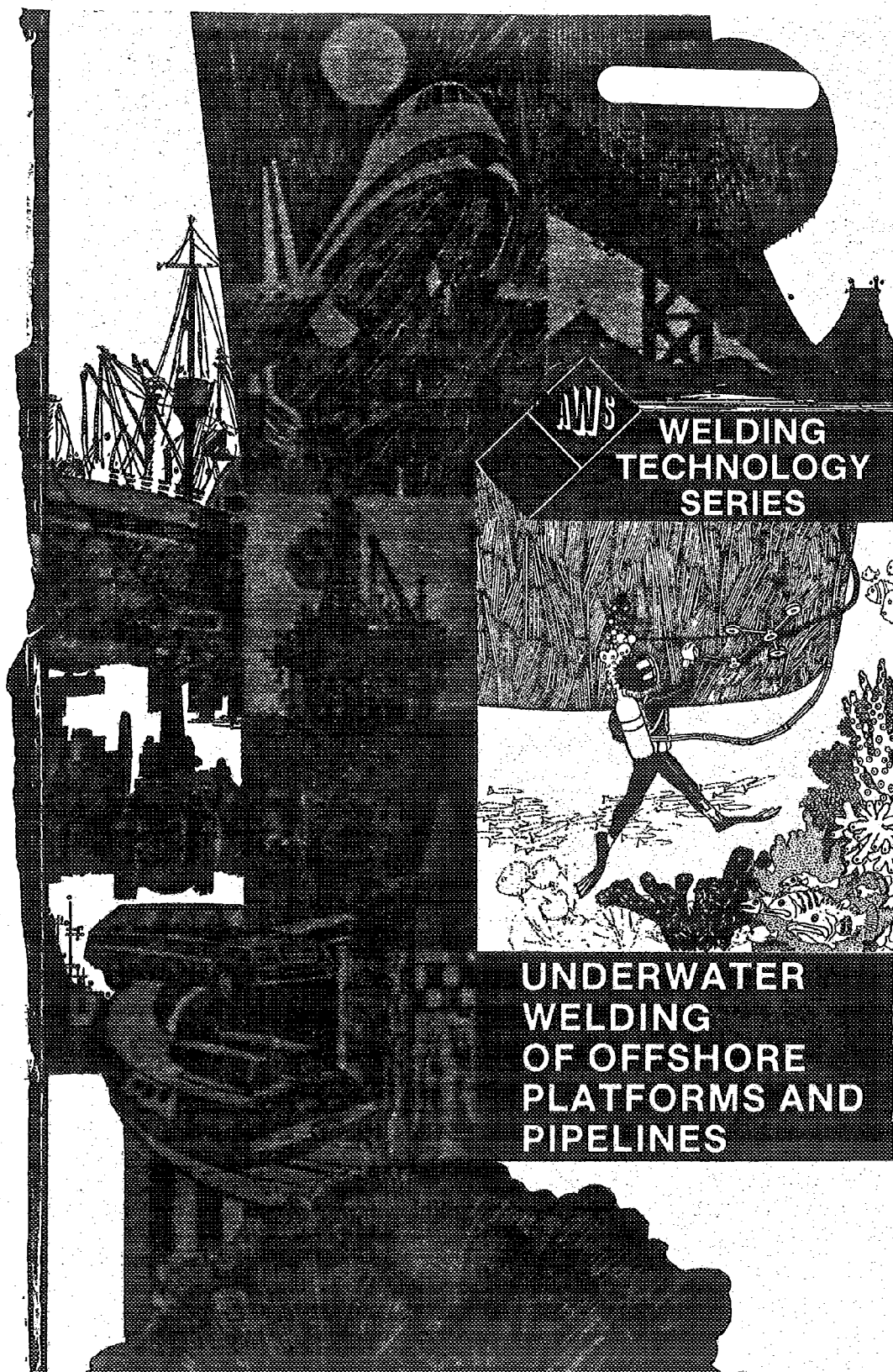




Underwater Welding of Offshore Platforms and Pipelines

*Proceedings of a Conference
November 5-6, 1980
New Orleans, Louisiana*

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**Underwater Welding of Offshore Platforms and Pipelines
Conference Program Advisory Board**

Buddy Delaune, Jr.
Senior Engineer
Taylor Diving & Salvage Company
Belle Chasse, LA

Conrad J. Schoppe
Research Division Supervisor
Tennessee Gas Pipeline Company
Houston, TX

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American Welding Society
Miami, FL

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President
Sylvester Underseas Inspection
Rockland, MA

James D. Theisen
Manager, Welding, Quality Control
and Training
Brown & Root, WHMC
Houston, TX

Dwight L. Turner
Welding Engineer
J. Ray McDermott & Company, Inc.
New Orleans, LA

James L. Watts
Surveyor, Hull Technical Staff
American Bureau of Shipping
New Orleans, LA

Debrah Weir
Director, Education
American Welding Society
Miami, FL

Preface

This highly successful conference was designed to offer insight into emerging technology of great importance in future pipeline and offshore platform design and construction, including practical information on diving and equipment options, welding processes adaptable to the underwater environment, maintenance and repair operations, safety, and the latest AWS recommended practices for underwater welding.

AWS feels that the more than 250 welding engineers, designers, offshore maintenance personnel, QA and QC managers, inspectors, and NDT technicians who attended "Underwater Welding of Offshore Platforms and Pipelines," November 5-6, 1980 did so because of the planning of the Conference Program Advisory Board: P.T. Delaune, Senior Engineer, Taylor Diving and Salvage Co., Belle Chasse, LA; C.E. Grubbs, President, D & W Underwater Welding Services, Inc., Slaughter, LA; Conrad J. Schoppe, Research Div. Supervisor, Tennessee Gas Pipeline Co., Houston; Bruce J. Sylvester, President, Sylvester Underseas Inspection, Rockland, MA; James D. Theisen, Manager, Welding Quality Control and Training, Brown and Root, WHMC, Houston; Dwight L. Turner, Welding Engineer, J. Ray McDermott & Co., Inc., New Orleans, and James L. Watts, Surveyor, Hull Technical Staff, American Bureau of Shipping, New Orleans.

The two days of the conference focused on hard-hitting facts on the construction, maintenance, and repair of offshore platforms and pipelines and highlighted these objectives:

- what available equipment can upgrade underwater welding productive performance
- advantages (and disadvantages) of the submerged one atmosphere welding system
- how to logically schedule inspection, maintenance, and repair work on underwater structures
- newest underwater ultrasonic thickness gauging system
- proven procedures and methods to follow for a successful major underwater project
- superiority of GMAW—underwater
- critical factors affecting metallurgical and mechanical properties of underwater welds
- where OCS regulations are heading

- how simulation produced welding procedures that increased safety margins underwater
- how to adapt fitness-for-purpose as THE underwater welding criterion
- present limitations in saturation diving
- how to obtain quality welds through proper training
- when explosive welding is the proper alternative to conventional joining
- which equipment is the safest and most efficient
- how to minimize both inspection time and diving costs in repair or maintenance operations
- the newest in stereophotographic systems

An important objective was how AWS proposed Underwater Welding Specification would impact attendee operations. In fact, a goal of an AWS conference is to provide a forum for AWS Technical Committees to introduce latest standards, specifications, and codes. This opportunity has been used in many conferences in the past and was successfully handled at "Underwater Welding of Offshore Platforms and Pipelines" by AWS D3b Committee member E.A. Silva.

The international flavor of "Underwater Welding of Offshore Platforms and Pipelines" was represented by the line-up of speakers from not only the U.S. but from England and France. Attendees were attracted from the U.S., Canada, England, France, Mexico, Japan, and the Scandinavian countries. In fact, of the 7,000 conference or seminar attendees expected by AWS to participate in one or more of our programs, roughly 20 percent are targeted as overseas delegates.

AWS is indebted to the volunteers who contributed so much of their time and effort to create the successful "Underwater Welding of Offshore Platforms and Pipelines" — the speakers: H.C. Cotton, Welding Engineering Consultant, London, England; Michael C. Bateman-Cooke, Project Manager, Taylor Diving and Salvage Co., Belle Chasse, LA; Walter T. Bugno, Project Engineer, Standard Oil Co. of California, San Francisco; David Groves, Materials Engineering Manager, Brown and Root (U.K.) Ltd., London, England; Herman B. Smith, Head, Test and Development Branch, Welding Engineering Div., Norfolk Naval Shipyard, Chesapeake, VA; Edward M. Briggs, Director, Div. of Ocean Engineering and Robert E. Adler, Manager, Ocean Systems Section, Southwest Research Institute, San Antonio, TX; Gilbert Coriatt, Manager of Hyperbaric Welding, Comex Services, Marseille, France; Dr. David J. Leidel, Senior Research Engineer, Jet Research Center, Inc., Arlington, TX; Koichi Masubuchi, Professor, Massachusetts Institute of Technology; David B. Wyman, Senior Project Engineer, Diver Tools Div.,

Naval Coastal Systems Center, Panama City, FL; Thomas J. Dawson, Metallurgical Engineering Consultant, Naval Facilities Engineering Command, Alexandria, VA; E.A. Silva, Ocean Technology Program Director, Office of Naval Research, Dept. of the Navy; Richard J. Gangerelli, Structural Engineer, U.S. Geological Survey, Reston, VA; Bernard G. Sudreau, Project Manager, Pipeline Dept., Compagnie Francaise Des Petroles and J. Paul Gaudin, Ingenieur Manager, Hyperbaric Laboratory, Institut De Soudure, Paris, France; John W. Robinson, trial attorney, Gretna, LA; and Bruce J. Sylvester, Sylvester Underseas Inspection.

The AWS New Orleans Section was especially helpful in recruiting attendees to join AWS as Associate Members and we particularly thank Mr. Shelton L. Ritter of Braun Welding Supply for his untiring efforts.

Debrah Weir

The Challenge of Deep Sea Diving

*Michael C. Bateman-Cooke
Taylor Diving and Salvage Company, Inc.*

Introduction

Down through the centuries, technology has decreased step by step the limitations of diving, but probably more in the past decade than ever before. The original limitations were very basic things, such as how long could one hold one's breath, how deep could one breathe with a snorkel, and how long could one survive on the air contained in a diving bell. The first real breakthrough occurred around the turn of the 19th century with the invention of the air pump and the closed deep sea diving rig by August Siebe in 1837. Today, however, there are many methods of diving employed in offshore oil fields, depending upon the nature of work, the depth of water, and the required bottom time. This paper will deal basically with the rather recent and rapid progression of deep diving over the past decade and a half and its relationship to the advancement of hyperbaric welding.

General

Anyone who has participated in the performance of a deep water hyperbaric weld will certainly agree that the successful welded connection, repair, and attachment of two (2) pieces of steel in a dry environment is still one of the most ambitious and challenging projects with which the diving industry is confronted today.

It is not the intention of this paper to elaborate on the history of diving and its progression from shallow air diving through surface mixed gas and eventually to that mode known as saturation. However, the majority of hyperbaric welding being performed is by saturated diver/welders, and, for the benefit of those who are not familiar with the expression "saturation diving," a brief explanation is in order.

