MMS

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Minerals Management Service
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ASSESSMENT OF DEEPWATER PIPELINE REPAIR IN THE GULF OF MEXICO

FINAL REPORT

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ABSTRACT

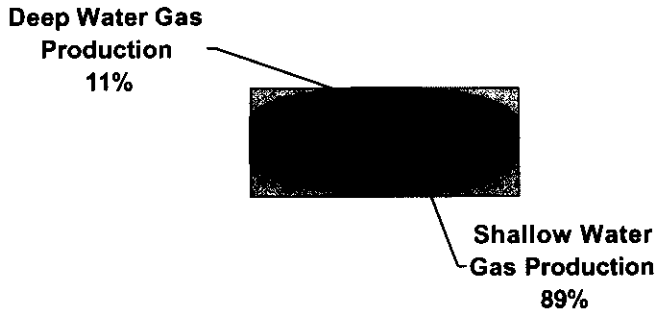
Over the last decade, a need has arisen to address the repair of Gulf of Mexico pipelines in water depths greater than 1000 feet (deepwater pipelines). Incidents of damage during the construction of deepwater pipelines as well as the growing deepwater pipeline infrastructure has instilled an urgency within the oil and gas industry to develop complete repair solutions for pipelines in all water depths. A rapid expansion of remote intervention technology integrated with proven end connection systems has occurred worldwide during the past year. Pipeline repair systems based on the integration of resident and foreign mechanical end connector systems with mature European subsea repair systems are beginning to emerge in the Gulf of Mexico. One system under development is being designed for both a surface lift repair and a remote diverless on-bottom repair providing the first comprehensive pipeline repair system in the Gulf of Mexico. The goal of the system is to complete a repair within one month of the damage incident. Additional technology being developed in the Gulf of Mexico and overseas shows promise of reducing repair times and cost significantly by revolutionizing conventional subsea intervention techniques. There are increasing trends to produce from deepwater and ultra deepwater fields. The deepwater pipeline repair industry is rapidly adapting to provide reliable repair solutions for existing and new deepwater production.

TABLE OF CONTENTS

INTRODUCTION:

The Gulf of Mexico region produces over five (5) trillion cubic feet of gas per year and almost 500 million barrels of oil per year. In 1998, 36% of the total oil production and 11% of total gas production is attributed to deepwater production.[1] Deepwater production figures in 1999 are poised to capture an ever increasing fraction of Gulf of Mexico production with seven (7) new fields on stream with now familiar names such as Allegheny, Angus, Gemini, Genesis, Macaroni, Marlin and Ursa. In 2000, an additional 14 fields are planned to begin production including Diana/Hoover, Petronius, and Europa. Production from deepwater fields is expected to account for 64% of the daily oil production and 30% of the daily gas production in the Gulf of Mexico by year-end 2000.[2] The trend of increasing commitment by the oil and gas industry to invest in deep water Gulf of Mexico exploration and production is evident by the increasing number of commercial discoveries in deep water. The number of deepwater discoveries in the Gulf of Mexico doubled in 1997 to 16 after six (6) years of a slow climb from almost none. The number of discoveries reported in 1999 topped the 1997 figures at 17. 2000 is promising even more.[3]

