by its internal gas pressure becoming equal to that of the surrounding water, after which the natural cooling effect will lower the temperature of the gas bubble, decrease its pressure, and the water pressure will cause the bubble to collapse inward upon itself.
d) In collapsing, the pressure of the gas will rise as it becomes confined into a smaller space, as a result, its temperature will rise, and at a certain point the gas pressure will once again exceed the surrounding ambient pressure.
e) The gas bubble will now expand for a second time, performing "work" for a second time, until again water pressure, assisted by its cooling effect, prevents further expansion, and the bubble again collapses.
f) This oscillation continues until the gas is entirely dissipated through heat losses, after which the remnants will slowly bubble towards the surface. The "target" is therefore subjected to a number of repeated "blows", each weaker than its predecessor, as the gas expands and collapses. This is a situation which cannot be achieved on land, and hence allows work to be achieved in an underwater situation, using far less material than the same task would require in a dry situation.

### Shallow-water Explosions

It follows that should explosives be detonated in water sufficiently shallow for the first expansion of the gas bubble to break the surface, giving a "depth-charge" effect, then no further compression of the gas is possible, and the advantage has been lost. This circumstance may prove unavoidable, in which case the size of the charge may need to be reduced, and consideration given to the surface effects of the shock wave and noise, particularly near buildings or structures.

### "Safe" and "lethal" distances For Divers to Underwater Explosions

Submerged explosive charges should never be detonated with a diver knowingly underwater, nor in the vicinity of surface swimmers or public beaches where people may be partially or wholly in water.

There is no such thing as a "safe" distance from an underwater explosion, and the guidance that follows is only that gained by the armed forces during two world wars, in which there were opportunities to record certain incidents. If it is intended to carry out blasting operations underwater, then it is the responsibility of the appointed diving supervisor to ensure that no lives are placed at risk.

This may entail the co-operation of other diving contractors in the area, and it must be accepted from the outset that there may be delays, even to the point of withdrawing or defusing charges already laid, or even cancellation of the entire operation. The alternative is the risk of possible fatalities, injury, legal action, and the possible withdrawal of the authority to use explosives.

Planning of blasting operations is therefore essential, with full consultation regarding local authorities, the police, public services, harbour authorities and others. The safety and welfare of the public must always be the prime consideration. The golden rule is always - IF IN ANY DOUBT - WAIT.

## "Safe" distance for a diver

The so called "safe" distance = 40 x the TNT equivalent weight of explosives, measured in pounds, where the distance is measured from the point of detonation in feet.

Example: What would be the "safe" distance for a diver, if a charge weighing 50lbs (TNT) were detonated underwater ?

40 x 50lb = 2000ft

## "Lethal" distance for a diver

The so called "lethal" distance = 7 x the TNT equivalent weight of explosives, measured in pounds, where the distance is measured from the point of detonation in feet.

Example: What would be the "lethal" distance for a diver, if a charge weighing 50lb (TNT) were detonated underwater ?

7 x 50lb = 350ft

## Typical Working Calculation

Example: A contractor wishes to detonate charges underwater, to carry out demolition work, but due to the circumstances, can only guarantee an area with a radius of half a mile (nautical), to be free of divers. What is the maximum weight in pounds, of the charge he can "safely" detonate at any one time ?

Answer:

1 x international nautical mile = 6076ft

therefore half a mile = 3038ft

$$\text{Weight (lb)} = \frac{\text{Distance (ft)}}{40}$$

$$\text{ie: Weight (lb)} = \frac{3038}{40}$$

$$= 75.95\text{lb}$$

To nearest lb = 76lbs

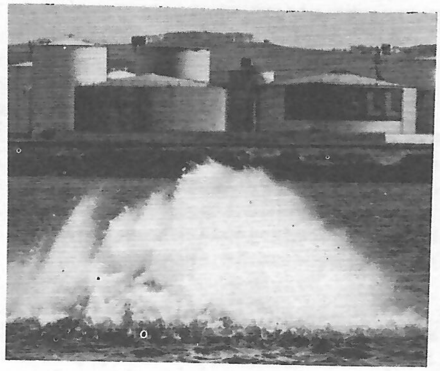


Fig 18-1 Typical surface disturbance following a shallow water explosion. Note the fuel storage in close proximity

## Types of Explosives

Military:

### TNT.(Trinitrotoluene)

Made by digesting toluene, which is obtained from the fractional distillation of coal-tar, with nitrating acid (ie. a mixture of nitric acid and sulphuric acid). There will be an incomplete combustion on detonation, due to a deficiency of oxygen in the TNT molecule, and the resulting uncombined carbon gives rise to a thick black cloud, typical of an unbalanced explosive detonated in air. Pale yellow in colour, can be poured or moulded hot, changes to light or dark brown when cast; poisonous.

RDX (Cyclonite)

Manufactured by treating hexamine with a cold concentration of nitric acid. Hexamine itself is made by combining formaldehyde with ammonia. More sensitive than TNT, it is a white crystalline powder with a very high melting point. Normally mixed with TNT, which then allows it to be poured. Can be mixed with a plasticiser to make a plastic explosive. The nitric acid content will eat its way through containers that are not lined or varnished.

Amatol

A mixture of ammonia-nitrate and TNT in the proportions of 60/40. The nitrate provides the necessary additional oxygen for the complete combustion of the TNT. The mixture melts at 80°C and readily absorbs water. Causes serious corrosion when damp and in contact with steel or non-ferrous materials, forming "blue-salts" or picric acid crystals in the case of the latter, which are extremely sensitive to shock. Amatol expands when hot, and at 30°C can be as much as 5%, causing containers to burst open.

Minol

An Amatol mixture of explosives, to which aluminium powder has been added, usually in the proportions of TNT-43%, aluminium powder-20%, ammonium nitrate-37%, making a more powerful material.
100lb of Minol 0 150lb of TNT

RDX/TNT

A mixture of 60% RDX and 40% TNT, to which wax has been added as a lubricant. Known as Cyclotol in the U.S.A.

Torpex

Another version of RDX/TNT in an aluminised form, the aluminium being added at the expense of the RDX to increase its power. More sensitive than TNT alone.