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In conventional diving (that is, surface-to-surface without the use of a bell), the diver is decompressed during the ascent. This is accomplished by following a precalculated schedule that consists of a prescribed rate of ascent plus a number of stages or stops. This provides for the elimination of gases that have been forced into solution in the various body tissues by escaping without forming bubbles in the blood stream and thus causing decompression sickness or bends. The time of the dive is limited by what is considered a reasonable amount of decompression. In deep water, the dive must be relatively brief in order to avoid an unbearable decompression schedule. Employing the saturation diving technique, the divers are sealed in a deckboard chamber and pressurized close to the depth pressure at which they intend to work. A diving bell at the same pressure may be attached to or detached from the deck chamber so the divers can be lowered away under pressure to the job site and, upon completion of their mission, be returned to the deckboard chamber still under pressure. After 12 hours at a given pressure the body is said to be saturated; that is, it has absorbed or taken into solution the maximum amount of gas it is capable of containing at that pressure level. The main object of saturation diving is to eliminate decompression after each and every dive; thus, the length of time the diver may spend working at depth is limited only by his physical endurance. Finally, when the project is completed after a matter of days or weeks, the divers are then decompressed in the deckboard chamber by very slowly lowering the pressure while observing certain stops at predetermined levels as part of the schedule. This method necessarily requires that an artificial atmosphere be maintained in the bell and chamber and that a somewhat complicated environmental control system be employed. Temperature and humidity levels must be maintained. Carbon dioxide and other harmful gases must be removed, while oxygen has to be maintained at a constant level.

While all helium and oxygen (HeO_2) total saturation equipment is built around the same basic theory, it varies in physical configuration from one company to another. Even the nomenclature varies. For instance, the diving bell itself, which we call a submersible diving chamber (abbreviated SDC), is referred to by many other companies as a personnel transfer capsule (abbreviated PTC). One of the main differences is in the variety of ways the SDC is attached to the deckboard decompression chamber (DDC). There are various davit-like arrangements for handling the SDC on the surface and mating it to the DDC. Some SDCs referred to as the side-entry type have a transfer door in the side that flanges to a transfer tunnel in the end of the DDC, while others mate to a transfer hatch on top of a DDC and the personnel transfer is made through the hatch in the bottom of the SDC. Most of our saturation equipment is designed in this manner. A structural steel base frame, which extends over the side of the support platform, is fitted with an A-frame on the outboard end. The SDC is lowered and raised from the A-frame. When on the surface in position for transfer, the SDC is held firmly in the guides of the A-frame and locked in a fixed position. The DDC is mounted on skid runners that match channels of the base frame. By means of a hydraulic cylinder, the DDC is slid outboard until the flange of the transfer tunnel matches with the side-entry flange of the SDC.

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While many of the SDCs are cylindrical in shape with either hemispherical or elliptical heads, others are spherical and built as dual pressure vessels.

Total saturation HeO₂ diving is the ultimate technique in the industry. However, it is seldom used at depths shallower than 150 feet, except in the case of hyperbaric welding. The reason for this is that most people consider saturation diving not economically feasible in shallow water or in deep water where only an occasional dive has to be made. A surface-to-surface compressed air diving system has a value of from approximately \$20,000.00 to \$35,000.00; surface-to-surface HeO₂ diving systems range from approximately \$50,000.00 to \$100,000.00; while a complete saturation diving system with all the ancillary equipment would run in the neighborhood of \$1,000,000.00. As the depth of water increases, a saturation system becomes more and more economically feasible.

Following is a typical example of the economics of saturation diving at a depth of 300 feet. The 300 ft depth is being used as an example for several reasons, among which are: (1) the majority of hyperbaric welds undertaken by Taylor Diving have been completed in the 200 to 400 ft range with less than 10 percent of all welds completed at depths greater than 400 ft; and (2) Federal regulations dictate that the cutoff depth for surface supplied diving is 300 feet.

The daily cost for surface-to-surface diving using 8 divers rather than 6 saturation divers includes surface-to-surface equipment at 27 percent of the cost of saturation equipment; labor, 75 percent; depth bonus to the divers, 171 percent; total daily cost being 87 percent of the saturation cost. But here is the difference in *actual* cost per hour of productive work: Six saturated divers can produce 22 hours bottom time per day; eight surface-to-surface divers, 8 hours bottom time per day. The cost per hour of surface-to-surface bottom time is, therefore, 240 percent higher than that for saturation diving. A surface-to-surface diver is between 65 and 70 percent as effective as the saturated diver. One of the reasons for this lack of efficiency in deep water is the encumbrance of the long umbilical and the effects of current against it. When divers are changed every hour or less, much time is lost while the succeeding diver becomes oriented. Sometimes 15 minutes or longer is required to get oriented to where the other diver left off. Taking this into consideration, the surface-to-surface diver is now costing 350 percent more per hour of productive bottom time.

As a final example, if 100 productive hours of work were to be performed in a depth of 300 feet, it would require over 15 days of surface diving, whereas the saturation divers could perform the same task in approximately 5 days. Considering that the diving support platform is usually a construction barge costing over \$1,000.00 per hour, to say nothing of support vessels (such as tug boats, crew boats, and supply vessels), and the cost of support from shore, there are tremendous savings to be realized by using the saturated technique. In the deeper depths now being encountered, saturation is the only feasible method.



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Along with the virtues of SAT diving, one disadvantage may be found in the cost of mobilizing the equipment, which is greater than for the simpler methods. For instance, it is *double* the cost of mobilizing a surface-to-surface system. Among the topside support personnel, more technically oriented people are required. After a crew has been in saturation for 30 days, they are generally decompressed and a new crew saturated, if the work is to continue. Whether or not the work continues, it requires approximately 24 hours of decompression for each 100 feet of depth pressure. During this time, the equipment remains on rent and the personnel can be reduced. Most of the Taylor systems are built in such a way that one crew can be undergoing decompression while another crew is in saturation continuing on with the work, thereby eliminating job shutdown due to decompression. In many instances, this type of shutdown is a major complaint on the part of the contractor when mixed gas surface diving is being advocated.

Hyperbaric Welding

Before getting into a comparison of deep diving and hyperbaric welding, a brief review is required to acquaint anyone not familiar with how the diving industry and, in particular, Taylor Diving and Salvage Company, Inc. proceeded to get involved in the art of subsea welded connections.

In the early 1960's, the founder and president of Taylor Diving saw the future need for industry to have the capability of making code-quality welded pipeline connections or structural repairs beneath the sea's surface. A research and development project was initiated to develop the equipment and procedures required to reach this goal. It soon became apparent that future requirements for the application of hyperbaric welded connections or repairs would most likely be dictated by (1) the type of weld required, (2) the reliability of mechanical connections, (3) environmental conditions, and (4) increased water depth. The types of welds required can be varied and considerable, ranging anywhere from a rather straight forward riser tie-in to that of a complicated structural repair.

The argument over the reliability of mechanical connectors (and Taylor's philosophy) is one of assurance rather than one of justification. In other words, it is possible to justify various other forms of connectors as a substitute for the hyperbaric weld, with emphasis being plainly put on the word *substitute*. Complete assurance, however, can only be provided by a welded joint that has been proven 100 percent reliable. Although there are several applications for hyperbaric welding (pipeline repairs, riser tie-ins, expansion loops, structural repairs) involving various items of specialized equipment and complexity, this paper will dwell on the pipeline connection simply because more pipeline welds have been completed and at deeper depths than any other type of welded repair. The pipe is welded in place on the seabed with the pipe ends inside a dry environment so that the joint properties will be comparable to those obtained from a conventional surface weld. This

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involves the use of an open-bottom enclosure or underwater welding habitat, which is placed over the pipes to be joined. This method of joining pipe together is called "habitat welding," which has come to mean "fusion welding at hyperbaric pressure by diver/welders wholly within an underwater dry environment."

The first habitat welds made by Taylor Diving and Salvage were pipeline repairs in the St. Lawrence River and in the Gulf of Mexico in 1968, made at a water depth of 60 feet.

From this first year's operation, the present hyperbaric welding process was developed and has been used since to weld all the major grades of pipeline steel and many proprietary grades. This process basically consists of:

- (1) The procedure qualification
- (2) The diver/welder qualification
- (3) The offshore phase

The weld procedure qualification has to be carried out at the same depth or slightly deeper than the depth of the pipeline repair. This is necessary to ensure that the effects on the weld of the ambient gases and gas partial pressures are fully reflected in the finished product. The environmental conditions required to sustain life at a depth of 500 ft would be 3.0 percent oxygen, the remainder being helium, for example. This represents an oxygen partial pressure of 0.5, which compares with 0.2 at the surface in the atmosphere. This increase of partial pressure results in an increase of oxygen absorption in the weld. At 500 ft, this increase is approximately 100 percent by weight in oxygen content in the weld when compared to the equivalent surface weld.

The helium, while it is an inert gas, has a thermal conductivity six times greater than air. Therefore, to prevent very rapid cooling of the weld and the heat-affected zone, which could lead to thermal stress problems such as cracking and excessive hardness areas, the pipe temperature is maintained throughout the welding process by the use of heating blankets. The entire weld procedure qualification and weld testing are observed and approved by the customer and a representative from a certifying authority, such as Lloyd's Register or Det Norske Veritas.

The properties obtained from a hyperbaric weld will meet or exceed the specification requirement expected from an equivalent surface atmospheric weld.

Before a diver/welder is permitted to weld a pipe repair, he has to qualify to that particular pipe weld procedure at the appropriate depth. This qualification is carried out either in the depth chamber or in the habitat at the job site. The qualification and the destructive testing that follows is witnessed and approved by the customer and the certifying authority. This qualification is approved for a set period and is renewed by further experience or a retest.



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The diver/welders are also given instruction in the use of radiographic equipment, which eventually leads to the Assistant Radiographic Technician Level 2 qualification.

Training is also available in the use of ultrasonic equipment. Such training is set up to a particular project requirement at the time it is needed.

Offshore Phase

After the procedures are qualified, the submarine pipe alignment rig, the habitat, and other equipment are mobilized for the job, based upon the joining requirement. An adequate work platform facilitates habitat welding. It must have hotel facilities for the personnel involved and a positioning system that will enable it to maintain location in poor weather. It must have a crane or davits, or both, to handle the submarine pipe aligning rig and underwater welding habitat.

When the work platform has been located over the job site, divers go down, survey the pipe, and rough-cut it with an oxyarc torch. The cut is made by first removing the concrete weight coating from the top of the pipe, cutting a hole in the pipe, and then cutting the remainder from the inside. The cut sections of pipe are then removed and recovered. Depending on the circumstances, this may involve many hundreds of feet of pipe.

The concrete weight coating, which frequently contains reinforcing rods, is kerfed circumferentially and longitudinally with a diamond-tipped saw blade over the area where the habitat will rest. The saw is driven by an underwater hydraulic pump, which is electrically powered via umbilical from the surface. After the cuts are made, sections of the weight coating are pried off and removed by the diver. Approximately eight feet of each pipe end is bared. Davits are used to place the pipe ends in line with each other. Next, guide ropes are attached to the pipes a measured distance from the ends to ensure the habitat will land over the joint(s) to be made.

After all systems have been checked out, the submarine pipe alignment rig and underwater welding habitat are lowered to the bottom with the vessel's davits. The guide ropes, having been attached to the pipe ends a distance wider than the guide eyes on the SPAR, restrict movement of the latter, yet allow small longitudinal position corrections to be made immediately before the submarine pipe aligning rig and the underwater welding habitat are placed on the bottom.

The pipe ends are grasped and raised off the bottom with clamps of the submarine pipe aligning rig by divers operating local controls. The pipes are then coarsely aligned horizontally, each end opposite the other. The clamps are moved by hydraulic cylinders in either the vertical or horizontal direction and are powered by underwater hydraulic pumps.