1998 Gulf of Mexico Gas Production



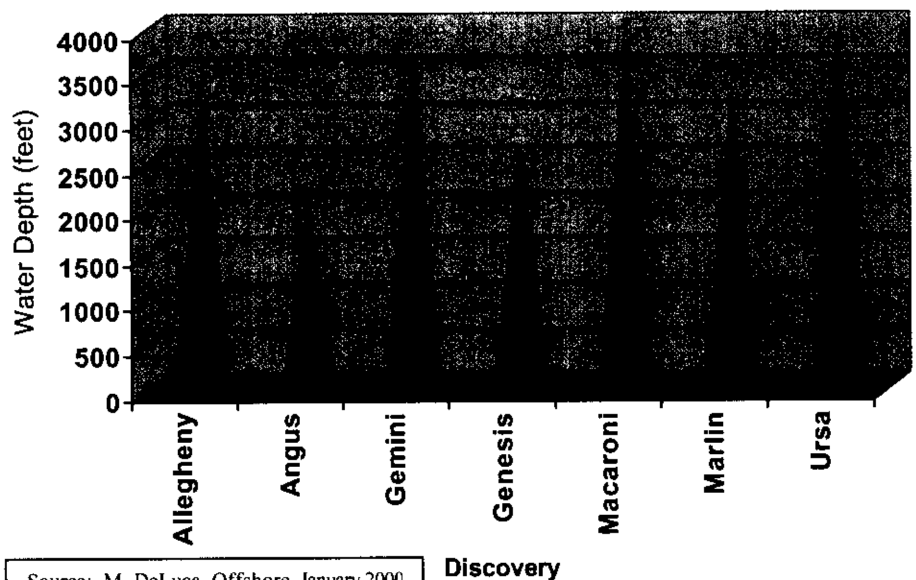
Source: http://www.gomr.mms.gov, February 2000

1998 Gulf of Mexico Oil Production

Source: http://www.gomr.mms.gov, February 2000

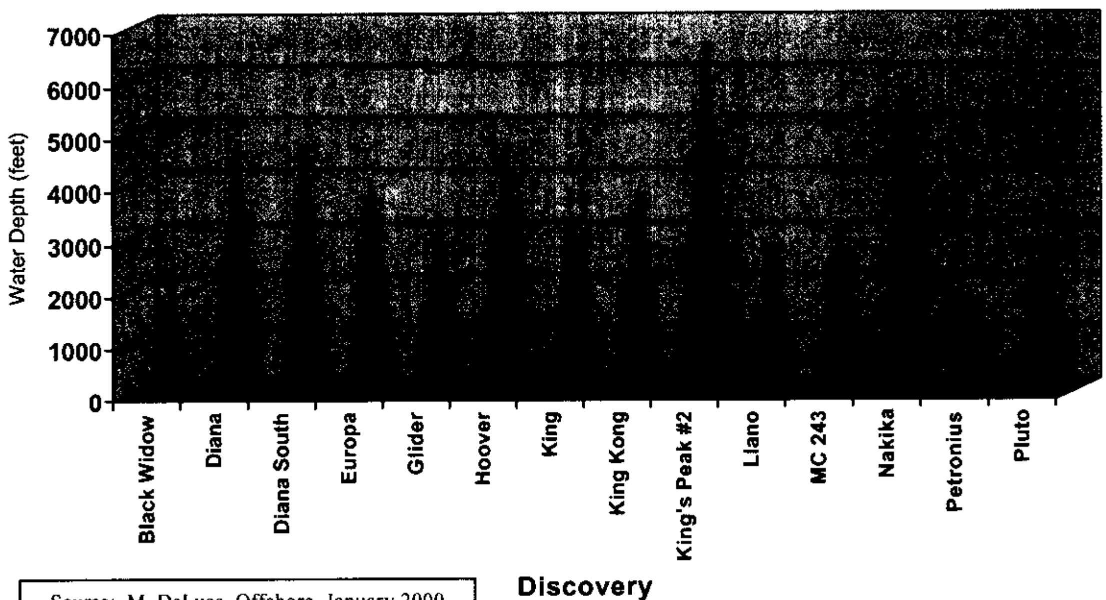
[1] http://www.gomr.mms.gov/homepg/offshore/deepwatr/summary.asp, February 2000
[2] World Oil, Deepwater Technology Archive, "Cooperative Efforts Needed for Deepwater Challenges," August 1998.
[3] DeLuca, M., "U.S. Gulf has 112 discoveries in water depths greater than 1500 ft.," Offshore January 2000.