Plastic Explosives (PE-2/PE-4)

Manufactured by incorporating RDX with oil and gelatine, so as to reduce the RDX content to about 88%.

Commercial Explosives

Nitroglycerine

The most important sensitiser for commercial explosives. Made by reacting purified glycerine with a mixture of nitric acid and sulphuric acids, with water. Readily initiated by impact or shock. It is a viscous yellow fluid, which can be frozen at 13.2°C, to make a sensitive solid explosive. In order to prevent unwanted freezing when part of another explosive mix, ethylene glycol (anti-freeze) is introduced.

PETN

Pentaerythrito-Tetranitrate, an explosive material sensitive to friction and mechanical shock. Used as the dry white powder filling for Cordtex and Superflex.

Nitrocellulose

Used to thicken nitroglycerine during the preparation of both gelatine and semi-gelatine type explosives, the basic raw material being cotton. Normally handled wet during manufacture, nitrocellulose contains 30% water, and in such conditions is non-explosive, ie. when the nitrogen content does not exceed 12.6%. When more highly nitrated, it becomes "gun-cotton", and as such is very sensitive, even when wet. Dry nitrocellulose is an extremely dangerous material.

Gelatines

The main constituents are nitro-glycerine, nitro-cotton, sodium nitrate and cellulose materials. Gelatine explosives are of high density, malleable (within reason), offer good water resistance, are free from fumes and store well. The normal range comprises strengths from 45 to 75%, which meets the requirements of most underwater, mining, quarry and tunnel work.

Special Gelatines

So named since they contain a proportion of ammonium nitrate in manufacture. Other ingredients are the same as for plain gelatines plus absorbents. Since ammonium nitrate readily absorbs moisture, cartridges of this explosive are either dipped in wax, or packed in a special manner to prevent ingress. Opened cases should not be exposed to the atmosphere longer than necessary before being resealed.

Two-part "Mix" Explosives

Developed in the United States, these are conveniently pre-packaged, two component, high-explosive "mix" kits. Consisting of a coarse blended solid, sealed in an anti-static pvc container, which can be bags, bottles, or pre-shaped charges, and a thinner liquid substance, neither component being an explosive material by itself, nor are they classified as highly-inflammable.

When the activating liquid component is added to the semi-solid, an explosive compound with a 40-60% power equivalent of commercial dynamite is produced. Although a relatively low yield explosive, the advantages of storage, transportation etc far outweigh its disadvantages. Since neither component is classified as explosive, it readily overcomes many of the restrictions and regulations which relate to the conventional explosive materials.

As yet, this development has not had any great impact on the UK market, and in any case, has lost some of its flexibility by being classified in accord with other explosives, for obvious reasons.

DETONATORS

It has already been stated that certain combinations of chemicals will form explosive compounds, which can only be initiated by shock. ie. high explosives and primary explosives. This "shock" is normally obtained by the use of a detonator, which itself contains a sensitive primary explosive, and hence should be treated with the greatest respect.

There are a wide range of types of detonator, which can be classified under the headings of "plain" and "electric".

Plain Detonators

These comprise of an aluminium tube, approximately 1.25in length, open at one end, the sealed end of which holds a base charge of high-explosives, overlaid with a priming charge. A typical base charge would be 0.24g of PETN, compressed into place at a pressure of 4000psi. On top of this will be placed an initiating charge of dextrinated lead azide and lead styphnate in the proportions of 2:1.

Plain detonators are designed specifically to be used with safety fuse.

Electric Detonators

Instantaneous electric detonators consist of a copper or aluminium tube, similar to plain detonators, except that they are fitted with a pair of either tinned iron or copper "lead-in"wires, which are insulated with a pvc sleeving.

Their construction is as shown below:

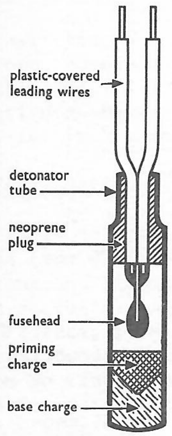



Fig 18-2 Section of an electric detonator, showing components

Neoprene plug:

This holds the "lead-in" wires in place, and forms a watertight seal at the point where the tube is crimped, which compresses the plug in place.

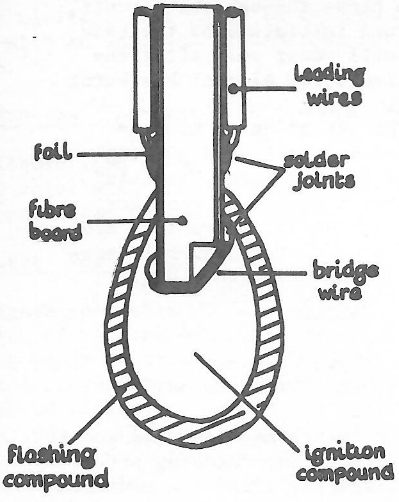



Fig 18-3 Construction and components of a fuse-head

Fuse-head

Fig 18-3 shows the construction and components which make up the fuse-head. The metal foil strips make the electrical connection between the lead-in wires and the "bridge" wire. When a current in the order of lamp is passed through the "bridge", it heats this small section of high resistance wire, which glows white hot before burning out. During the peak of the intense heat generated, it automatically ignites the ignition compound, which in turn fires the flashing compound, so setting in motion what has already been described as the "explosive train" of initiation.

The sequence of events in firing an electric detonator is shown diagrammatically in Fig 18-4

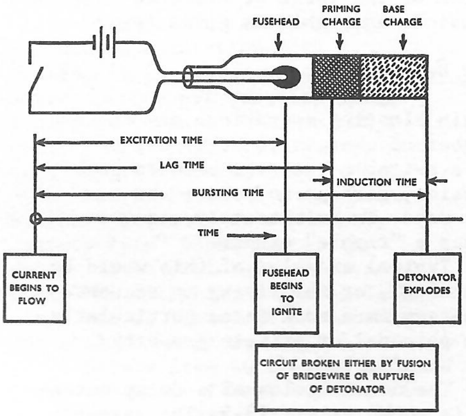



Fig 18-4 Sequence of events in firing an electric detonator

The electrical resistance of the fuse-head alone, without the lead-in wires, is usually kept between the limits of 0.9 to 1.6ohms, and a current flow of 0.5amps applied for 50 milliseconds is the minimum necessary to start the cycle of initiation. This figure is for a single detonator, and with a multi-detonator firing circuit, a greater current flow will be necessary, as outlined later in the Chapter.