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The habitat is now lowered down over the pipe ends and seals are established. Plugs are inserted in the pipes and inflated. The bubble of gas in the top of the habitat is increased to below the habitat floor, displacing the sea water that was within. The environmental control system is energized and all systems are checked. Video cameras are activated to monitor the activities in the habitat.

The pipe ends are accurately aligned with the submarine pipe aligning rig clamps through the use of remote controls located within the habitat. The pipe ends are cleaned of the mastic corrosion barrier thereon, then beveled for welding with a hydraulically powered orbital milling machine. Within the habitat, a short piece of pipe called a "pup" has been stowed. This pup has been very carefully selected for circularity, examined ultrasonically, and prebeveled for welding. The dimensions between the cuts of the milling machine on the pipes are made to match the length of the pup, plus allowance for weld shrinkage. The pup is then placed between the pipe ends and held there by line-up clamps, which are used to reform the pipe ends to concentrically match those of the pup. After alignment is obtained, preheating equipment may be installed, depending upon the weld procedure. If used, the root and initial filler passes are deposited while maintaining the preheat and are made without removing the line-up clamps. The remaining fill passes and cap passes are usually applied without the line-up clamps in place. Postheating, when required, is regulated automatically without the presence of divers in the habitat.

The habitat environmental control system is used to maintain safe and comfortable conditions for the diver. The breathable gas environment facilitates fit-up of the pup since the divers need not wear masks. From the onset of welding through to completion, the wearing of masks is required.

After the welding is completed, each joint is radiographed. Three or four overlapping exposures are made circumferentially around the joint using a small, remotely-operated exposure device. The exposures are made after the diver/assistant radiographers temporarily leave the habitat and are completed before they return. The exposed film is transported to the surface for developing and interpretation.

After gamma radiography, the pipe is wrapped many times with plastic tape or cloth that has been soaked in catalyzed epoxy. The weight coating is seldom replaced, but if protection is desired, the catalyzed epoxy can be applied in water. The habitat equipment is stowed away and the end seals cut, flooding the habitat to about half its height. The pipeline is then lowered to the sea bottom and all of the clamps are released. The submarine pipe alignment rig and underwater welding habitat are raised to the surface, placed upon the work platform, and readied for the next job.



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The greatest economic value of habitat welding occurs with new pipeline construction, because the integrity of a welded joint eliminates potentially high maintenance costs associated with mechanical joints. For the same reasons, habitat welding is advantageous for pipeline repairs and likely the only "universal" joining method able to be used on a large variety of pipe sizes and repair situations. For such repair contingencies, a prequalified weld procedure would significantly reduce the time a flowing pipeline would be out of service or a structural platform would be restricted. As for welder qualification, jurisdictional authorities have permitted qualification of experienced diver/welders on site to facilitate such matters.

To date, Taylor Diving and Salvage has completed approximately 200 hyperbaric welded tie-ins. In service, not one weld has ever leaked or required any subsequent maintenance. Approximately 20 percent of the welded tie-ins have been pipeline repairs. Anchor damage has accounted for 40 percent of repairs; replacement of leaking couplings and mechanical connectors by welded tie-ins for 35 percent; defective material, 15 percent; and pipeline buckles and unknown causes, 10 percent.

The maximum size of pipeline presently being welded is 48 in. in diameter. Fifty-four inch diameter pipe is within the present equipment capability, subject to minor modification. This modification is the increasing in size of certain components that have been purposely kept small to reduce helium gas consumption. The maximum depth proved in open sea tests is 1036 feet. The ultimate depth that hyperbaric welding can be used is limited by the diver's physiological limits. Although a diver's work output at extreme depths is somewhat reduced, this is not considered to be a limiting factor.

Welding at these extreme depths, therefore, will probably be done under atmospheric conditions by working inside a pressure vessel attached to the pipeline.

Most of the atmospheric welding systems so far designed and developed require the permanent installation of a pressure vessel on the pipe. While this is satisfactory for new construction where the location of the weld is previously known, this system is not suitable for the random location of welds such as required for pipeline repairs. The atmospheric welding system being fabricated and developed by Taylor Diving and Salvage has been designed for new construction, and specifically, pipeline repairs. This is achieved by using a split pressure vessel that closes over the weld area. The vessel is evacuated to atmospheric pressure for the welding process, and then after the weld completion and nondestructive testing, the pressure vessel is flooded to depth pressure, opened, and lifted clear of the pipe.

The system is being designed initially for 1,000 feet with the use of divers for carrying out preparation work such as concrete cutting and equipment setting, and will ultimately be capable of diverless operations to 2,000 feet with the use of a special submersible and remote control equipment.



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Conclusion

The challenge to perform coded welds at depths greater than those presently established is one being confronted every day. Continuing research is being undertaken to overcome the various obstacles. The comment could easily be made that man has successfully spent considerable time and performed limited tasks at pressures exceeding that of the deepest laid pipeline. As encouraging as this may sound, it does not present a true perspective of the actual situation. In order to do that, it is necessary to provide certain factual information, which has been acquired through past experience. For example, there have been very few actual offshore working dives at depths greater than 1000 feet. I can cite two with which I am familiar: (1) the setting of Shell Cognac Platform and (2) the hyperbaric weld already referred to. Although both dives were undertaken in relatively the same time frame and by the same company, each required a considerable amount of pre-dive preparation. In the case of the hyperbaric weld, it was four years from concept to actual completion. Therefore, from this example, it becomes quite obvious that deep diving is not done on the spur of the moment or on a call-out basis. Then again one might ask the definition of deep diving, and how deep is deep. A hundred years ago, sixty feet was deep. Fifty years ago, one hundred fifty feet was deep. Twenty-five years ago, three hundred feet was deep. As recent as five years ago, who, but a very few, would expect a diver making his first saturation dive offshore to be working at a depth of one thousand feet? Also, who would have thought it routine for divers to spend anywhere from 100 to 200 days a year confined under pressure? Today, this is not the unusual, but the norm. What about tomorrow? Will deep be 3000, 4000, 5000 feet? For today, 2000 feet is deep, and this is where the immediate challenge lies. This challenge is not only being met by such companies as Taylor, but also conquered.



Keeping it Going Economically: Preventive Maintenance

*David Groves
Brown and Root (U.K.) Ltd.*

Preface

In the early days of underwater inspection, the diving contractor was given little guidance from the platform operator regarding the objectives of the inspection task. The result was that underwater inspections, costly in both time and money, did little to assure the platform operator or governmental bodies of structural integrity.

The many conferences, seminars, and technical papers devoted to underwater inspection since 1976 have fostered the realization that the continued safety and operation of an offshore structure can be assured economically by logically planning underwater inspection and maintenance tasks, and by ensuring that details of the tasks performed are well documented and filed in an easily retrievable manner. Failure to plan ahead for inspection and maintenance could result in:

- (1) Structural design details that create additional inspection and maintenance tasks or hinder their execution
- (2) A critical structural member not being regularly inspected, which could result in major structural damage
- (3) Inspections being inefficient and costly as two or more inspections may be carried out in the same area at different times
- (4) Unplanned inspections, which disrupt platform schedules
- (5) Hasty inspections, whereby inspection data is inadequately recorded and often insufficient relevant information is gathered
- (6) Unreliable underwater equipment being utilized, thereby invalidating surveys and inspections made

Brown and Root's approach to underwater inspection and maintenance has undergone a logical development since 1976 and now reflects well-proven quality assurance techniques.

The aim of this paper is to outline Brown and Root's approach to underwater inspection and maintenance, which has as its ultimate goal the minimization of costs.

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Introduction

Offshore structures will progressively deteriorate during their design life if no preventative measures are taken. In order to keep the oil or gas field profitable by unimpeded production and to minimize risk to operating personnel and environment, the oil operator is required to maintain the structure both above and below the water line.

With the greater emphasis on planned underwater inspection and maintenance during the past few years, it is now relatively rare for an oil platform operator to embark upon underwater inspection without clear objectives in mind. However, the planning of inspection programs is still often left to a very late stage, i.e., after installation of the structure, at which time the underwater engineer is rarely able to modify the design of the structure to either reduce inspection and maintenance requirements or facilitate the execution of the inspection and maintenance (I and M) program.

Brown and Root utilizes a three-stage approach to underwater I and M that substantially reduces I and M costs.

Stage 1: Eliminate or Facilitate Inspection and Maintenance Tasks by Improvements in Design

During the conceptual design of the offshore structure a list is prepared of all underwater items and areas that require inspection or maintenance, or both. Each area or item is examined for ease of access, frequency of inspection and maintenance, and type of underwater equipment required for accomplishing the I and M task.

The objective at this stage is to consider design changes or incorporation of special design features that will eliminate, reduce, or facilitate the execution of I and M tasks. No I and M problem is left unresolved.

Stage 2: Establish Inspection and Maintenance Philosophy and Strategy

An I and M philosophy and strategy is agreed upon between the platform operator, certifying authority, and inspection contractor. This includes the firming of manpower organization, establishing communication routes, defining acceptance criteria for defects and satisfactory completion of maintenance tasks, and establishing key milestone dates in the I and M program.

The main objective at this stage is to satisfy governmental I and M requirements for the renewal of the Certificate of Fitness.

(It is considered that the governmental requirements are general to all offshore structures and do not take into account local environmental factors or design peculiarities; therefore, the Certificate of Fitness requirements are viewed as the minimum requirements to be met.)

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Stage 3: Establish a Detailed Inspection and Maintenance Program

A detailed I and M program is established and agreed upon with the platform operator and certifying authority and is designed so that by the time the Certificate of Fitness needs renewal, all governmental I and M requirements have been met. The program is also made flexible, in that I and M tasks can easily be rescheduled, so that there is adequate contingency for bad weather and equipment malfunction.

It is essential that the program is agreed upon well in advance of the starting date so that the selected diving contractor has an opportunity to review and comment on the program content and schedule.

Brown and Root (U.K.) Ltd. has utilized this three-stage approach successfully on a variety of offshore structures, including steel jacket oil platforms, submarine pipelines, semisubmersibles, and bouyant tension legged platforms.

The remainder of this paper gives details of the work undertaken in each of the three stages and generally outlines Brown and Root's philosophy of underwater inspection and maintenance.

Stage 1: Eliminate or Facilitate Inspection and Maintenance Tasks by Improvements in Design

Unfamiliarity with the problems of underwater inspection and maintenance requirements of offshore structures on the part of structural design engineers can make the tasks more onerous than need be. Therefore, during the conceptual design of the structure, it is imperative that all subsea items are examined to establish possible failure mechanisms and maintenance requirements. Consideration must also be given to the consequences of credible accidents, including vessel collisions, and damage due to environmental factors such as storms and, in susceptible locations, earthquakes.

Each failure mechanism and maintenance task is first examined with a view to its prevention or elimination by modifying structural design. If this is not possible, an inspection and/or maintenance requirement is assigned to it, and further work is carried out to establish:

- (1) The importance of the item subject to failure or maintenance. The consequences of failure or lack of maintenance are examined and the importance of the item as regards safety and continued operation of the structure is assessed. The importance of the item will determine the frequency of inspection and maintenance, and even whether the item is of sufficiently low importance that it's demise can be tolerated.