1999 Deep Water Production Start Ups



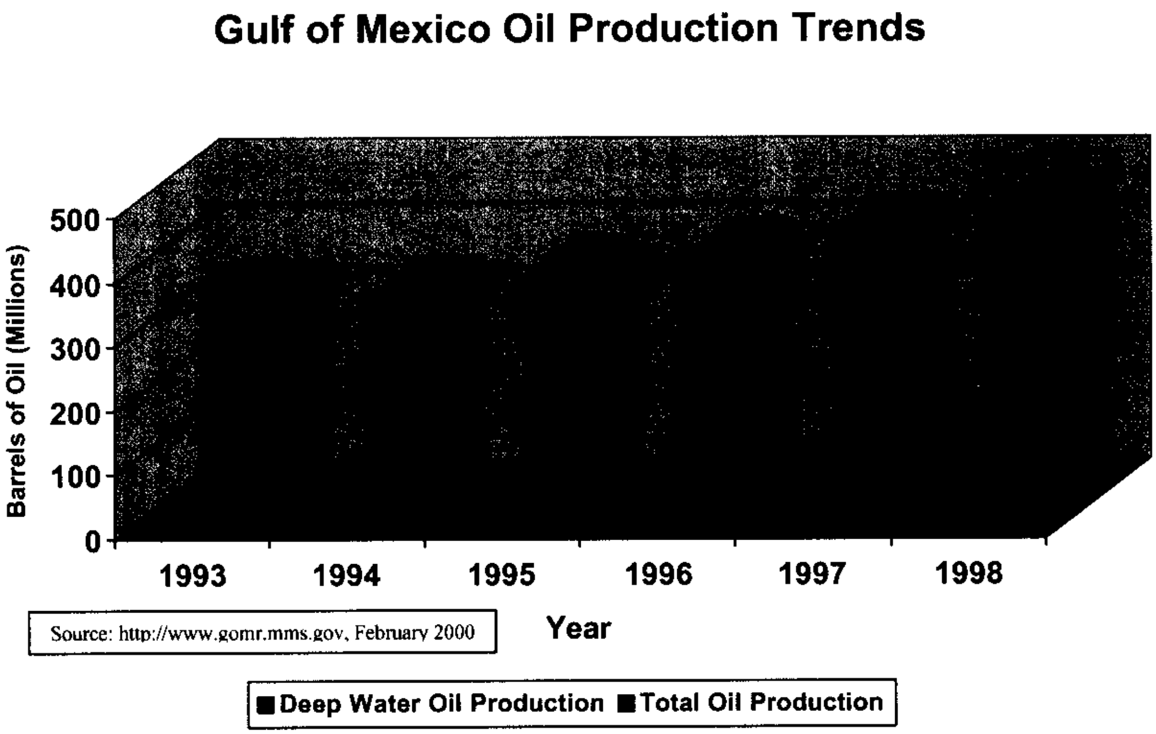
Source: M. DeLuca, Offshore, January 2000

