UNDERWATER WELD REPAIR OF OFFSHORE STRUCTURES

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ABSTRACT

Offshore platforms serve as artificial bases, supporting drilling and production facilities above the elevation of waves. They have to serve in harsh environments and hence are likely to be damaged. Therefore the damaged structure has to be repaired to enable it to continue to serve its intended function during its designed life. There are over 7000 offshore platforms worldwide. It has been estimated that, globally, more than 50 platforms per year require some form of upgrading, strengthening and/or repair. The strenghtening and repair of existing offshore installations is an important part of offshore engineering. Design codes provide little or no guidance in this area. The need to repair or strengthen offshore installations is likely to increase due to various causes.

Many offshore structures, damaged during their operation, have been repaired using welding technique. The currently available welding technique used in underwater jacket repairs can be broadly classified as Hyperbaric or Habitat welding, Cofferdam welding and Wet welding.

Different welding processes that are employed in dry Hyperbaric welding are : SMAW, GMAW, FCAW, etc. Special electrodes have been developed for carrying out wet welding processes. Automated wet underwater welding for construction of offshore structures, called Mega-float, has been developed. A mechanized wet welding by the water curtain nozzle was executed for the Mega-float during open field demonstration in July 1996 at Yokosuka harbour.

The paper has dealt with the current underwater welding processes which have been adopted for the repair of damaged offshore jacket platforms. Case histories of welded repair of existing platforms are also reviewed. Problems associated with the underwater welding processes and difficulties faced in their applications are also discussed.

INTRODUCTION

Steel towers are installed on the sea bed for production of oil from sea bottom. They support drilling and production facilities above the elevation of waves. They serve as artificial bases and hence are called offshore platforms. Among the various types of platforms, jacket or template platforms are the most popular structures for shallow water depth of up to 200m. Cylindrical tubular members are mainly used in the construction of these structures. The intersection between various tubular members are welded and form tubular joints. The main member is called a chord and the secondary member a brace or branch. At present there are over 7000 offshore platforms all over the world (Digre et at., 1994). In India there are about 148 platforms in Bombay High alone [11]. Since these structures have to serve in hostile environments, they are likely to be damaged.

In the North Sea alone, the incidence of major repairs undertaken has steadily increased from just two major repairs (out of a total 52 platforms) in 1973, to twenty-one major repairs (out of a total of 120 platforms) in 1981 (Bayliess et al., 1988). A majority of these were carried out above a depth of 20m below sea level. It has been estimated that, globally, more than 50 platforms per year require some form of upgrading, strengthening and/or repair. The strengthening and repair of existing offshore installations is an important part of offshore engineering. Design codes provide little or no guidance in this area. The need to repair or strengthen offshore installations is likely to increase as the number of installations increase, as the age of the structures increase, as shipping movements in the oil and gas fields increase and as the severity of the environment increases.

Many offshore structures, damaged during their operation, have been repaired using welding technique. About 90% of the offshore structures are fabricated by welding of steel tubular jackets. Design procedures for welded structures are well-established and new materials can be designed to meet the applied loads economically. Different types of welding that have been carried out so far for the repair of offshore structures are : habitat or hyperbaric welding, coffer-dam welding, and wet welding.

The paper has dealt with the current underwater welding processes which have been adopted for the repair of damaged offshore jacket platforms. Case histories of welded repair of existing platforms are also reviewed. Problems associated with the underwater welding processes and difficulties faced in their applications are also discussed.

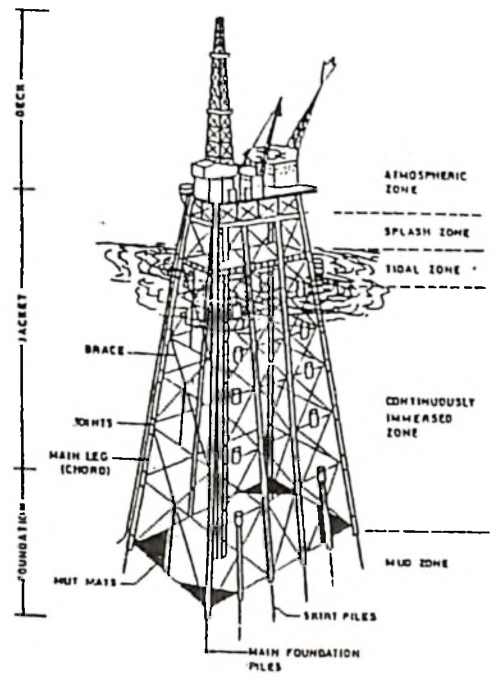


Fig. 1 : Typical Jacket Platform

UNDERWATER WELDING PROCESSES

Underwater welding and cutting has been done for years. The shortcomings of existing welding and cutting methods are due primarily to [1] :