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- (2) The available access to the item concerned. All modes of access to the item are considered including air and saturation diving, manned submersibles and unmanned tethered submersibles, and one atmosphere suits, together with various launch techniques. The selection of the most appropriate access mode and launch technique takes into account the flexibility of the diving system, depth, current, weather profile, cost, safety, power restrictions, and efficiency (i.e., diving time compared to standby time). In the case of inspection tasks, consideration is also given to the use of monitoring devices permanently situated on the structure and interrogated from the surface, i.e., use of corrosion monitoring half cells, strain gauge attachments, etc.

The underlying approach to determining the appropriate access mode is the avoidance, where possible, of divers, as there is no point in unnecessarily exposing men to potential danger. Unfortunately, the most cost-effective method to date of achieving overall oil platform inspection in waters over 150 feet deep is bell diving from a diving vessel, preferably through a moon pool. As it is not possible to eliminate the diver from inspection and maintenance tasks on oil platforms, consideration must be given during conceptual design of platforms as to whether diving will take place off-platform or from a monohull or submersible vessel. However, diving from monohull or submersible vessels can be expensive compared to diving from the platform deck, as the day rate of the diving vessel is the major part of the overall diving costs. In addition, bad weather conditions can prevent diving and add further costs, especially in the case of monohull vessels. Platform diving, with the diving spread accommodated on the lower deck and the diving bell suspended on a monorail system located under the deck, gives access to the majority of the platform structure; it is necessary, however, to use a guide weight system to lower the bell through the bracing structure. Other considerations include lowering the diving bell on a guide rail system down a jacket leg, although access would be less than that provided by the underdeck monorail system. While the proposition of platform diving may appear attractive for a single platform, it may not be economically feasible where more than one platform exists in a field.

- (3) The inspection and maintenance equipment that will be necessary for the task. Failure prevention in subsea items depends upon underwater equipment to detect the impending failure in its early stages. Previous underwater trials and the experience of oil companies have shown that a large percentage of the underwater equipment currently available does not meet the manufacturers' claims, especially in the field of reliability. Often the deficiencies of the equipment are not fully realized until the inspection dive is in progress or until after the inspection program has been completed. The cost of abortive dives and uninformative inspection programs is considerable, without considering the implications for structures that are pronounced sound based solely on results supplied by unreliable equipment or the interpretation of an inexperienced diver. It is, therefore, important to select equipment that is capable of carrying out the inspections required and has a proven track record of reliability. In view of the vast range of purpose-built underwater equipment now in use or nearing final development, the responsibility placed on the inspection contractor operator to select reliable equipment and qualified personnel for surveys and inspections is considerable in terms of inspection costs.

The same comments apply to equipment selection for maintenance work, although a greater emphasis is placed upon efficiency and, hence, cost saving.

If no equipment is commercially available for the inspection or maintenance task, the issue is raised with the certifying authority in order to reach an agreement regarding a lowering of inspection or maintenance requirements until suitable equipment is available or can easily be developed for the task. Although this resolution seems a backward step, there is little point in specifying an inspection or maintenance requirement if it cannot be accomplished.

- (4) Method of navigation and identification. The ease of locating and identifying items or areas on structural members underwater decreases with the decrease in visibility. Consideration must be given to navigation and identification during conceptual design to eliminate these problems during inspection and maintenance.

Vertical navigation is rarely a problem using depth gauges or the diver's pneumo. Horizontal navigation can either be accomplished by using painted lines or numbers on the structural members, or by using acoustic transponders.

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Bracing nodes are probably the diver's biggest problem, as it is often difficult for a diver to determine which node he is looking at and even more difficult to determine the bracing stub identification. The problem is usually alleviated or resolved by:

- (a) Permanently attaching a node and bracing stub identification prior to platform installation. The identification system must be acceptable from a stress-interaction point of view with the node, must not accelerate corrosion of the surrounding steel, and must not be obscured by marine growth. (The installation of the identification system must be monitored closely, as a mistake prior to platform installation could cause havoc later during underwater inspections.)
- (b) Continuously monitoring the position of a diver by topside personnel using a scale model; the diver's location being determined by fitting on him a transducer and tracking him using transponders. (This system can be supplemented with video pictures from cameras attached to the diver's helmet.)

If method (a) is decided upon, the identification system needs to be agreed to early so that the attachment of identification tabs or painting on of numbers can be arranged prior to load-out.

In addition to identification of node members, divers also experience problems in the actual performance of nondestructive testing. Invariably they require both hands to operate equipment and are required to maintain their position against the current. It seems ridiculous that construction yards are forced to remove all fabrication aids from the jacket (such as pad eyes) when these aids may provide the means to the diver to maintain his position underwater. This is not to say that all fabrication aids should be left; clearly other considerations such as stress concentrations or the presence of sharp edges may require their removal.

Recording Format. The considerations given to inspection and maintenance tasks in Stage 1 are recorded on a standard format (see Fig. 1) so that the requirements are easily identifiable in the subsequent detailed planning of the inspection and maintenance program. In addition, a standardized format allows easy transfer to a data processing system for quick retrieval of information and sorting capabilities.



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Sheet 1 of 2

Inspection and Maintenance Identification Format	
Item identification:	Category (I or M):
Component or Area:	Material:
	Depth:
Inspection/maintenance need:	Importance:
Cause of need:	
Design impact:	
Potential I and M procedure:	
Frequency:	

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Sheet 2 of 2

Inspection and Maintenance Identification Format				
Item identification:				
Mode of access:			Manning:	
I and M equipment necessary:			Cost factors:	
Navigation/identification requirements:				
Recommended I or M procedure:				
Comments:				
Brown & Root (U.K.) Ltd.			 ENGINEERING STANDARD	
				Rev:
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Stage 2: Establish Inspection and Maintenance Philosophy and Strategy

The inspection and maintenance philosophy and strategy should be finalized as early as possible in order to give a long lead time prior to the first year's inspection and maintenance program. Failure to do so leads to a short preliminary organization period that often results in later organization and communication problems.

Experience has shown that in the case of oil platforms, the operator's main interest after installation is getting the platform on-stream, and little time is spent considering underwater inspection and maintenance requirements until hook-up is virtually complete. Fortunately, there are certain advantages in delaying Stage 2, in that the inspection philosophy and strategy can be based upon "as-installed" drawings and, hence, reduce the problem of divers reporting "missing bracings" or identifying "unknown" items. In addition, it is likely that the platform schedules are more firm.

Inspection and Maintenance Philosophy. As the I and M requirements are already known (Stage 1), the remaining work is as follows:

- (1) Review the requirements against "as-built" or "as-installed" drawings to ensure they are still valid
- (2) Agree with the certifying authority and platform operator on the defect acceptance criteria for each inspection task and the acceptance criteria for the satisfactory completion of each maintenance task

The major problem experienced in early inspection and maintenance work was the lack of definition regarding acceptance criteria, i.e., the diver or topside overseer was often unsure whether a defect was significant. In agreeing upon acceptance criteria, a realistic approach must be taken; for example, it is pointless stating that all weld defects greater than 1 in. in length should be reported if the nondestructive testing equipment is incapable of reliably detecting defects less than 6 in. long.

All acceptance criteria must be carefully determined and checked to ensure that they do not infringe upon governmental legislation and thereby create problems in the renewal of the Certificate of Fitness. All infringements must be resolved by compromise before field problems are met; otherwise, there could be substantial and costly delays in the I and M program.

Inspection and Maintenance Strategy. The effort behind the I and M program must be organized; otherwise, decision making is made almost impossible due to ill-defined responsibilities of personnel and the copious paper work usually generated by I and M programs.

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The operator's organization for managing the program needs to be defined so that lines of communication between the operator, the inspection team, and the diving contractor are made clear and will operate under pressure on a daily basis. Job descriptions need to be written so that personnel know to whom they report, for whom they are responsible, and the details of the function they are to perform.

A competent engineer, probably a corrosion or structural engineer, should be assigned to each inspection or maintenance task. His prime function would be to supervise and monitor proceedings and ensure proper recording of results. He should be qualified to recognize significant structural defects or deterioration on the spot. He will ultimately watch the video output on the surface and direct divers or unmanned tethered submersibles to obtain the information required by the survey or inspection program and request additional information in the case of damage observation. This engineer would also assist the operator's data recording team to analyze the inspection results to see whether the next annual inspection needs modifying in the light of current results; or he may require more detailed examination of items in future yearly inspections if he suspects a problem is developing, or less inspection if he feels the inspections are too frequent.

A procedural system must be developed for data collection and storage; otherwise, the operator's inspection and maintenance groups will find it impossible to monitor progress, assess performance, and interpret inspection data. The advantage of developing the procedural system early is that the inspection program can be modified quickly to concentrate effort on areas that are proving more susceptible to deterioration. The worst mistake that can occur in terms of data acquisition is the production of reams of data forms and miles of video tape, not collated in a form that can be interpreted. (It is considered essential to have video tapes with a date/time reference to pinpoint the place on the tape where certain information will be available.) Consideration must be given by the operator to establish a system (data processing or card system) whereby information is readily retrievable.

The various schedules for accomplishing the I and M program need to be examined from a cost point of view as follows:

- (1) The cost can be substantially reduced by limiting the types of operation; e.g., it could be uneconomical to utilize air and saturation diving techniques in conjunction with manned submersibles if the cost of two support vessels must be met.
- (2) The platform schedules should be examined and a tentative I and M program schedule made out to avoid delays in I and M work due to interference with other platform work.
- (3) Advantage should be taken of "weather windows," primarily for inspection and maintenance tasks in the splash zone region, and secondly for the majority of the annual I and M work.

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Stage 3: Establish a Detailed Inspection and Maintenance Program

Once the inspection and maintenance philosophy and strategy have been agreed upon, work can continue to establish a detailed I and M program. A separate instruction sheet for the diving contractor is made for each I and M task identified in Stage 1; the sheet lists:

- (1) Purpose of inspection
- (2) Parts and location of the structure to be examined with applicable drawing numbers
- (3) Preinspection cleaning and NDT equipment to be used
- (4) Method of access (note that this must be agreed upon previously with the diving contractor, as he is the specialist.)
- (5) Description of inspection and inspection procedure

The instruction sheet also gives practical directions to the diving contractor and, hence, ensures that the overall inspection philosophy is met.

Log sheets are attached to the instruction sheets to enable the topside engineers to record directly the inspection results. The reasons why topside personnel are required to record the data directly are as follows:

- (1) It is extremely difficult for divers to record information with wax crayon and slate while working with their hands.
- (2) Understanding verbal commentary from a saturation diver with an unscrambler may be difficult even for trained diving personnel. Therefore, if the topside engineer hears the commentary on the spot, he can request clarification or further information if required.

(In view of the problems, the best route for information to reach topside is either via video cameras and surface readout underwater equipment, or by the use of manned submersibles with specialist engineers on board. Colored still photographs are, however, still the best method for recording structural damage for permanent records.)

The log sheets completed by topside engineers will contain all information relating to the I and M identification number, the diving contractor and divers involved, diving time log, item being inspected or maintained, video tape number, observations, and a special report in the case of observed damage. The log sheet may also indicate areas likely to warrant further investigation. The sheets not only serve as a means of recording current inspection findings, but also form a permanent record which, with other reports giving the platform inspection history, counts towards the recertification.

Each instruction sheet and the time allotted for the execution of the I and M tasks detailed are discussed with the proposed diving contractor, as it is his responsibility to perform the I and M tasks and meet the schedule milestones.