Since the reliability and standard of detonators is of the utmost importance, each stage of the manufacture is carefully controlled, so that characteristics and performance are consistent throughout.

## Detonators for Underwater Use

The standard electric detonator is not suitable for any "in-water" use except at very shallow depths. For deep water or "long soak" conditions, ICI in particular manufacture a special submarine detonator range known as "Hydrostar" underwater detonators, which have a copper body tube, slightly longer and wider than a conventional surface elctric detonator, plus blue pvc insulated "lead-in" wires.

These are designed to operate in water, to a maximum pressure of 1000psi. Details of the range of electric detonators available is given later.

## Delay Detonators

Certain blasting operations may require a number of charges to be fired, but with a suitable interval between each explosion, perhaps to reduce the shock wave, or deliberately, to produce a "ripple" effect.

Typical examples of this would be "trenching", or the firing in sequence of charges in a rock face, particularly where personal or private property might be affected.

The construction of a delay detonator is shown in Fig 18-5. The assembly is that of a standard electric detonator, except that an additionalsection is added, which gives the delay element between the fusehead and the priming composition. In some detonators, the fusehead may be enclosed in a tubular neoprene insulating sleeve, as an added precaution against the possibility of static discharge between the fusehead and the tube wall, which might cause a premature initiation.

The actual delay element consists of a thick walled tube loaded with a suitable delay composition. The delay period is controlled by the nature of

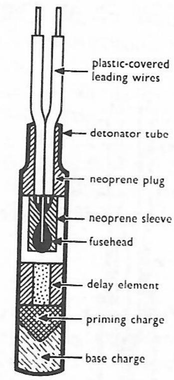



Fig 18-5 Components and construction of a delay detonator

this material, and the amount enclosed in the tube.

Due to the nature of their manufacture, all delay detonators can be used in "wet" conditions, being able to withstand water pressure of at least 60psi (equivalent to a depth of 132ft). Delay detonators can be wired in series or parallel, in the same manner as ordinary electric detonators. The fusehead of each unit will ignite as the firing current flows through the circuit, but actual initiation of the base charge will occur only after the respective delay element has burnt through.

The actual delay time is indicated by a coloured pvc tag attached to one of the "lead-in" wires, which will bear a number. With ICI products, these tags are colour coded as follows, but these should be checked before use:

No 1 - Yellow
No 2 - Blue
no 3 - White
No 4 - Red :and so on.

This aids identification, and greatly facilitates the checking of shotfiring circuits, after the connections have been made.

Range of Delay Detonators Available

Half-second Series

In the half-second series, there are 13 detonators, numbered 0 to 12, each with a nominal time interval of 0.5sec between consecutive numbers. No 0 acts instantaneously, ie. it has no delay.

Short-delay Series

There are 19 detonators in this range, numbered from 0 to 18, with No 0 being instantaneous. The nominal delay between successive numbers from No 1 to 4 is 0.0 25secs; from No 5 to 12 inc. is 0.05sec,
and from No 13 to 18inc. is 0.07sec. Short delay detonators are of particular value for blasting operations in quarries and open cast work where ground vibration must be kept to a minimum. They improve blasting efficiency, and give better rock fragmentation.

"Carrick" Short-delay Series

These are specially designed for use in coal mines, since they incorporate a new type of fusehead and a special delay element which eliminate the risk of firedamp ignition. The range is from No 0 to 10, with an interval of 0.025sec between each.

"Hydrostar" Underwater Short-delay Series

Available in a short series from No 0 to No 3 only, with a nominal delay of 25milliseconds between each consecutive number.

Electric Powder Fuses

Designed specially for the electric shot firing of blackpowder. Each consists of a thick paper tube containing blackpowder, with a conventional electric detonator fusehead fitted at one end. On firing, this ignites the powder in the tube, which in turn ignites the main charge. The charge weight in each tube is in the order of 5 grains, and they are not waterproof.

SAFETY FUSE

The flexible, waterproof, textile covered "tube" containing blackpowder, that is used to fire plain detonators. Supplied in lengths of 24ft(7.3m), each known as a "coil" of fuse, or spooled in longer lengths of 3000ft(914m).

The construction and manufacture is such that safety-fuse can be relied on to burn at a uniform rate, so that a carefully measured length cut from a coil, will act as a "time-delay" fuse to ignite a blackpowder charge, without the use of a detonator. Or, if inserted into the open end of a plain detonator and crimped in place, will initiate high explosives. A typical "burning" time would be 1ft per 30 seconds, but other times are available.

On purchase, and prior to its use in connection with a charge, it is recommended that after cutting off and discarding the first 4-6in (100-150mm) of a coil, a 1ft length is measured and cut, and the burning time tested.

Due to physical compression by water pressure at any depth, "safety fuse" burns faster the deeper it is employed, and over 60ft(18m) will have risen to 3.5ft (1m), and is therefore recommended for shallow water use only.

Safety fuse is ignited by any form of heat or flame, and should be stored in a dry atmosphere. This type of fuse is known sometimes as Bickford fuse, after the naval officer that invented it.

CORDTEX DETONATING FUSE

Cordtec is the trade name for a highly efficient, flexible, cord-like fuse with a very high detonation velocity, being in the order of 21,000ft per sec.

It consists of a core of PETN explosive, enclosed in a tape wound "tube", reinforced by textile yarn, the whole enclosed in a white pvc sheath.

Cordtex is initiated by either a detonator taped parallel and as close and tightly in contact as possible, or else, by enclosing one end inside a single cartridge of high explosive. In either case, it is sympathetic detonation which causes the Cordtex to be initiated.

Its tensile strength is 180lb, which coupled with the tough pvc outer covering, makes Cordtex highly resistant to strain and abrasion, and is particularly suitable for underwater use to considerable depths. At temperatures down to -10°C Cordtex will remain flexible, but below this figure will stiffen, and cracking may occur. Used as an instantaneous fuse between charges of high explosive, hence allowing any number to be linked together, simply by passing the Cordtex through the centre of each charge, and on to the next.