1. The surrounding water environment.
2. Poor visibility
3. Equipment not specifically designed for underwater use
4. Severe limitations on diver performance
5. Effects of pressure on the behaviour of the process

Considerable research effort has been expended to improve process performance and control strategies for the various underwater welding processes over the last quarter century. But there are still many problems to overcome. The influence of the hyperbaric environment (i.e. pressure, humidity, high cooling rate, etc.) on the quality and efficiency of the welding operation is a great problem to be solved.

Habitat Welding

This form of welding being acceptable by the concerned authorities is currently the main type of welding employed in the North Sea. Habitat welding is the welding at hyperbaric pressure within an underwater dry environment. In hyperbaric welding the work site is enclosed within a waterproof chamber from which the water is expelled by admitting gas at the same pressure as the surrounding seawater. The gas mixture in use is oxy-helium, so that saturation techniques can be employed for the welder divers [2]. This pressure increases by approximately one bar for each ten metres of water depth. Welding is, therefore, carried out in a nominally dry atmosphere, at a pressure significantly higher than that on the surface, and this has a significant influence on the performance of the welding arc [3]. Higher environmental pressures increase arc voltage and reduce arc stability. An added advantage of dry welding in a chamber is that the welding operation can be performed more efficiently due to better working conditions and better visibility. With better visibility, the welder can make a much better weld than he could in the water environment.

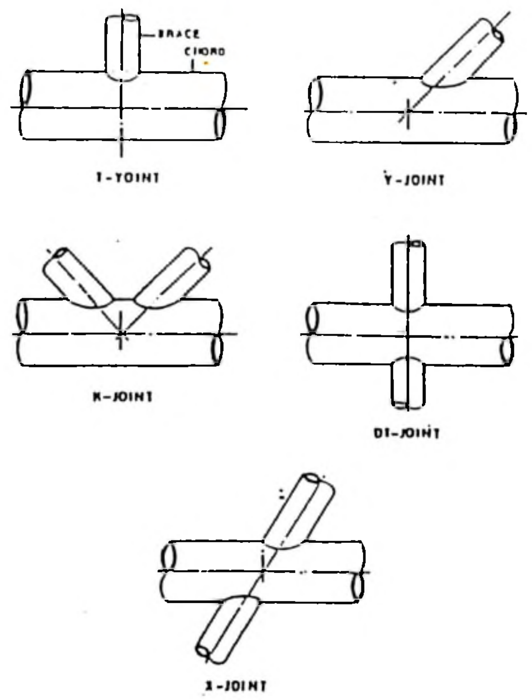


Fig. 2 : Typical Welded Tubular Joints

The two welding processes that have been used in dry welding are gas metal-arc (GMA) and gas tungsten-arc (GTA) welding. The shielded metal-arc process is unsuited for welding in a chamber since the electrodes produce large quantities of smoke and noxious fumes. In the closed chamber, these would accumulate quickly and become intolerable.

The welders are usually selected for this type of work and the normal method of working is to have divers do all the preparation such as cutting away unwanted material, placing the seals, the chamber and any associated tasks. The welders then enter the hyperbaric chamber for the final weld preparations and the welding itself.

The oxy-helium hyperbaric welding technique is usually used below depths of 30 m. At depths of less than 30 m, air can be used, and the welding can be undertaken using air saturation techniques. Thus, the welding techniques are the same whether the welding process takes place in shallow or deep depths; the main difference is simply the breathing mixture used. The main difficulty with shallow water welding is that it can be much more troublesome to install the chamber itself because of tidal and wind effects [2].