Planned 2000 Deep Water Production Start Ups

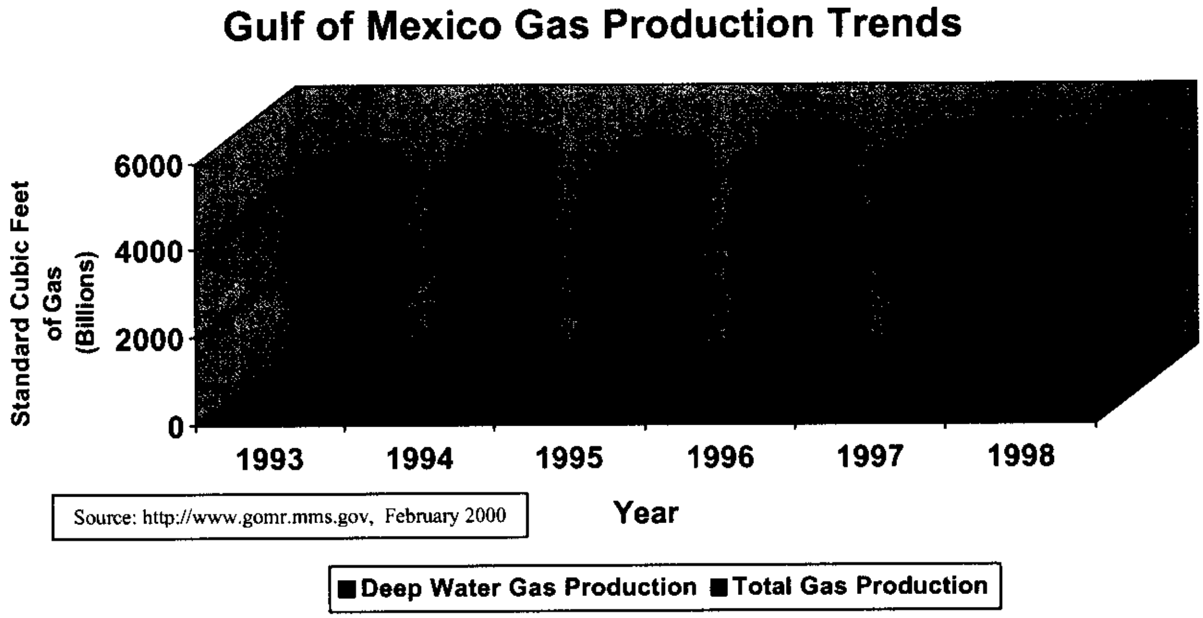


Source: M. DeLuca, Offshore, January 2000

There are 112 deepwater discoveries in the Gulf of Mexico up to the end of 1999 of which 27 of these are currently producing. It is reported that there are future plans to develop 83 of the discoveries that are not currently producing.[4] The pipeline is currently the only transportation method in the Gulf of Mexico used to transport deepwater production to market. As reported by the MMS to date, there are currently no FPSOs (floating production, storage and offloading facilities) in use in the Gulf of Mexico.[5] Even with the introduction of FPSOs, gas production will continue to rely on pipelines for transport to market. Currently, each of these deepwater developments in service must rely on the use of in-field flowlines and export pipelines to transport the production within and away from the field. As the deepwater infrastructure continues to grow it is likely that the number of pipelines will continue to grow even as other technology such as FPSOs are instituted in the Gulf of Mexico.



[4] Ibid.
[5] http://www.gomr.mms.gov/homepg/offshore/deepwatr/summary.asp, February 2000

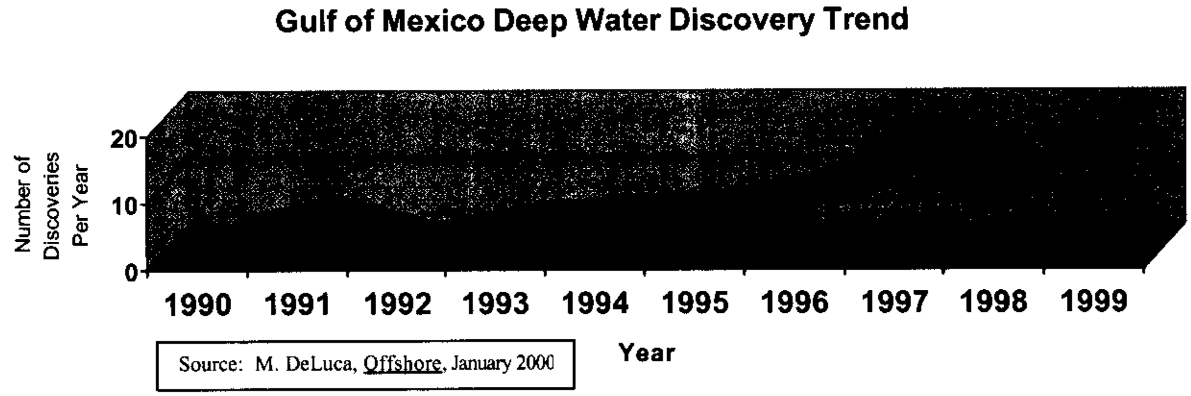


Source: http://www.gomr.mms.gov, February 2000

As the demand for deepwater pipelines increase, oil and gas companies must invest in the development of new technology to install, operate, maintain and potentially repair these pipelines in deepwater. As deepwater production captures an increasing portion of total Gulf of Mexico production it is evident that reliable oil and gas supply will be increasingly dependent on this new pipeline technology. The problem of deepwater pipe lay is well understood and has been overcome with the recent advances in J-lay and S-lay technology. The limiting factor is not in the capabilities of deepwater pipeline installation but in the capabilities of deepwater pipeline repair. Current technology suggests that even though a pipeline can be installed in deep water, it does not mean that technology exists to make an immediate repair if the need should arise. In order to maintain confidence in the deepwater pipeline infrastructure, the repair technology must accommodate the pipelines and the water depth in which they are installed.