It offer a considerable financial saving in that possibly only one detonator will be required, the risk of electrical misfires are greatly reduced, and charges can be linked over great distances. Cordtex can be used to form any number of "branch lines, provided that these are made correctly, and that the "streaming" effect of Cordtex is taken into account. Such "branch" junctions, which can be made by binding with wire, tape or string, should be over a minimum distance of 4in(100mm).

Since on detonation there is a tendency for the detonation wave passing down a length of Cordtex to continue on in a straight line, sharp kinks or bends, with a radius of less than 4in(100mm) should be avoided. Neither should Cordtex fuse be allowed to lay across itself. In both cases, the fuse is very likely to be severed at the point of crossing or bend, and misfires will result.

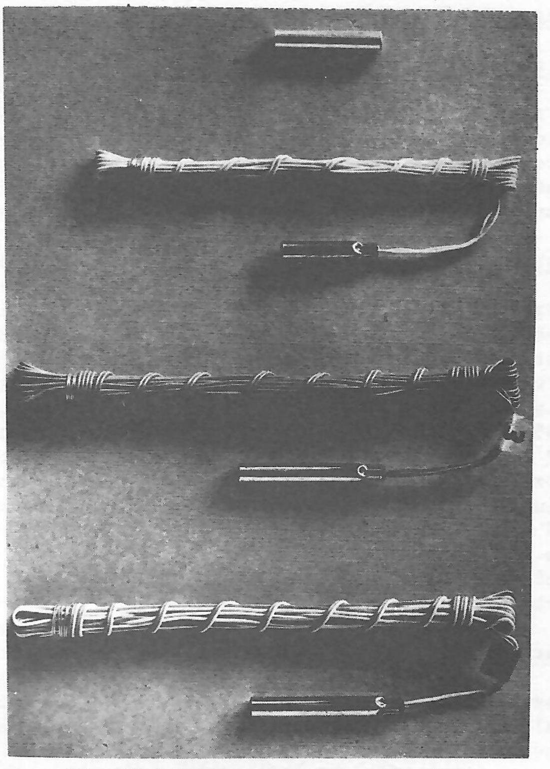


Fig 18-6 Detonator types, showing a plain detonator (top), an electric detonator, followed by two electric delay detonators with tags showing

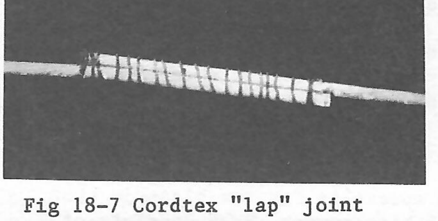


Fig 18-7 Cordtex "lap" joint

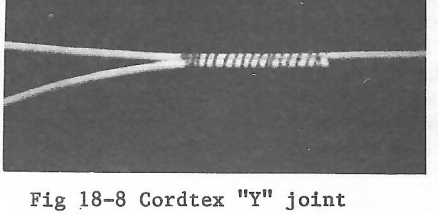


Fig 18-8 Cordtex "Y" joint

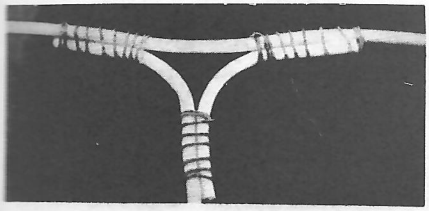


Fig 18-9 Cordtex "double L" joint

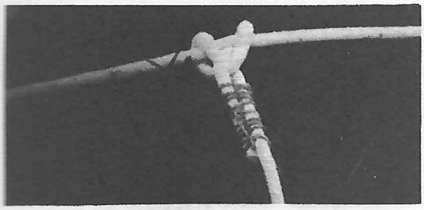


Fig 18-10 Cordtex "Clove-hitch" joint

Cordtex Used Underwater

Particularly valuable in an underwater environment, Cordtex reduces the time taken to lay charges, and reduces the actual number of electrical connections the diver would otherwise have to make.

In bad visibility this can be a great advantage, and the only consideration necessary, other than that of joints and bends, is the possibility of water ingress of the PETN core of the fuse. Underwater, a "free" end of some 4-6ft(1.5-2m) is desirable, and if there is the possibility that the fuse may be left submerged for a matter of days, or weeks, then the free ends should be sealed with special blank "caps", obtainable from the manufacturers, or else a plain detonator.

It is essential that the portion of fuse at the point of detonation is dry, after which satisfactory initiation will continue from dry to wet Cordtex, provided they are in the same section or length. If the Cordtex used for a branch line is wet, then the initiation wave will not pass into that branch, and a misfire will result.

If circumstances are such that all the Cordtex available is wet,

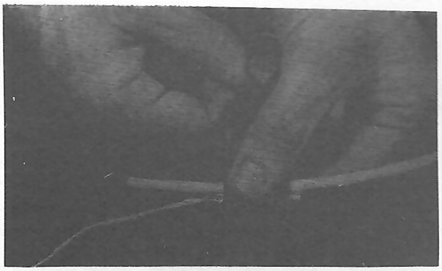


Fig 18-11 Attaching an electric detonator to Cordtex with adhesive tape. Note the amount of fuse left as an overhang, to allow for possible water ingress.

then it can still be used in conjunction with a commercial waterproof primer unit.

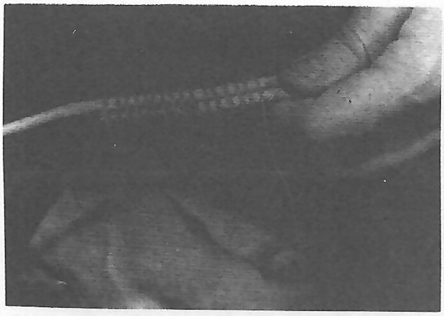


Fig 18-12 An alternative method of attaching a detonator using wire binding with a "plain" detonator and a length of safety fuse. Note that the streaming effect of the detonator is the reverse of that shown in Fig 18-11 above

Cordtex is available in rolls of 500ft(152m), which contain 3.5lb (1.65kg) of high explosive, which must be taken into account when considering purchases and storage allowances of explosive material.