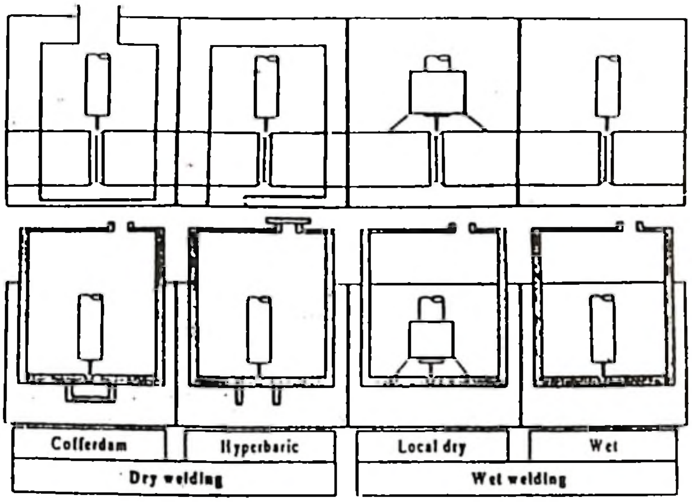
Coffer-dam Welding

Coffer-dam welding is welding at atmospheric pressure from within an underwater dry environment that is linked directly to the surface by a down-tube. The welding chamber could be positioned up to 30 m below mean sea level. Below 30 m, the installation of the down-tube and the maintenance of effective seals becomes difficult. The major advantage of this technique over habitat welding is that the welding and testing can be carried out at atmospheric pressure by personnel who do not need to be experienced divers. As coffer-dam pass through the water line, they need to be robust enough to withstand wave loading. The damaged structure must also be re-analyzed to check that it can withstand the higher wave forces it will be subjected to once the coffer-dam is fitted. The coffer-dam can be as difficult to position as a habitat, and sealing the coffer-dam can present problem. Unlike the habitat, where that gas pressure inside the chamber equals the hydrostatic pressure, there will always be a hydrostatic pressure on the walls of a coffer-dam.

Wet Welding

This technique which has been in use for many years has been demonstrated as being reasonably effective during that time. The basic technique is arc welding, where a DC generator provides power to an electrode and an earth clamp. The clamp is secured to the workpiece and the electrode consists of a mild steel rod coated with a flux covering which has a water proof covering over the top. As soon as the electrode comes in contact with the workpiece, the circuit is complete and the welding continues as normal. There are numerous problems associated with wet welding.

Wet welding is done with the conventional manual shielded metal-arc process, commonly known as stick electrode welding. This underwater-welding technique is basically unchanged after 20 years. Some improvements have been made in electrodes and equipment. For example, special electrode holders have been designed for underwater use to minimize the electrical shock hazard. Other improvements include waterproof coatings for the electrodes with improved arc stability.



(upper) underwater welding for pipe structures, (lower) for barge structures.

Fig. 3 : Classification of Underwater Welding

Most of the world's wet welding is carried out in the USA, where the generally smaller sizes of structures, different steel compositions, and warmer weather conditions all mitigate in its favour, although a limited amount of wet welding had been carried out in the North Sea, mainly on secondary structures [10]. A description is given of the design and installation of several wet welded repairs made to appurtenances on 2 North Sea jackets. Details are given of the mechanical properties obtained for welds made in both the tank and offshore [7].

Virtually all wet welding is carried out using the shielded metal arc welding technique, using specially designed electrode holders to protect the welder/diver from electric shock. The fast cooling rates associated with wet welding are harmful to the high strength, low alloy steels used for the construction of offshore structures, producing hard, brittle structures in the weld and heat affected zone [20]. While it is evident that wet welding operations do not involve deployment of a welding habitat, as required for hyperbaric welding, this must be offset aginst the lower depostion rate and the lower quality of the deposited weld metal. Wet welding is generally considered a shallow welding technique. At greater depths, similar diver capability problems to those associated with hyperbaric welding would be encountered.

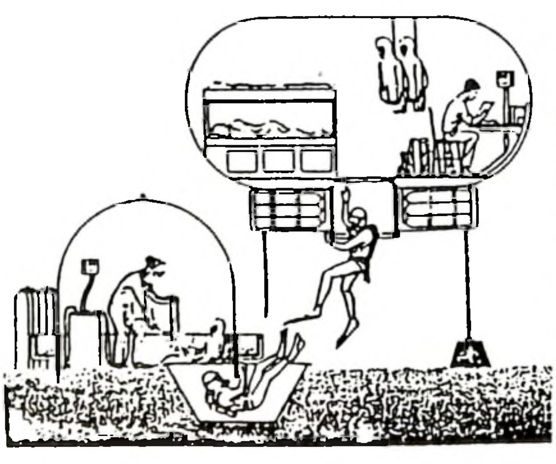
Mechanical properties for wet welding is usually poor compared to dry welding because of bad influence by surrounding water at the welding part. Water curtain which is jetted around the nozzle edge was considered to improve mechanical properties for wet welding. A special welding nozzle, which has a wide range of allowances for root gap width and mis-alignment of butt joints, was developed [14]. The technique is so simple to reduce much cost and working time. A mechanized wet welding by the water curtain nozzle was executed for the Mega-float during open field demonstration in July 1996 at Yokosuka harbour. The weld quality was good enough for certification. Fig. 5 shows schematic illustration of automatic wet welding machine with a mechanical touch sensor.