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Usually the I and M program is preceded by a "base-line" survey that commences with location and removal of debris lodged within the structure and proceeds to check the structure against the "as-built" drawings in order to account for all structural members and detect obvious installation damage. The removal of debris can be a particularly hazardous task for divers due to either falling debris or the possibility of entanglement with wire hawsers, etc. Remote control vehicles should be used to locate debris so that divers can then proceed to remove it from the top, working downwards. It is unfortunate that the high loss rate of R.C.V's inside platform structures must be weighed against diver safety. Only when the "base-line" survey is complete and the danger to divers from debris is removed should subsequent inspection and maintenance programs be carried out.

The use of scale models when discussing I and M tasks with the diving contractor is recommended. In addition, divers and topside overseeing personnel can use the model to quickly familiarize themselves with the structure. The cost of the model is often saved by reduced diving time.

Underwater Repair. Inspection and maintenance programs sooner or later lead to underwater repairs. It is advisable therefore that the operator includes in his I and M organization a small team of structural engineers and a fracture mechanics consultant who are available at short notice and are familiar with the structure.

Immediate major repairs are impractical offshore as the time lag between detection and repairs must be as long as is required to accomplish the following:

- (1) Obtain a full report of the damage extent
- (2) Mobilize repair equipment and personnel
- (3) Plan the repair operation around platform and I and M schedules
- (4) Carry out computer runs to determine whether damaged areas can be removed entirely, or additional temporary bracing is required, etc.

This delay means that the first priority will be a computer run to determine the safety of the structure; therefore, the computer program and personnel must be in readiness not only throughout the structural survey, but also throughout the operating life of the platform. Failure to have this facility readily available will delay decisions that could endanger the platform and put operating personnel at risk.

* * * *

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No attempt has been made in this paper to state actual costs of underwater inspection and maintenance work, or to relate Brown and Root's experience of particular diving systems and underwater equipment. The reason for this is that there are so many variables that may affect the underwater operation, including geographical location, weather profile, marine conditions, structural design, and the everchanging market for diving and support vessels. However, detailed planning of underwater inspection and maintenance tasks commencing at the conceptual design stage of the off-shore structure is a logical and cost-saving approach that can always be utilized to take advantage of the latest developments in underwater technology.

Wet Welding Equipment

*Herman B. Smith and Robert G. Hirsch
Norfolk Naval Shipyard*

This paper deals with the effective development of methods, procedures, and satisfactory production performance in underwater wet welding in relation to currently available underwater wet welding equipment.

In late 1978, we in the Welding Engineering Division of the Norfolk Naval Shipyard were given the task of developing and qualifying an underwater wet welding procedure and then training a number of divers to qualify to it. This was necessary to accomplish some urgently needed repairs to the outer sill of our largest drydock. At the time, there were no commercially available companies who could meet our schedule requirements.

Our investigation revealed that there was very little concrete, meaningful data or information available in the technical area nor any readily available information on equipment for underwater welding. One obvious lack was a comprehensive welding standard to work to, such as the proposed AWS underwater welding specification now nearing completion.

We decided to work as much as possible within the framework of Mil-Std 248, "Welding and Brazing Procedure and Performance Qualification," for qualifying procedures and diver/welders, and fabrication document Mil-Std 278, "Fabrication, Welding and Inspection for Machinery, Piping and Pressure Vessels" of the U.S. Navy. We also used NAVSEA 0900-LP-000-1000, "Fabrication, Welding and Inspection of Ship Hulls," as a reference document. The requirements of these documents are stringent, and coupled with stipulations from NAVFAC via Mr. T.J. Dawson, we proceeded.

We built a small enclosed tank (Fig. 1) equipped with watertight door, lexan viewing window, and sleeves/gloves cut from old diving suits. The tank is designed for rapid flooding and emptying (two minutes to fill, two minutes to drain). The appropriate welding lead, ground, waterproof light, weld cleaning equipment, and plate rack were installed. We used a 400 amp Westinghouse DC rectifier as our power source, and after many problems in welding, added an arc-drive unit to the set-up, which was very beneficial in reducing arc outages.

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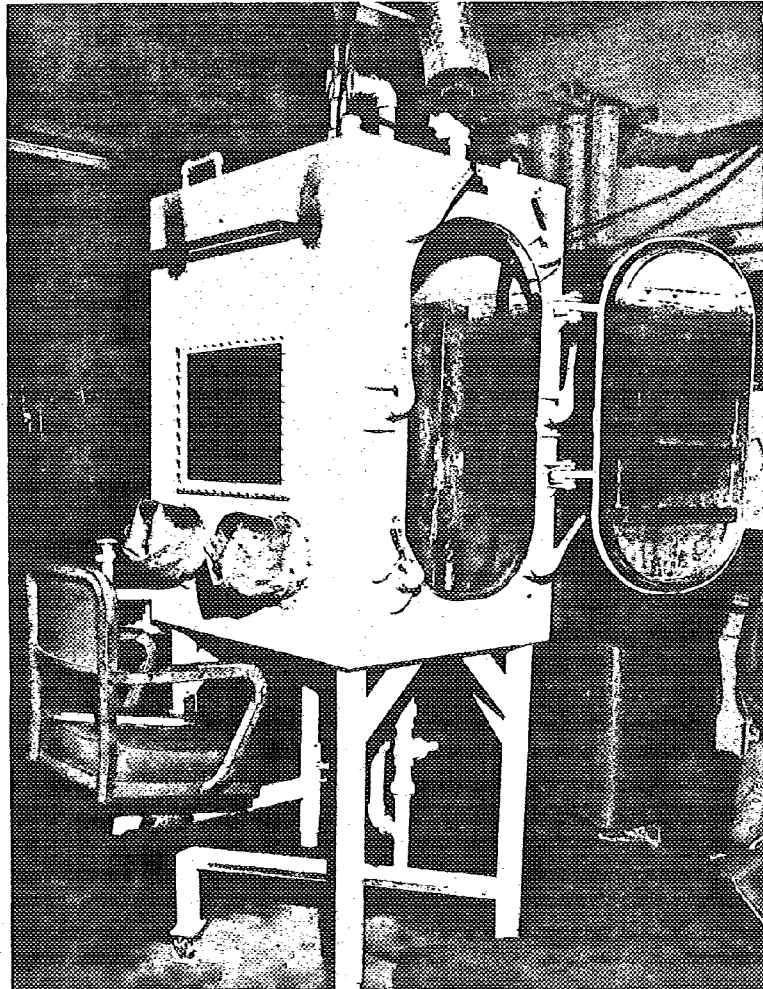


Fig. 1 – Small enclosed tank (or 'glove-box')

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Using one of our lab welders and the glove box (Figs. 2, 3, and 4), we qualified a procedure for HTS and mild steel plate in the flat, vertical, and horizontal positions, obtaining results meeting terrestrial weld requirements by both nondestructive and destructive tests. Using that procedure, we trained and qualified 14 divers as wet welders, using tests in both the glove box and the river. The river work extended our qualification to 60 feet in depth, which is more than sufficient for our shore facility and ship afloat repair work.

These men have successfully completed the dry dock sill job, which has led to other work including replacing segmented waster sleeves, Seachest splitter bars, and shafting fairwaters, all waterborne at a great savings over the costs of drydocking a vessel for this work.

As to equipment, arc-drive units (Fig. 5) equal to those built by Westinghouse have proven very beneficial in maintaining a close underwater wet welding arc. That company fabricated several units for us. We also found it economical and expedient to utilize a "stinger" or electrode holder equal to the "Arc-Air Sea-Stinger." Also very useful when we worked into material prep and removal is the "arc-water" torch, proprietary to the Arc-Air Co. The divers have found this very effective.

In the area of electrodes, we regret to state that certain proprietary wet welding electrodes were found deficient in areas such as cup depth, restarting, and arc stability. We, as many others in this field, have evolved our own electrode and coating combination for best results.

Since first building the glove box, we have modified it to use clamping rings on jetline dry box gloves with accordin sleeves. This simplifies greatly the sleeve/glove replacement problem.

We also found that using soft foam rubber on the welding shields prevented scratching the lexan viewing windows.

We now accomplish overhead welding and arc-water cutting in the glove box (Fig. 6).

Use of the glove box makes possible a disciplined introduction to wet welding with guidance right at hand for diver/welder improvement, with no danger from climbing into and out of water, or handling and equipment problems. It also saves a great amount of time since immediate instructor and/or technical evaluation of progress is possible.

In summary, we have found the glove box approach to the training of diver/welders a very effective method. It is valuable both for controlled initial training and later instruction on innovative methods as they come into use. We have been very stringent in our glove box weld quality requirements, which has occasioned some biting whispers from personnel being trained; but, in every case, this discipline has paid off in the river. These same diver/welders return to thank us for our demanding approach because as they have stated, "It makes the river jobs easy."



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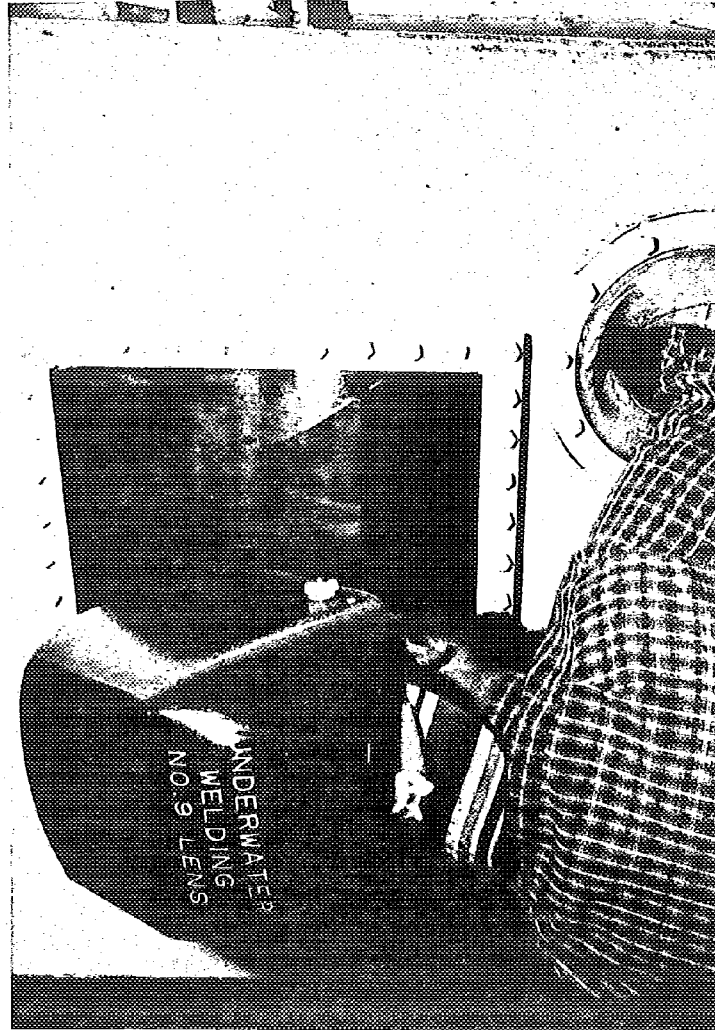