SUPERFLEX DETONATING FUSE

This is a special high-energy detonating fuse developed for the initiation of slurry type explosives. Similar in construction to Cordtex, it also contains PETN but

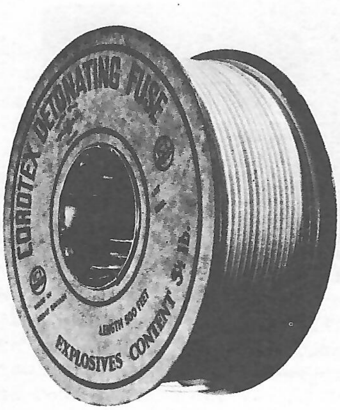



Fig 18-13 A roll of Cordtex fuse

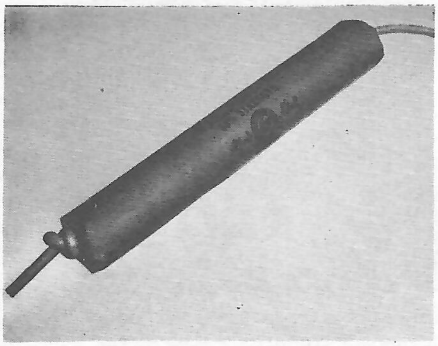


Fig 18-14 A cartridge of high explosive, primed with Cordtex

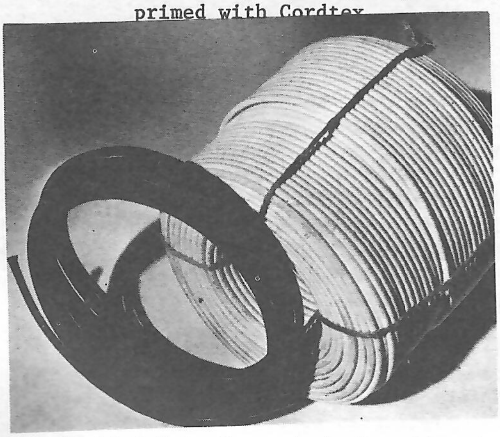


Fig 18-15 Safety fuse, in both coil and reel form

in a larger cross-sectional diameter. It initiates at approximately 21,300ft(6500m) sec, and is easily identified by its bright red pvc outer sheath.

PLASTIC IGNITER CORD

The greatest disadvantage of using safety fuse, is the time taken to "light! a given number of branches in a multi-shot circuit, and the difficulty in ensuring initiation in the desired sequence. Also, in damp or severe weather conditions, the operator runs a serious risk of being exposed to the effects of blast, since the physical "lighting" of each length of safety fuse can prove difficult. This can be overcome by the use of "Fast" or "Slow" igniter cord, which burns with an intense flame progressively along their length once ignited. Used in conjunction with "Beanhole" connectors, they offer a safe and reliable alternative to the "manual" method.

"Fast" igniter cord burns at not less than 1.5 sec/ft(4.9sec/m) and "Slow" igniter cord at a nominal 10sec/ft(33sec/m). Both have excellent water resistance.

If manual initiation of the plastic igniter cord is not suitable, an electric igniter can be used. These have the outward appearance of copper electric detonators, but have a filling of a burning composition, and are slotted to allow for easy crimping on to the cord.

BEANHOLE CONNECTORS

These are similar in appearance to "plain" detonators, except that they are manufactured with a slot in one end, and have a "flashing" type compound fitted between the slot and the open end. Designed to be used as a means of igniting safety fuse from plastic igniter cord, the former is placed and crimped into the open end, and the

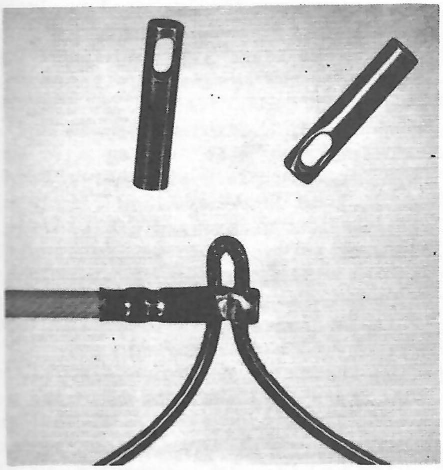


Fig 18-16 Bean-hole connectors, showing method offitting safety fuse, and plastic igniter cord

igniter cord into the slot.

EXPLODERS

Although there are alternative ways of firing an electrical explosives circuit, the use of an approved exploder offers a number of safety factors.

It has already been stated in the section dealing with electric detonators, that a minimum of 0.5amp is required to "ignite" the fusehead and initiate the base charge; this can be obtained from a small lead acid battery, such as used in a car, or even some of the larger dry-cells, but none of these offer the portability, safety or reliability of an exploder.

Exploders usually take the form of an AC generator, built into a suitable carrying case, and fitted with a "safety" device regarding the method of firing. The majority have some sort of detachable handle, without which the device cannot be operated. This handle may be the means of operating a gear-train, which in turn winds up the generator, or cause a circuit to charge up a capacitor. Both in turn, provide an output of sufficient voltage and current to meet the minimum rated output of the particular model.

Exploders are generally rated as being "2 shot" or "100 shot" or what ever capacity stated, which means they are designed to initiate as a minimum, 2 electric, or 100 electric detonators in series connection. They may well fire more than the minimum number, but are not designed to do so.

The detachable handle or similar "safety" device, ensures that the exploder is incapable of being used until it has been re-fitted, and should be retained by the person in charge of blasting operations, until it is required for use.

SHOT FIRING CABLE

This is the cable used to join the exploder to the detonator initiation circuit. It should be well insulated to prevent short-circuits between the wires, and of choice should be twin cable, in the order of 300ft (100m) in length, and with an electrical resistance of about 2.5ohms per 300ft length per single conductor.

Resistance greater than this will lead to a serious voltage drop, and hence current flow, and may give rise to misfires, especially if an exploder is being used at, or close to, its top capacity rating.

In use shot-firing cables often suffer cuts and abrasions, and should be inspected before each firing to avoid the time wasting business of misfires etc. The end connections should frequently be re-made, to give good electrical contact.