The purpose of this report is to provide to the Minerals Management Service (MMS) an understanding of the issues behind, involving, and as a result of deepwater pipeline repair technology and an understanding of how the offshore oil and gas industry is addressing these issues. It includes the practical assessment of current technology considering historical development, current technological advantages and limitations of current systems, economic factors, and emerging trends. Incidental project planning and operational issues are also discussed as a matter of necessity as they are an integrated factor in the maintenance and repair of offshore pipeline systems.

The repair of pipeline installed in water depths greater than 1000 feet (deepwater pipelines) is an issue in not only the Gulf of Mexico region. Extensive work is underway to develop or improve existing deepwater technology in the North Sea and Mediterranean areas. Technology is also emerging in offshore Brazil, southeast Asia, and Indian Ocean areas. This makes deepwater technology commercially competitive on a global scale which only serves to enhances deepwater technology in the Gulf of Mexico. This also provides Gulf of Mexico operators with a greater number of options when a deepwater pipeline repair solution is required.



PURPOSE OF THE DEEPWATER PIPELINE REPAIR INDUSTRY

Offshore pipelines currently provide the Gulf of Mexico with the safest, most reliable and cost effective method to transport oil and gas from offshore production fields to the marketplace. Offshore pipelines are generally designed to meet or exceed production field life. They are also designed to be maintenance free over their life span, which can typically range from 20 to 40 years, due to the high cost of offshore maintenance. There are risks, however, that a pipeline can be damaged by unpredictable events relating to weather, commercial / industrial activity and operational risks. When a pipeline is damaged, operators rely on methods to effect a timely repair to resume production as quickly as possible in order to avoid further deferred revenue due to shut-in. There are a variety of methods available to repair shallow water pipelines. Most of the shallow water repair methods are adapted from routine pipeline construction procedures. Diver assistance is a necessity for most conventional shallow water pipeline repair procedures. As water depth increases, the choice of repair methods decrease to the point where divers can no longer be of use. The theoretical limit of saturation diving is approximately 1,200 feet sea water. Practical limits are set by operators and contractors according to individual safety policies and the underwater tasks at hand. For instance, North Sea operators are pushing to limit maximum depths of all planned diver intervention to 500 feet sea water. Beyond these water depths, alternative means must be developed to address pipeline maintenance and repair intervention. Pipeline operators and the offshore pipeline industry have long realized this dilemma that pipelines will extend into areas that require diverless intervention. It is only recently that complete systems are being realized in the Gulf of Mexico that can effect a timely repair of almost any deepwater pipeline damage scenario.

As more pipelines are constructed in deepwater, the likeliness of deepwater pipeline damage also increases. These risks have been realized with several incidences of deepwater pipeline damage in the Gulf of Mexico, primarily during pipeline construction. Pipeline failure can also be attributed to events such as physical impact, natural disasters, operational error, corrosion and from pipeline installation. A brief discussion of each of these failure modes follows with their associated relevance to deepwater pipelines.