Fig. 2 — 'Glove-box' filling, preparatory to welding vertical butt plate

Herman B. Smith and Robert G. Hirsch/29

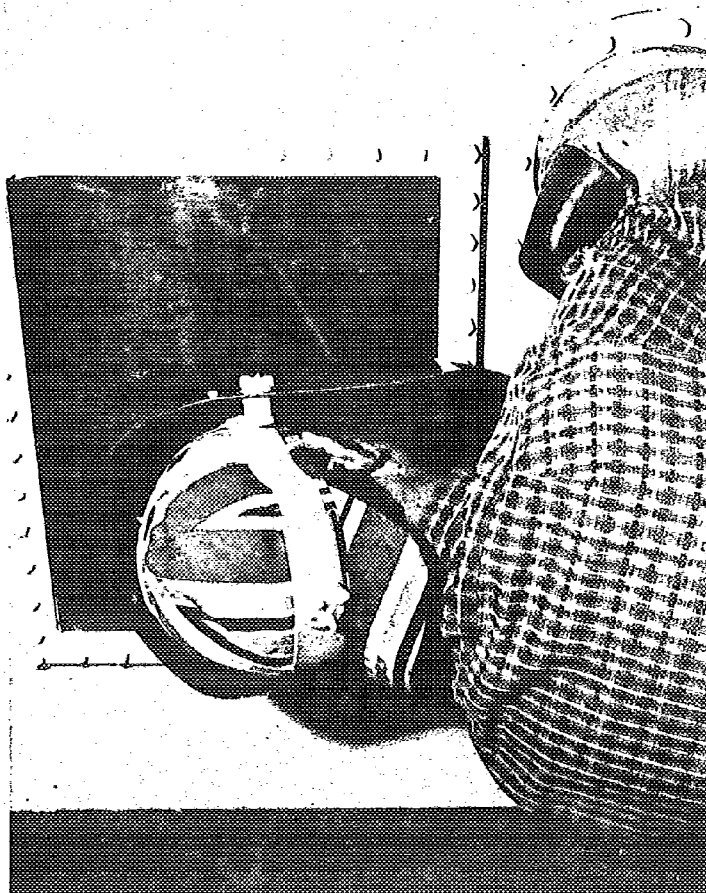


Fig. 3 — Welder ready for 'switch-on' to commence welding

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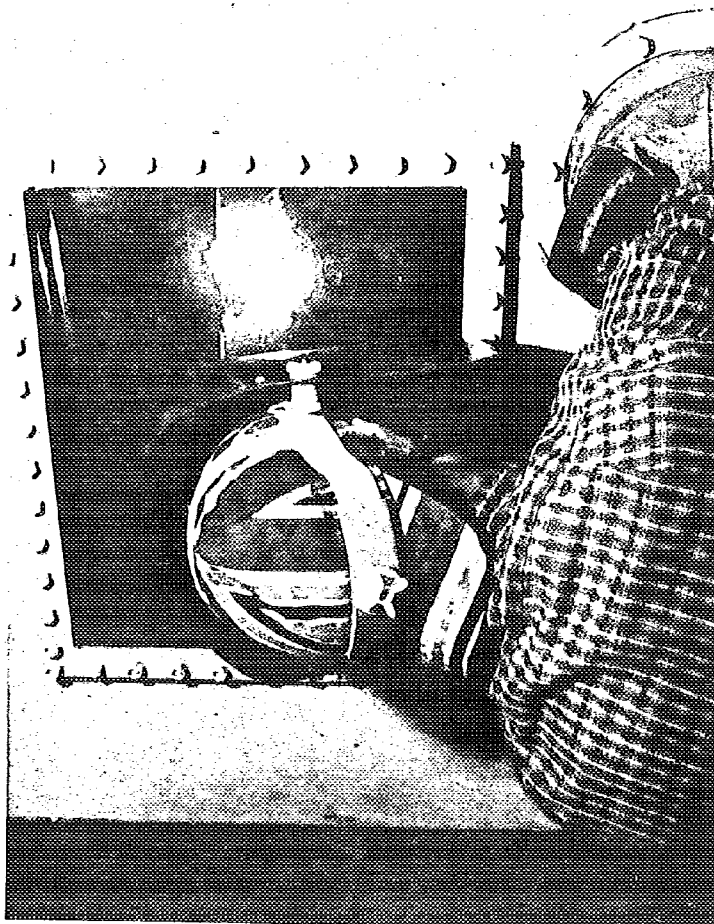


Fig. 4 — Arc initiated (note clarity of view for instructor Jr observer)

Herman B. Smith and Robert G. Hirsch/31

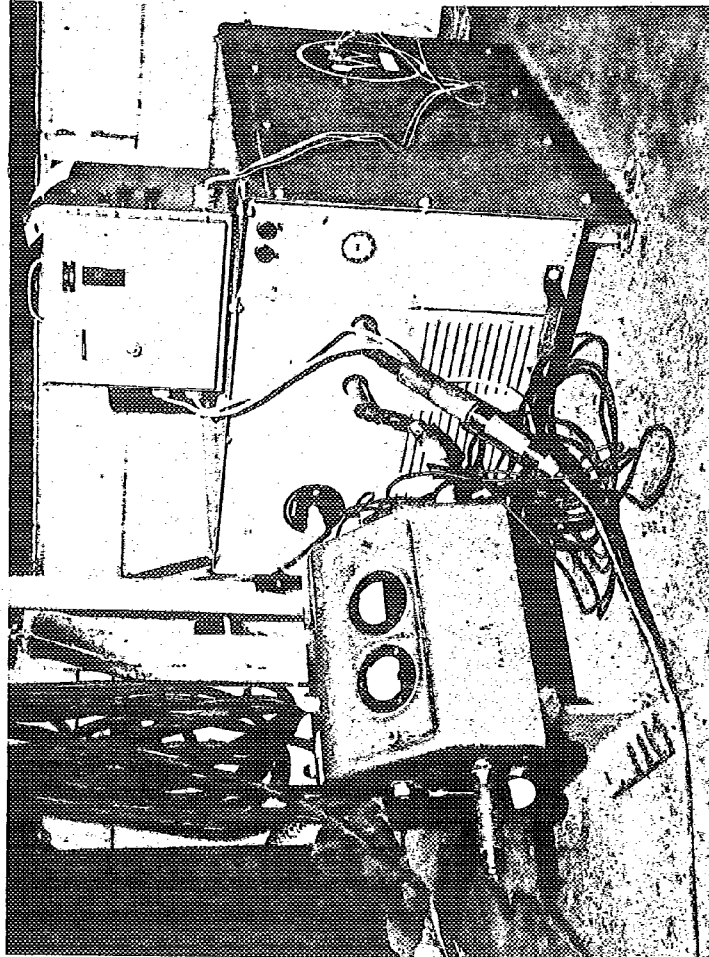


Fig. 5 — Arc-drive unit atop rectifier power source with volt/ampere meter unit hooked into circuit

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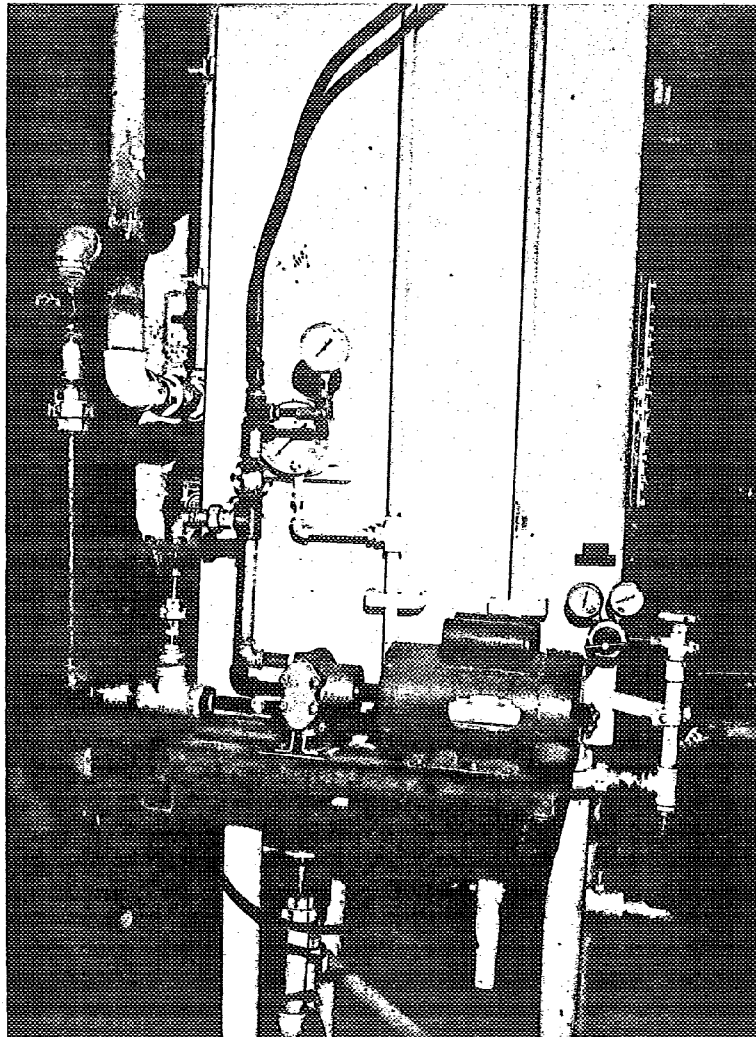


Fig. 6 — Showing modified 'glove-box' with positive action piston pump added together with proper gauges and by-pass to permit varying output pressure as needed for 'arc-water' cutting unit.

Herman B. Smith and Robert G. Hirsch/33

We have at the shipyard a large HY-80 tank (Figs. 7 and 8) with heat-treated glass viewing windows, very good pumping, and associated equipment that we plan to utilize for further training and improvements. One advantage will be the opportunity to do full-scale mock-ups of certain critical type jobs and then evaluate them through both nondestructive and destructive tests.

All of the out-of-the-river glove box and tank training is done in full compliance with U.S. Navy diving safety regulations.