CASE STUDIES OF WELDED REPAIR

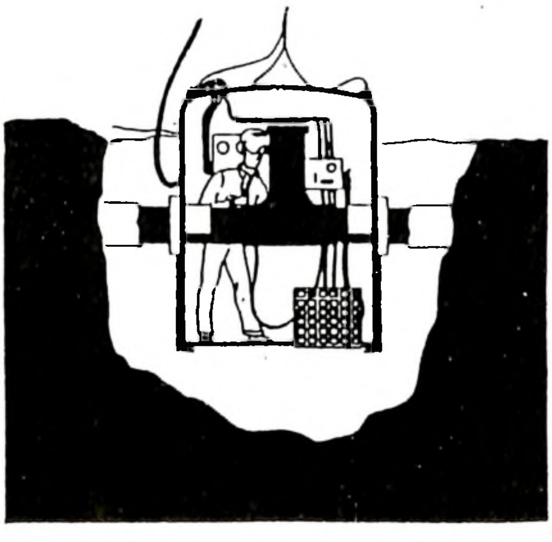
Welding repair of six platforms situated in the Gulf of Mexico damaged by corrosion has been reported [9]. There was no definite pattern to the location of the corrosion damage. A number structural welds were affected and substantial weld material loss had occurred. Holes, all of relatively small diameter, were scattered throughout the bracing system on the structure. The location and extent of corrosion did not seem particularly related to depth. However, most of the repair work was done at the shallower levels. Visibility was better at the shallower levels and the cost of operation was substantially less.

When a large number of pits were discovered, it was decided that these openings in the structural members should be sealed to prevent further influx of fresh sea water to the interior of the braces. After the braces had been cleaned and the structural damage located, small steel patches were prepared using coupons cut from pipe rolled with an inside diameter matching the outside diameter of the brace to be repaired. These coupons were tack welded in place and then welded permanently to provide a water tight seal. Over 3000 such patches were installed on one of the platforms. There were also a number of areas where the original structural welds had deteriorated substantially. In these cases lost weld material was replaced by underwater welding.

The repair of the damaged single-sided closure weld at a brace to stub joint in a diagonal brace member in the BP Magnus structures in the North Sea has been carried out by hyperbaric welding at a depth of 182 m [19]. The damaged section of a corner leg of a tubular steel jacket, caused by hitting of a crane derrick barge during installation, was replaced in its entire form within a coffer-dam. The welding was carried out both from inside and outside the leg [23].



a. Pipeline Welding



b. Tubular Joint Welding

Fig. 4 : Hyperbaric Dry Welding

Fatigue data for repair welded offshore structures are still lacking. As a contribution towards this subject, laboratory tests on the fatigue strength of hyperbaric dry repair welded butt welds have been carried out [15]. The tests were carried out in air. In order to obtain reference data (metal-insert-gas) MIG-process [8] with optimized welding parameters was applied for repair welding. Fatigue strength of initial and repair weld have been found to be equivalent.

An investigation of the fatigue performance of repaired joints in flat plates [24] found that fatigue lives are generally lower than those of the original joints, even when the repairs are made under ideal laboratory conditions. A series of fatigue tests on welded tubular T-joints in which fatigue cracks had been repaired by welding has been described [22]. The joints were loaded in out-of-plane bending. Fatigue lives of repaired joints were compared with those obtained during fatigue precracking in order to assess the efficacy of the repair. The fatigue strength of as-welded repairs was found to be marginally lower than the mean for unrepaired joints.

Experiments were conducted in the Netherlands on the joints of four different multiplanar truss frames constructed in circular hollow sections [16]. Trusses were subjected to fatigue loading until each joint has failed. Failed joints were repaired by two methods, namely, box reinforcement and gouging in combination with re-welding from which the remaining fatigue strength after repair had been determined. It has been concluded that the remaining life of joints repaired with box reinforcement was equal to 50% of design life where those repaired using gouging in combination with rewelding was equal to 40%.