Causes of Pipeline Failure

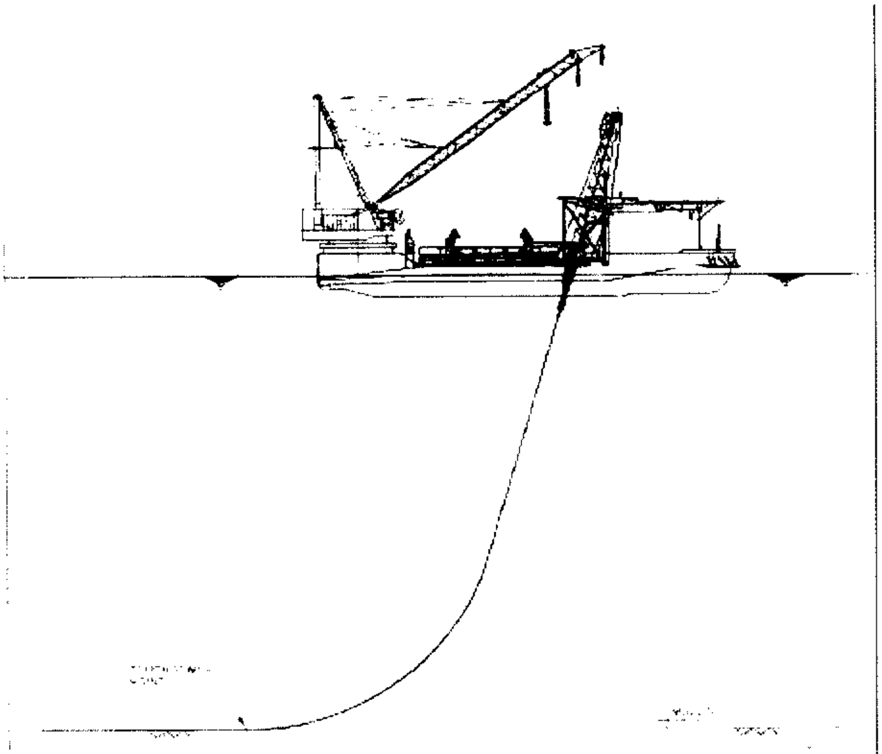
The likelihood of a pipeline failure event from impact depends on a number of factors including location of pipeline with respect to geological features, water depth, marine traffic, commercial fishing activity and proximity to other oil and gas field developments. Deepwater and shallow water pipelines share some common risks, however there are risks that are somewhat exclusive to deepwater pipelines and risks that are somewhat exclusive to shallow water pipelines as well. Shallow water pipelines, for instance, are more prone to damage by the commercial fishing activity and oil and gas industrial activity. These pipelines are located closer to shore and in prime fishing and industrial areas. Pipelines are a target for objects such as trawls, anchors, jackup legs, and spud barges. The industry requires Gulf of Mexico pipelines in less than 200 feet of water to be buried 3 feet below the natural sea floor to reduce the risks of inadvertent pipeline damage from these sources. Pipelines in deep water are less likely to be affected by this activity since there is little hazard from fishing activity in deep water. The oil and gas industry also poses less risk to deepwater pipelines because the use of anchors is seldom, if even practical, in deep water, and there is physically less activity than in shallow water. Construction activity also poses less risk in deep water since many deep water vessels are capable of dynamic positioning (DP). The use of DP eliminates the requirement of mooring the construction vessel with anchors. The elimination of anchors in the construction spread reduces the likeliness that an existing pipeline will suffer from impact damage during field construction.

Natural disasters including events such as storms, earthquakes, mudslides, and bottom currents, pose a threat to pipelines in both shallow and deep water. Due to the extensive oceanographic, geophysical survey data and geotechnical survey data and research available for the Gulf of Mexico, the likeliness, frequency, and magnitudes of many natural disasters can be predicted with reasonable accuracy for the life span of a pipeline. Pipelines can be designed such that there is minimal chance of damage by natural disaster during the design life. There are certain phenomena specific to deepwater such as loop currents that until recently have not been well understood. As operators move more into deep water, the necessity of gathering information will allow an increasing understanding of natural disaster potentials in the deepwater Gulf of Mexico.

Operational error can be attributed to events such as upsets in pipeline control systems or human error that causes pipelines to operate outside design parameters. This may include pressure extremes, temperature extremes, or flow rate extremes. Operational errors are generally rare and occur randomly. This is the result of well developed industry standards, industry practices, and regulation applicable to all OCS operators. Deepwater pipelines are no more or less susceptible to operational errors than shallow water pipelines, therefore the natural cycle of continuous improvement of standard industry practice is the primary mechanism for their prevention.