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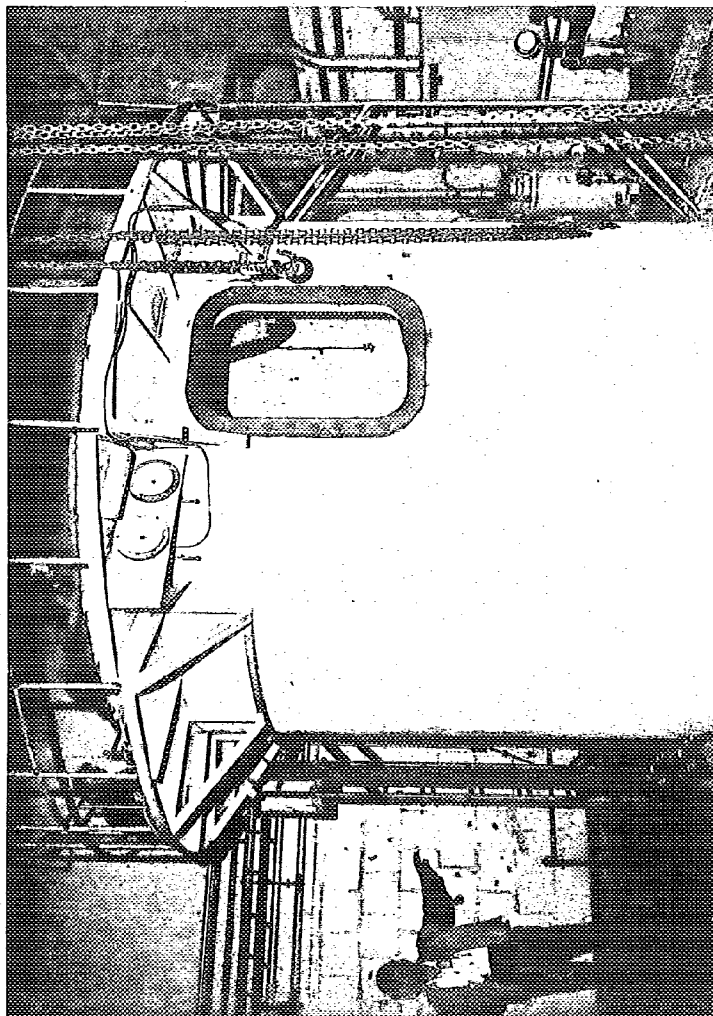


Fig. 7 — Large HY-80 tank with thick heat-treated glass windows

Herman B. Smith and Robert G. Hirsh/35

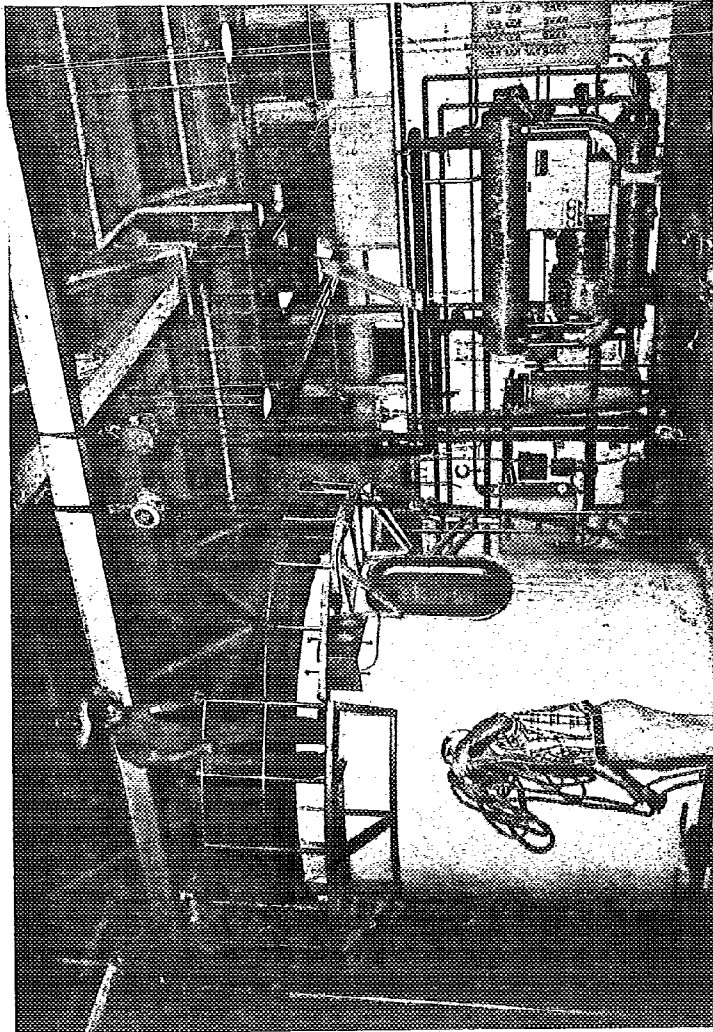


Fig. 8 — Tank with cover, associated pumping, filtering, and other equipment

Submerged One Atmosphere Welding System

*Edward M. Briggs and Robert E. Adler
Southwest Research Institute*

Introduction

A one atmosphere welding system is proposed as an alternate to hyperbaric welding or mechanical coupling of pipeline in intermediate or deep water.

The development of a one atmosphere welding system for deep submerged operations is feasible with the use of current technology. The system would provide a dry, one atmosphere environment, independent of depth, to allow conventional welding equipment and personnel to perform the work. The quality of the welds would be better than those done in underwater, wet, or hyperbaric conditions. This paper reviews the state of the art in the development of submerged one atmosphere systems. It provides a detailed description of one such system with emphasis on special requirements, advantages, and disadvantages and provides a basis for system tradeoffs.

Overview of Single Atmosphere Welding

Problems associated with a single atmosphere welding system are not caused by current and projected welding practices. The method of pipe preparation, pre- and postweld heat treatment, and the actual weld itself are well enough understood for other uses not to pose new or unique problems, other than the fact that they must be accomplished on a confined area and that the welders face an atmosphere that will be continuously contaminated by the products of the welding process itself.

One atmosphere welding, of course, provides a much more favorable situation for welding the quenched and tempered steels of 65 ksi to more than 100 ksi required for deep water pipelines. Therefore, it behooves the designer to design a system that is compact, meets the appropriate codes, and can allow the work to be accomplished in a confined space. The amount of automation desired is dependent upon the size of the pressure vessel in which the operation is being performed. While it is obviously one of the requirements to be able to perform the welding service as fast as possible, it should be kept in mind by the designer that a major portion of time and expense result from preparation of the pipe, and that the actual welding process part of the operation is very small. Reductions in the welding time save very little time

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or expense on the overall process. Some attention should be paid to the inspectability of the weld and to the equipment necessary to inspect and re-code the weld. There are a number of technical and operational problems in the single atmosphere welding that control the overall costs and economic success of a single atmosphere welding system. The cost of the welding system is nominal. In fact, operational and technical problems are overriding in their importance. Basically, the intent of this paper is to describe those areas to which the designer must pay most attention in order to have a successful and economically viable single atmosphere weld system. In order to go over these systems, it is necessary to look at the total operation.

First, of course, the failed area or the area to be welded must be located. Once it is located, certain preparations must be made. Some knowledge of the topography and geotechnic properties of the soil must be made. Once this is accomplished, the pipes to be welded must be moved into position so that the pipe welding device can be lowered upon it. Depending upon the user's interest, they must be lowered into position very accurately, or they can be left askew and slightly out of line by several feet. Most of this pipe movement can be done using lines from the support barge. Since it takes a great deal of horsepower to lift and maneuver the pipes, the use of the barge lines will always be advisable. The placing of transducers and the possible preparation of the pipe, that is, cutting off jagged edges and preparing the sea floor, should be performed before a pipe repair system is lowered. Currently, these tasks are accomplished primarily by divers. They could be accomplished by manned or unmanned, tethered or untethered submersibles or work systems. However, if the designer should incorporate a device for preparation of the pipe and terrain into the pipe repair total system, a savings, not only in money but certainly in time, can be realized.

Once the pipe repair chamber and auxiliary equipment are lowered onto the system, a number of new problems will face the designer. However, before lowering the chamber, some attention should be paid to the frame or frames that are necessary for aligning the pipe sufficiently so that they can be welded without a miter. Certain kinds of pipe repair will require a very heavy strong frame in order to force the pipe by overbending into the weld chamber. Here the designer is faced with two options. One is to put the frame out some distance so that the pipe is flexible enough that it does not require a powerful manipulator system in order to align the pipe. The other is to perform this operation using an integral frame, which by means of a hydraulic system will force the pipe into position. There are strong arguments for both systems. However, it should be noted that some operations will be eliminated by going with one system or the other. After the pipe weld system has been placed on the pipe and we are able to maneuver it into position, we now face some designer choices that certainly affect costs, reliability, weight, etc., of the overall system.

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One of these operational choices is the method of pipe cleaning. To clean the pipe out in open water to make an O-ring type seal precludes even the most minor blemish be made on the pipe. This is a very difficult operation requiring automation and a "smart" computer controlled system. Another system to be considered is the pigging operation. Pigs must be put in the pipes in order that one atmosphere may be formed in the pressure vessel. Since pig plugs can be very heavy and must be inflated and deflated, pumped out, and inserted into the pipe with a complex mechanism, careful design processes can save considerable time and expense. The third important operational feature is the seal of the chamber to the chamber and most importantly around the pipe. We face several methods of doing this. Currently, in the literature we can find a welded seal that means potential damage to the pipe and leaves an expensive structure on the bottom with the unknown metallurgical problems. While the weld system is simple, it presents several very difficult problems if one considers operating one of these systems for a great period of time. The second system is a conventional sealing system moving some sort of captured elastomeric seal. These systems, of course, have the advantages of years of experience. However, with the very complex seal required, that is, the circumferential and longitudinal seals meeting, and with the difficulty of cleaning the large diameter pipe sufficiently until a reliable seal can be made, some difficult problems are presented. The advantage, of course, is that no residual material is left after the seal is made. To ensure against blowout, back-up seals can be placed by welders after chamber entry. Coating the pipe can present some problems since it cannot be recoated until the seal is broken. The third method is to seal by injecting some sort of material that has good bonding qualities and will set up with sufficient strength to stand the external pressure. The advantages of this seal would be more tolerance in alignment and more tolerance in cleaning the pipe. Problems exist in the fundamental nature of the R and D necessary to prove the third method will work, since experience with this kind of system in the oceans is not well defined. This sealing system will require more extensive procedures than either of the other two.

The selection of the method of pipe cleaning, pipe pigging, and welding chamber seal will have a direct impact on the cost, weight, and reliability of the system. The other major problem the designer must contend with is system safety; that is, emergency procedures must be identified at the design stage to provide both redundant and fail-safe systems to protect the personnel. The final severe problem is the pig. In any case, a pig must be inserted in both ends of the pipe in order to seal the pipe. If the pig is a hydraulically expanded rubber bladder with grippers, the designer must be absolutely sure that no leaks or failures can occur without sufficient advance notice. Pig movement must be detected and advance warning provided. There are currently no codes or regulations covering the use of an inflatable pig in man-made chambers. Therefore, it is necessary for the designer to prove to the code and regulatory agencies that this system is as safe as a normal hatch or window or other penetration normally found in a man-rated chamber. Of course, a pig that is

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noninflatable with a strength member between the two sealing ends and with both mechanical and hydraulic seals would probably present an easier time with the code and regulators; however, it presents severe problems with installation since it must be carried with and installed as the pup is installed in the chamber. Minor problems the designer must address are control of noxious gases and particulate matter from the welding processes and providing large amounts of power to the system. A one atmosphere mating and transfer system, of course, is necessary on all these systems. This problem has been studied and a variety of techniques have been used. The problem does not appear to be as severe as some of the other problems because of its wide exposure.

There is a depth limitation to the system that is really controlled by cost and technology. The deeper the system is deployed, fabrication and metallurgy problems begin to dominate the design. Operationally, the placement of the system and the extension of the cables and electrical umbilicals begin to become difficult. Using current technology predictions, it would seem that a practical limit is 5000 feet. One must also consider the capable range of the system to work at shallower depths and still maintain a cost competitiveness with hyperbaric welding systems at 600 feet. Single atmosphere welding systems do have limitations, but at the current time they are feasible to accomplish work to 5000 feet.

Description of a Single Atmosphere Welding System

The following system was designed to the specific requirements of Taylor Diving and Salvage Company of Belle Chasse, LA. The system is about 85 percent complete, and a detailed description is given to help the reader appreciate the problem outlined in the previous pages. An artist's conception of the SAWS is illustrated in Fig. 1. Its purpose is to permit welding on submarine pipeline in a dry, one atmosphere controlled environment. It consists of a submarine pipeline alignment frame (SPAF), several one atmosphere chambers, pipe manipulator system, and necessary hydraulic pneumatic, electrical, electronics, life support, and environmental control subsystems to support the welding operation and the life of repair personnel. The system is designed to operate at depths to 2000 feet. The system will meet the manned submersible requirements of the American Bureau of Shipping.