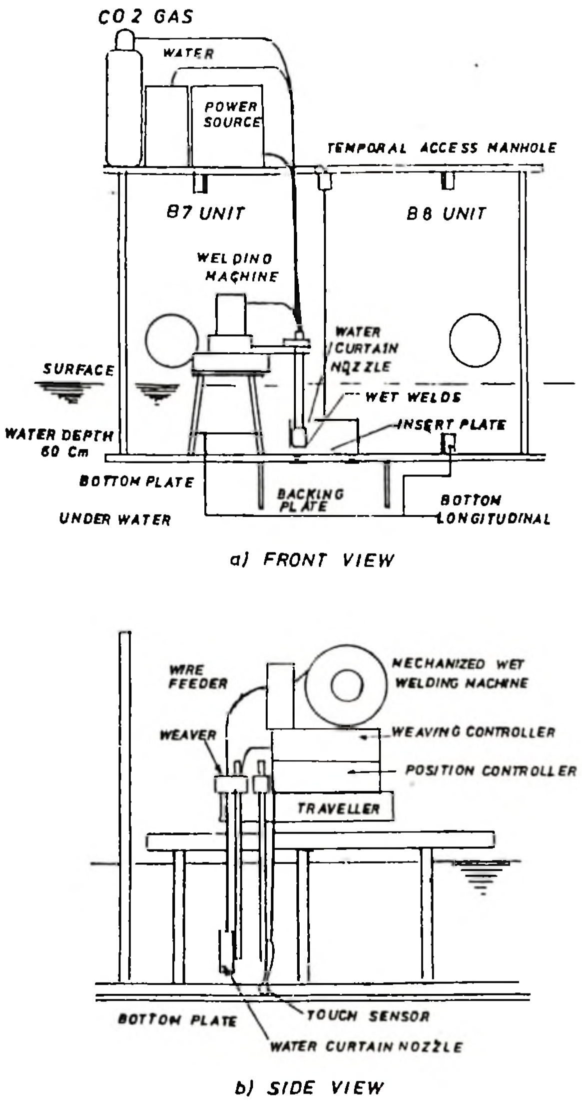


Fig. 5 : Schematic Diagram of Automatic Underwater Welding Machione

In the Indian context hyperbaric welding was resorted to in the past on six occasions for the repair of offshore jacket platforms in the Bombay High field. The type of work involved was replacement of damaged brace member and welding of crack at the joints due to fatigue loading. These works were carried out by foreign companies specialised in this type of welding because India does not have the requisite capability to carry out such underwater weld repair.

PROBLEMS ASSOCIATED WITH UNDERWATER WELDING

But welding in an underwater application is very expensive, time consuming and fraught with technical difficulties. An underwater project of any description invariably means the presence of divers. Repair by hyperbaric welding using saturation divers costs £2,000,000 [12]. The supporting workforce and supervision to the diving team can be budgeted at £40 per man hour with transport costs of perhaps £500 per round trip from shore to field as an additional item. Accommodation is either in floating hotel vessels costing in the region of £40,000 per day [5]. In the Indian context, it costs Rs. 2/- crores for a single operation of underwater welding.

Offshore repair welds have to be necessarily made under adverse conditions; normally in a hyperbaric chamber with welds being made from sides only, possibly with poor preparation and no opportunity for post weld heat treatment. In these circumstances, despite the care and attention devoted to such repairs, it is likely that the weld quality may be lower than that of the orignal joint. Presently all underwater welding activities are performed by diver/welder. It is generally recognized that the weakest link, in the transfer of satisfactory laboratory and land-based results to the subsea location, is the diver [21].

Prior to welding, the habitat has to be installed and sealed to the structure. The difficulty in succeeding in this task is to a large degree proportional to the number of members it has to seal round and difficulties increase when the habitat is installed near the surface where it is rocked and moved by wave and current motions. For a structural repair actual welding time is probably less than 10% of total diving time [5].

In the case of wet welding the water causes the weld to cool too quickly and also prevents preheat treatment. During welding, higher current has to be used to compensate for the quenching effect. This can cause undercutting. The high energy arc can break down the water molecules and allow hydrogen to percolate into the weld pool. In multipass welds, there may be lack of fusion between passes because of the problems of trying to maintain interpass temperatures.

CONCLUSION

Many existing offshore structures have been repaired using underwater welding technique. Different types of welding that are currently available are : habitat welding, coffer-dam welding and wet welding. In the Indian context underwater welded repair has been carried out with the help of the foreign agencies to rehabilitate damaged offshore platforms in the Bombay High field. Problems are numerous in employing underwater weld repair. It is all the more essential to carry out further research to improve the underwater welding process in terms of quality of weld. Development and execution of a mechanized wet welding by the water curtain nozzle for the construction of Mega-float has been reviewed.

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