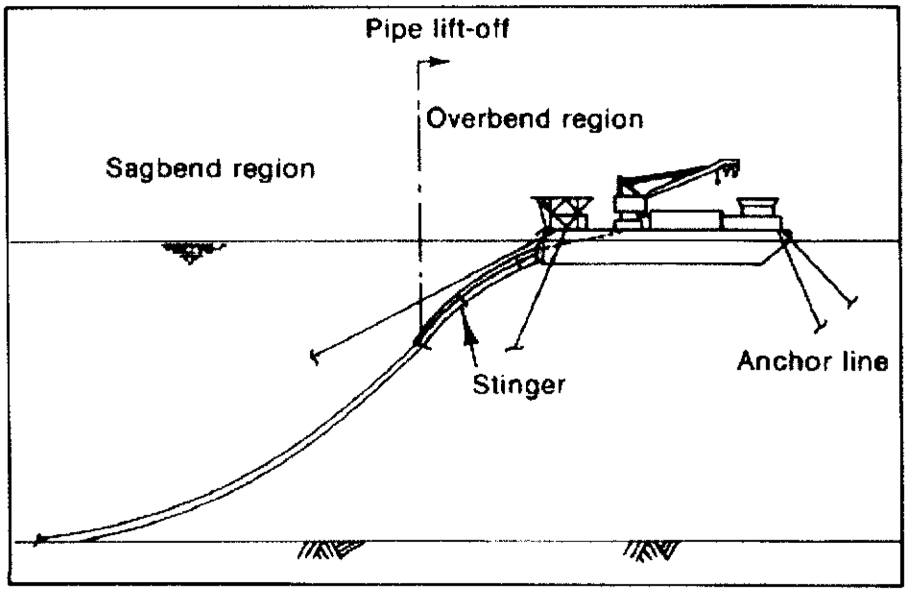
Both external and internal corrosion control of deepwater and shallow water pipelines follows the same principles. There are some considerations that are unique to deepwater pipelines that may be the result of environmental conditions such as low ambient temperature. External and internal corrosion protection systems can be designed to accommodate the deepwater environment. Generally corrosion failure of a submarine pipeline is a random event and occurs mainly on risers in the splash zone area. Deepwater pipelines are no more or less susceptible to corrosion failure that shallow water pipelines.

The track record suggests that risk of deepwater pipeline damage is greatest during pipeline construction. Great care is taken by the contractor and insisted upon by the owner / operator during the installation of both shallow water and deepwater pipelines to maintain fundamental parameters such as pipe profile and pipe tension within design limits. The installation of deepwater pipelines and associated systems such as steel catenary risers (SCRs) can be more sensitive to fluctuation in fundamental installation parameters thus requiring a narrower margin for error. This can increase the likelihood of damage to deepwater pipelines during an installation upset. The industry has responded to these challenges by utilizing different methods for deepwater installations such as J-lay and remote tie-ins as well as further refining and adapting existing shallow water procedures for deep water applications.



Installation of a Deepwater Pipeline by the J-Lay Method
(Source: PCS Archive Sketch)

Proper design of deepwater pipelines can minimize the risk of damage during installation and operation, however deepwater pipelines are susceptible to damage throughout their design life as with shallow water pipelines. The oil and gas industry must have methods and procedures to repair damages to deepwater pipeline to ensure reliable operation. Therefore, deepwater pipeline repair equipment to must exist to execute these procedures.



Conventional S-Lay Installation Method for Offshore Pipelines
(Source: A. H. Mousselli, 1981)

HISTORY OF DEEPWATER PIPELINE REPAIR:

The origins of the deepwater pipeline repair industry were traced to several joint industry projects (JIPs) on diverless pipeline repair, the earliest of which dates back to 1973. The history of the deepwater pipeline repair industry began with early conceptual studies which resulted in ideas that would become reality years if not decades later. The companies responsible for conceiving and/or funding most of this early work were pipeline operators. The work later evolved into physical equipment development by pipeline end connector manufacturers and pipeline installation contractors. As can be seen in subsequent discussion, much of the deepwater pipeline repair technology originated as deepwater pipeline construction tie-in systems developed by contractors during specific pipeline projects. Today several alliances exist between pipeline operators, mechanical connector manufacturers, and pipeline installation contractors to develop and maintain deepwater pipeline repair systems.

The first known project to specifically address developing a diverless pipeline repair system was a JIP sponsored by Exxon and in 1973 with a total of 16 participants. The scope was to develop a system capable of repairing 36" concrete coated pipe at water depths to 4000 feet. The system was based on HydroTech hydraulically activated mechanical connectors with subsea work being done by large ROVs (remotely operated vehicles). This concept predated the later and now common technology of today's large work class ROVs. The project ended in 1977 with a report and no further work or equipment fabrication being done.[6]

[6] Mohr, H.O., "Table 1 Diverless Repair Systems," 1996.