Recent developments, particularly in the United States, make full use of the electronic chip, and these exploders include a circuit tester, which can be used to check the continuity of the firing circuit, even with a detonator included. Whilst such circuit testers are not a new idea, their incorporation into the exploder is, but none of the devices illustrated in Fig 18-17 are thus fitted.

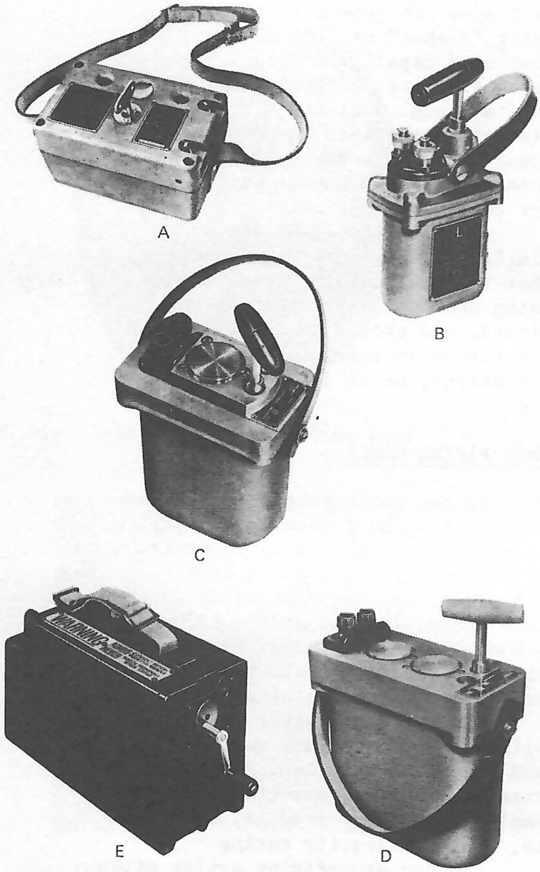



Fig 18-17 Types of exploder

A - ME12 (12 detonator)
B - Schaffler Type 350
(25 detonators)
C - Schaffler Type 750
(100 detonators)
D - Schaffler Type 770
(200 detonators)
E - Beethoven Type Mk 2
(100 detonators)

PREPARING TO FIRE CHARGES, USING ELECTRICAL DETONATORS

Check that the following minimum equipment and accessories are available at hand:

1 Explosive charges.
2 Detonators, in sufficient quantity to complete the task, allowing for the testing of firing circuits and possible misfires.
3 Firing cable, or sufficient length to reach from the "safe" firing position, and the place of work, with sufficient extra to allow for the cutting back of damaged cable.
4 Exploder, or sufficient capacity to fire the maximum number of detonators to be used at one time. NB: If it incorporates an internal battery, or has a re-charging facility, ensure that a new battery has been fitted, or the unit fully charged.
5 An aluminium or brass pricker tool, with which to pierce the cartridges and insert the detonators.
6 A sharp knife.
7 A roll of adhesive tape.
8 Spare single core connecting wire.
9 Suitable containers in which to store the explosives and detonators, separate from each other.
10 A suitable "red" explosives warning flag.
11 A whistle or other warning signal.

The serviceability of the firing cable and the exploder can be tested at the same time. Connect both leads of one end of the cable to the exploder terminals, and an electric detonator across the other end, some distance remote, and either with the detonator inside a steel pipe, or buried in the ground. Operate the exploder. At sea, it is the accepted practice to lower a weighted detonator to about 30ft(10m) depth, well below the keel of the craft, and clear of any fittings.

Charges are then prepared as required, being made up as individual small charges, larger quantities as "bundles", or even complete cases. Packets or cartridges can well be placed inside pvc bags and taped, or lashed together. Such charges should not have the detonators fitted - an act known as "priming" - until required for use, but kept stored in a safe place. Whether or not charges are completely prepared on the surface and taken down with the detonators fitted, or the detonators are fitted after placement, is a matter of choice, and circumstance. Provided that the bared ends of every detonators lead-in wires are short circuited by being twisted together immediately the detonators are removed from their container, and the charges are handled carefully, there should be no risk involved.

The priming of a charge is achieved by piercing a hole in a packet or cartridge of explosive using the pricker tool. This hole should be of sufficient depth to allow the detonator to be completely "buried" in the substance, thus ensuring close proximity contact, but not so deep set that the end of the detonator protrudes out the other side. After the detonator has been implanted, the lead-in wires are either "hitched" around the outside of the cartridge, or left secured by tape or string, to ensure that it cannot be accidently withdrawn after placement.

After ensuring that the shot firing cable is not connected to the exploder; that the inboard ends of it are shorted together, and that the "safety" handle has been rendered "safe", the business of connecting the detonator wires together can commence.

## Choice of Circuits

Electric detonators can be connected up as parallel, series, or series/parallel circuits. Since many blasting operations will require a number of charges to be fired at the same time, it is common practice to use a simple series circuit. When firing with an exploder, a series circuit should not be used when the number of detonators exceeds thirty.

When firing a number of charges in series, remember that as a safeguard a minimum of 1.5amp should be passed through the circuit. The actual voltage necessary to ensure this current flow can be calculated by Ohm's Law, ie. the voltage required equals 1.5amps multiplied by the total resistance of the circuit, in ohm's. This includes the resistance of the firing cable "there and back", plus the lead-in wires, plus the resistance of the individual fuseheads in the detonators.

In practice such calculations are not necessary, since exploders are "rated" by the number of detonators they will fire, which takes into account typical resistance values as above, based on the following figures:

Firing-cable resistance "there and back" should be in the order of 5ohms per 100yd(100m).

Lead-in wires and fusehead of an electric detonator is in the order of 2 ohms.

A parallel circuit will greatly reduce the possibility of a misfire due to insufficient current. In a series circuit insufficient current may cause the most sensitive fuseheads to fire, but break the circuit before they have all received sufficient current to achieve complete initiation. In similar conditions in a parallel circuit, the most sensitive fuseheads may still fire first, but the others will remain in circuit with all the remaining current available.