The total weight of this system is 400 short tons in air and 100 short tons in water. It was designed to be supported by special derrick/pipelay barges available to Taylor Diving and Salvage Company. To maintain buoyancy control and to provide a footprint pressure of less than 85 psf, the tubular SPAF will be pressurized to dive depth pressure.

The barge will be able to place the SPAF within ± 5 feet of the repair location of the pipe to be welded.



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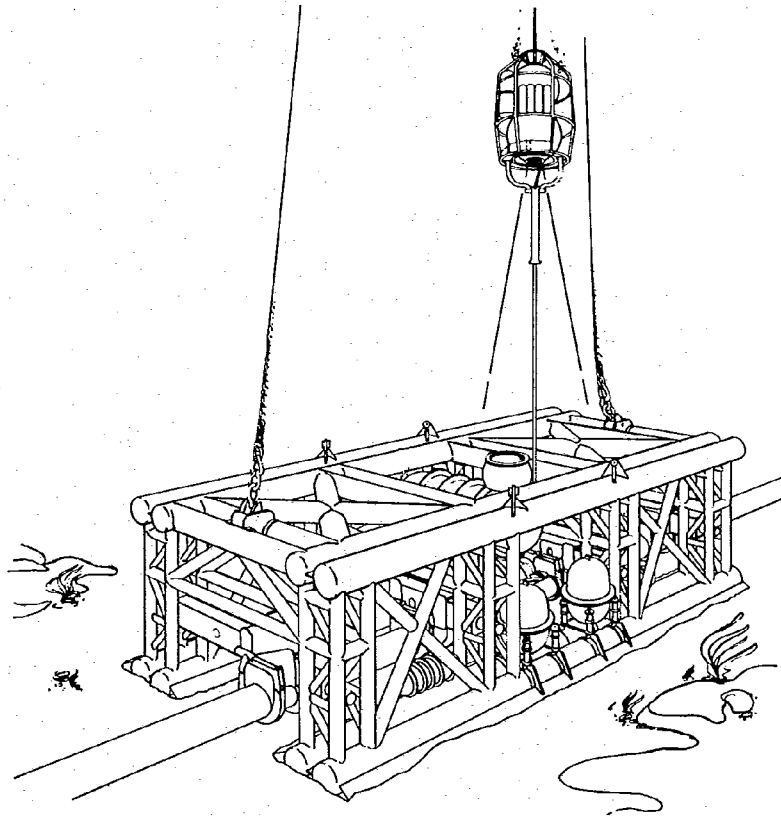


Fig. 1 — One atmosphere welding system

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The SPAF consists of four transverse frames forming three longitudinal bays. Within each frame is a hydraulically operated pipe claw and traversing mechanism (screw jacks). Semi-rigidly attached within the SPAF are the man-rated, single atmosphere chambers and interlocks shown schematically in Fig. 2. After emplacement of the SPAF, personnel are transferred to the auxiliary chamber (AC) by a tethered one atmosphere personnel transfer chamber (PTC), and entrance to the AC is accomplished by means of an interlock scheme. The buoyant PTC descends to the SPAF via a haul-down cable, which is attached to the SPAF, and the cable is collected on a winch mounted on the exterior of the PTC. The PTC is then latched to the "tea cup," and a seal is accomplished so that the tea cup can be dewatered. When water is cleared from the tea cup and pressures in the PTC, tea cup, and AC are equalized, personnel can open hatches and enter the AC to begin work.

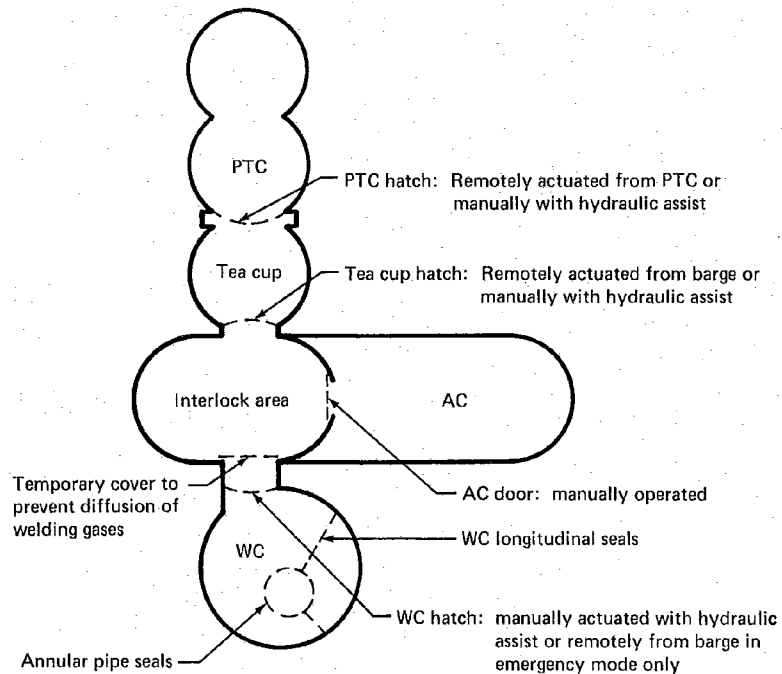


Fig. 2 – Schematic diagram of one atmosphere chambers

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Before the SPAF leaves the barge, the welding chamber (WC) will be opened so that its two sections may straddle the pipes when the SPAF is placed on the sea floor. After SPAF emplacement, an operator in the AC works the pipe claws to "nibble" and finally "grip" the pipes, then moves each pipe sequentially to the "pipe cleaning"/"plug insertion" stations. At these stations, the inside of each pipe is cleaned and pipe plugs (PIG) are inserted and "set" or energized. Following PIG insertion, each pipe is moved into the fixed half of the welding chamber. The extremely critical pipe alignment is accomplished by means of a coarse and fine stage pipe-position monitoring scheme.

After both pipes have been aligned in the fixed part of the WC annular seals, the WC door is closed and secured. The pipe is then gripped with a series of wedges to prevent axial motion of the pipe, after which the pipe alignment is checked and readjusted if necessary. The annular pipe seals are then actuated. Next the longitudinal WC door seal is "set" by creating a positive hydraulic pressure differential on the lips of the longitudinal seal. After the WC is dewatered, personnel may enter the WC to prepare the pipes for accepting a previously prepared pipe splice section, which is stored in the AC interlock area. Using a small hoist, the pup is removed from its stored position in the interlock area and hoisted through the WC hatch into the WC. Another small hoist within the WC is used to orient and position the pup for welding between the two pipe ends. In the event that the pup does not fit adequately between the pipe ends for welding, a second pup will be prepared to the required dimension on the barge and transported to the SPAF via the PTC.

Two heating elements are attached to the pipes to bring the materials to the correct preheat temperature prior to the welding operation. Before welding starts, pressures in the AC and WC are adjusted so that the WC pressure is approximately 0.1 psi below that in the AC, and a temporary shield is placed over the WC hatch to restrict the flow of contaminated air from the WC into other chambers during the welding operation. Two welders may work simultaneously and will wear breathing masks supplying filtered surface air. After the welding operation starts, any other personnel entering the WC will also wear breathing masks.

Following the completion of the welding operation, the weld joints will be nondestructively inspected by x-ray or ultrasonic methods in accordance with customer specifications. Equipment for these inspections will be transferred from the barge to the SPAF via the PTC. After acceptance of the welds, the pipe surfaces within the WC will be coated for corrosion protection. Following that, personnel will exit the WC with their equipment and close the WC hatch. The pipe plugs (PIG) will be de-energized, and afterwards the WC will be flooded. The AC operator will then open the WC door, lay the repaired pipe to the ocean floor, and shut down systems prior to returning to the barge in the PTC.

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SAWS Major Functional Subsystems

Electrical. The electrical power system will have three phase loads. Voltages will be 2400/4160 V, 277/480 V, 120/208 V ac and 24 V dc. The system will receive power through a power umbilical and transform it by means of two transformers located on the SPAF. An emergency and auxiliary battery power system for lighting, communications, and life support functions can supply power for a 24-hour period.

Life Support. Life support will be provided to the personnel transfer chamber, the auxiliary control chamber, and the welding chamber. It will consist of the following subsystems:

- (1) Environmental control
- (2) Mask breathing
- (3) Food and drinking water supply
- (4) Waste disposal
- (5) Smoke removal
- (6) Gas diffusion prevention

The system will have a capability of 1,200 mission hours. The environmental control system will maintain a working environment by the use of:

- (1) Pressure monitoring and control
- (2) Oxygen replenishment monitoring and control
- (3) Carbon dioxide scrubbing monitoring and control
- (4) Temperature monitoring and control
- (5) Humidity monitoring and control

A smoke removal subsystem shall dispose of the smoke generated by welding by means of fume filtering units and ozone filter units.

Note: The following gas levels will be periodically measured in each man-occupied chamber. The minimum detectable concentrations are shown below.

- (1) Phosgene (OCCl_2): 0.05 ppm
- (2) Phosphine (H_3P): 0.1 ppm
- (3) Hydrogen (H_2): 0.5% by volume
- (4) Carbon monoxide (CO): 5 ppm
- (5) Ozone (O_3): 0.1 ppm
- (6) Nitrous fumes (NO_2): 1 ppm

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The welding system shall provide the equipment, machines, subsystems, etc. required for welding in the WC. The welding system consists of the following subsystems:

- (1) Power units: Five welding machines; four power supplies housed in WC (two for preheating, two for welding), one power supply stored on the barge. (If needed, the latter unit would be transported to AC interlock via the PTC.)
- (2) Input power: 440 V, 30, 60 Hz at 50 amps
- (3) Weight: 1.1 tons (approximate total for 4 units)

The weld inspection system shall document the equipment, machines, subsystems, etc. required for x-ray inspection in the WC of performed welds. This equipment will be stored on the barge and transferred to the WC via the PTC.

Welding Chamber Atmospheric Control. Welding of the pipe sections will contaminate the atmosphere of the welding chamber. A smoke removal system will be used to remove the bulk of the contaminants, but the system will not be adequate to maintain the degree of air purity required for breathing. Therefore, before welding operations are initiated, personnel in the welding chamber will be required to don surface supplied air breathing apparatus (BIBS).

The welding operations will also contaminate the atmosphere of the interlock and possibly the PTC and auxiliary chamber unless it is isolated from the interlock. Therefore, a hatch cover will have to be installed prior to welding.

The welding chamber BIBS system will be from the surface supplied air manifold. Full face masks will be used, and the air will be expired into the welding chamber's atmosphere.

An air compressor will be used to draw the air from the welding chamber and expel it into the surrounding water through a small volume isolation tank. The primary air compressor will be supplemented by a second "standby" unit.

The air compressor(s) will be controlled by a barometric switch set to load the compressor at approximately 14.7 psia and unload it at approximately 14.6 psia.

The pressure in the interlock/auxiliary chamber area will be kept at four to six inches of water above 14.7 psia at all times by connecting the reference port of the differential pressure switch controlling the air compressor to the pressure of the auxiliary chamber. The positive pressure in the interlock/auxiliary chamber should preclude diffusion of the welding gases.

A smoke removal loop containing two filtering units will be used to remove the bulk of the welding smoke and fumes from the welding chamber's atmosphere. The filter units will be cascaded with three ozone filters.