Parallel circuits also reduce the possibility of misfires due to current leakage. The resistance of a series circuit is often of the same order as that of a leakage path, and therefore a considerable amount of current may travel down this path. Also, in parallel circuits, the overall resistance is very low to that of a leakage path, and hence current will choose the desired detonator path rather than that of the leakage path.

## Firing Charges Using Plain Detonators and Safety Fuse

Although safety fuse with plain detonators will provide a safe means of initiating high explosives, in most operations, and particularly underwater work, it is better to employ electric shot-firing methods, for the following reasons:

a) The ignition of safety fuse in open water conditions is not easy, and at sea in strong winds or pouring rain may be almost impossible.

b) Safety fuse, once ignited, offers a delay which can prove dangerous, since in the period between ignition and eventual detonation of charges, circumstances may change, but it would then be unsafe or perhaps impossible to stop the "explosive train".

c) Should a misfire occur with safety fuse, the accepted practice is to wait a period of 30 minutes before approaching the area of the charge to ascertain the cause. This may prove unacceptable at sea in certain weather or tidal circumstances.

The use of safety-fuse and a plain detonator on the surface, to initiate an underwater charge via Cordtex, should therefore be considered only as an alternative to normal electric firing, perhaps in the event of an exploder becoming unserviceable, or the loss of the firing cable.

In such circumstances, the surface end of the Cordtex is securely lashed or taped to the upper side of a piece of timber, sufficiently large enough to take the drag without sinking. The plain detonator and safety fuse are then mated and crimped together, secured tightly along the line of the Cordtex, and when ready, ignited. Considerable surface noise and disturbance should be anticipated when using this method, whereas electric firing is considerably more discreet.

## SHAPED CHARGES

The ability to accurately focus an explosive charge in any particular direction, will greatly enhance the amount of work achieved for a certain weight of explosive. This can be achieved by building up explosives into a cone or pyramid, with the least amount of explosive material furthest from the target, and the initiating detonator set in the very top, pointing straight at the target surface. Whilst the results will greatly exceed that produced for an equal weight of explosive, placed in a conventional manner, a far greater effect can be achieved by taking advantage of the "Munroe" effect.

The enhanced effect of a hollow gunpowder charge was first noticed by Davey as far back as 1790, and an American named Munroe developed the theory of hollow charges in Washington in 1885, but little practical use was made of this phenomena until the Second World War. Today, the effect of shaped charges feature in a number of commercial and military fields, and pre-charged, shaped charges are now available "off the shelf" for a number of offshore applications, including pipe-cutting.

If a cone, normally of metal, and of a pre-determined thickness, is backed by an explosive charge initiated from the rear, and if the base of the cone is "stood-off" from the target by a suitable amount, on detonation, a deep narrow hole will be produced. The technique is often called the "cavity", "hollow" or "shaped charge" effect, and its success is determined by a number of factors, all of which can be calculated.

The nature of this special effect has been closely studied by X-ray flash photography, which indicates that on detonation, the metal liner of the cone collapses towards its apex. From this collapse emerges a needle-like stream or jet of particles along this axis, which exceed the velocity of detonation at the tip, decreasing gradually towards the rear. This initial stream is followed by somewhat larger fragments and finally by a "slug" of metal moving at a lower velocity, which is the remains of the cone.

The exact nature of the enhanced effect of a shaped charge is still not fully understood, but it is accepted that the stream of jet particles strike the target area with a pressure in the order of 200,000 atmospheres, ie: in the order of 3,000,000 psi with the result that the material of the target is pushed aside, leaving a neat round hole.

Bearing in mind the effect, it will now be clear that the thickness of the conical liner, the "stand-off" height, which allows the jet to develop, and the amount of explosive, are all critical factors.

Conical liners must be made of a uniform thickness material, and the internal angle of the cone must be exactly 80°. Any form of obstruction along the axis of the intended particle jet will prevent its correct formation, so that for a cavity charge to be effective underwater, the space between the charge and the target must be an air space, free of all water. Once the particle jet has been correctly formed, it will equally well penetrate steel, concrete or hard materials generally.

The manufacture of such devices demands a high degree of mechanical accuracy, especially if they are intended for use underwater at considerable depths, where external pressure effects could well distort the outer case and hence alter the shape.

## SAFETY PRECAUTIONS

Unless suitable precautions are taken, electric detonators could be initiated accidently by:

1 Electrical energy entering the firing circuit from an outside source, ie:
Lightning
Static electricity
Stray currents
Electromagnetic radiation

2 Sympathetic shock from an outside source, ie:
Other explosive detonations

In the case of lightning or electric storms, it is strongly recommended that all work using explosives should cease, and that the materials are stowed away under cover. Should lightning strike a firing circuit, detonation is likely to take place regardless of what precautions are taken. It has even been known for a circuit to be initiated accidentally by lightning several miles away.

The best protection against static electricity is to ensure that the ends of all detonator lead-in wires are shorted by twisting them together, and that the shot firing cable is treated in the same manner.

Stray currents are only likely to be found in the immediate vicinity of portable power machines, motors, generators and the like. Where possible, all such machines should be stopped on board when handling any explosive charges, and to ensure that lead-in wires are not allowed to trail on the deck, touch such machinery, their mountings or accessories.

Although very rare, premature initiation of firing circuits has been known as a result of induced currents in closed circuits from high-power radar equipment and radio transmitters. Portable radio sets should not be allowed within 30ft (10m) of a site in which explosives are being handled.

### Accidents

In the event of an accident in which explosives were involved, all unused material should be collected and impounded awaiting examination.

A report and statement of events should be sent to the Health and Safety Executive (Inspector of Explosives), and if physical injury has resulted, the police should also be informed.

Failure to take these common sense actions could lead to a suspension of an explosives license or certificate, and possible withdrawl completely.

Misfires

In good explosives practicem misfires should not occur, especially if the equipment is kept in good order, and circuits are checked. Nevertheless, misfires do happen, sometimes for inexplicable reasons.

Since the chances of a defective detonator as regards its manufacture are almost impossible, misfires can almost always be accredited to incorrectly connected electrical circuits, badly made joints, unsuitable materials, wet fuse or defective exploders. It is a sensible practice to spend sufficient time before leaving base, to carry out the appropriate physical checks on all explosives material and accessories, since the necessary tools and cleaning gear will then still be readily available.

Do not approach a circuit in which safety fuse has been used until a minimum of 30 minutes has elapsed, or an electrical circuit for 5 minutes. The first action should then be to remove any detonators in the circuit, prior to any closer examination as to why the misfire took place. Suspect detonators or lengths of safety fuse should not be reused, but discarded in a safe manner, or destroyed by being wrapped around a charge which is to be detonated.

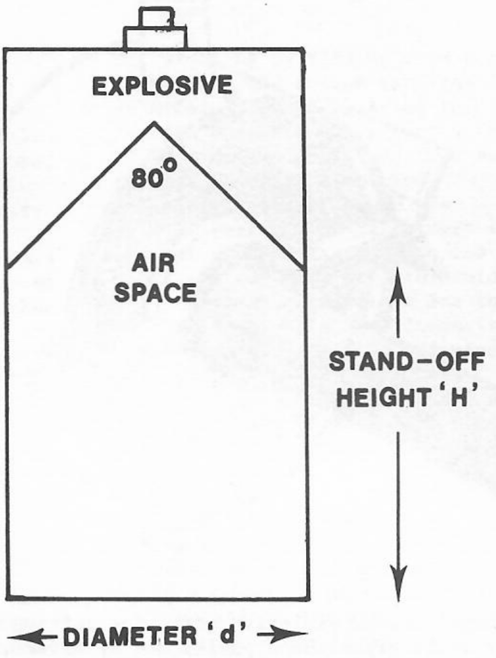



Fig 18-18 Outline of typical shaped charge showing ceitical dimensions

| Weight of explosive | Cone material thickness | | Diam d | Height H = 3/4d | Thickness of concrete cut | Thickness of mild-steel cut |
|---|---|---|---|---|---|---|
| 0.25lbs | 0.058" | 16swg | 2.125" | 1.625" | 9 - 12" | 2.75 - 3" |
| 0.50lbs | 0.073" | 15swg | 2.375" | 2,00" | 12 - 15" | 3.75 --4.25" |
| 1.00lbs | 0.092" | 13swg | 3.375" | 2.50" | 15 - 20" | 4.75 - 5.25" |
| 5.00lbs | 0.158" | 8swg | 5.625" | 4.25" | 24 - 32" | 7.50 - 8.25" |
| 10,00lbs | 0.198" | 6swg | 7.125" | 5.375" | 33 - 40" | 9.00 - 10.5" |
| 100.00lbs | 0.427" | | 15.50" | 11.50" | 75 - 85" | 20.00 - 21.5" |

Fig 18-19 Table of dimensions for shaped or hollow charges

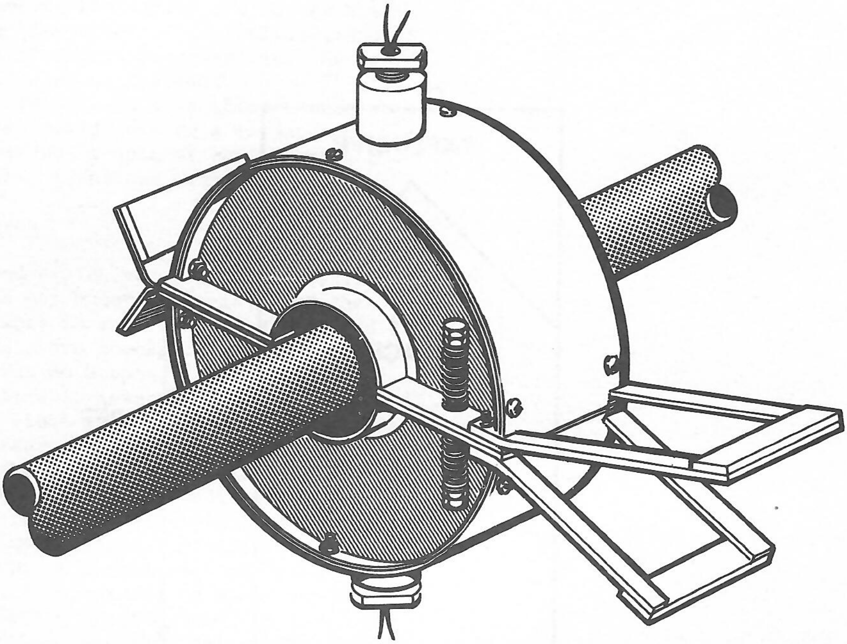


Fig 18-20 Shaped charge explosive unit, for cutting heavy cables underwater, or small pipes. Hand positioned by divers, with a maximum depth rating of 1000ft

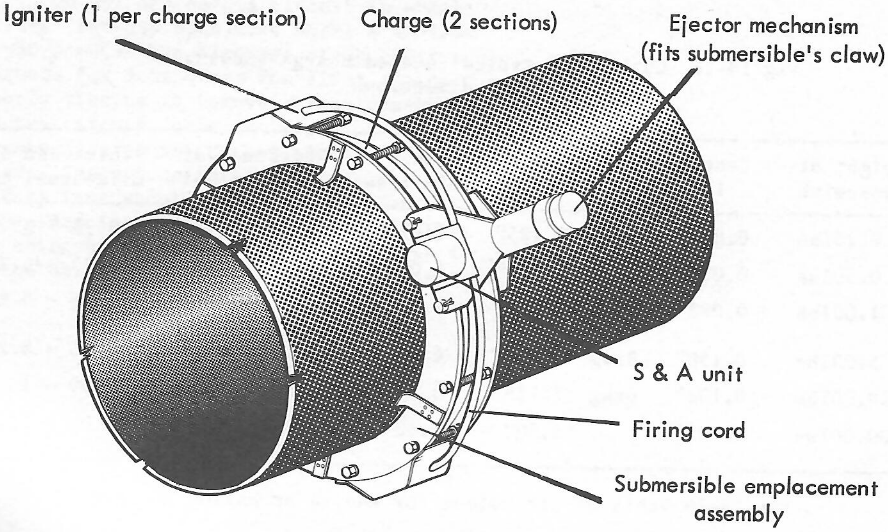



Fig 18-21 A "Euroshore" roughcut shaped charge for pipe cutting underwater, specifically designed for submersible vehicle placement