Shell sponsored a JIP in 1974 with 6 participants having similar requirements as the Exxon JIP. The method proposed was completely different from the original Exxon method. The system consisted of a large catamaran type vessel that could be sunk to the sea floor over the damaged pipeline section. Once in place, the repair could be made with on board tools, equipment and pipe spools. The project ended in 1977 with a report and no further work or equipment fabrication being done.[7]

Statoil funded a project in 1977 performed by HydroTech and Oceaneering. The requirements were to repair 36" concrete coated pipe in water depths of up to 1500 feet. Statoil used the concept of the HydroTech pipe handling frame and mechanical connectors, and Oceaneering's WASP Atmospheric Diving System. Several pieces of equipment were designed and fabricated, however Statoil soon discontinued the project.

From the late 1970's into the early 1990's a combination of several private and JIP studies were performed as listed in Appendix 1. These projects were cancelled for various reasons before a complete system was developed. These project were successful in the sense that they laid the ground work for later projects that would eventually provide meaningful solutions to the deepwater pipeline industry. Several of these early projects resulted in the creation of some of the first tools that were specifically designed for use with deepwater pipeline repair. It is not a coincidence that the pioneering deepwater pipeline operators, Snam and Statoil, their contractors, and suppliers are major influences in the deepwater pipeline repair industry today. The experience gained from these early programs with deepwater pipeline repair tooling, methods, and procedures has been carried into the successful designs of today's deepwater pipeline repair systems.

INDUSTRY PARTNERSHIPS AND CONSORTIUMS

The Gulf of Mexico's initiation into the deepwater pipeline repair industry was a slow, complex process. In the early 1990's, relatively few deepwater pipelines existed in the Gulf of Mexico and the rest of the world. Gulf of Mexico pipeline contractors were continuing to improve, develop and adopt more sophisticated deepwater pipeline installation equipment such as dynamically positioned vessels, J-lay systems and an array of diverless subsea technology. Some of this technology had been available in Europe for some time. Major Gulf of Mexico pipeline contractors had limited experience in the development of deepwater pipeline repair technology. Vendors of pipeline connectors had established a strong foothold in proven diverless mechanical connection technology which was primarily used for deepwater pipeline construction. Several JIPs, sponsored primarily by foreign pipeline operators, had come and gone with results that were limited and incomplete . Pipeline operators recognized the need but had little economic incentive to invest in the development, construction and maintenance of repair specific deepwater technology or at least to invest in such a massive undertaking alone.

A way for operators to minimize their risk and limit financial exposure of developing pipeline repair systems is to form partnerships, alliances, or consortiums sponsored by one operator. These consortiums allow not only the share of economic incentives, they also allow the share of

[7] Ibid.

technology among the partners involved. Pipeline repair systems generally consist of permanent pipeline clamps or end connectors that require custom specifications depending on pipeline diameter and other operating parameters. Material and equipment lead time is generally the driving factor of pipeline repair scenarios since lost production revenue from pipeline damage can greatly outweigh the cost of the actual pipeline repair itself. The concept that existing pipeline repair consortiums have adopted is to warehouse the long lead items required to make a pipeline repair and make pre-arranged agreements with construction contractors for repair equipment. The operators who are members of the consortium typically hire a third party manager who is responsible for the purchasing, maintenance, testing, replacement and upgrading of the long lead repair items for use. The third party manager is also required to be continuously available for emergency repair situations and ready to ship appropriate equipment to the field.

R.U.P.E.

One of the first pipeline repair system related partnerships is the R.U.P.E Co-ownership Project. R.U.P.E. stands for Response to Underwater Pipeline Emergencies. Its origin intention is the support of diver assisted repair capabilities for offshore pipeline sizes ranging from 6" to 36". The R.U.P.E. project stemmed from a study by Tennessee Gas Transmission Company in 1977 on behalf of eleven domestic offshore gas transmission companies. Over the 23 years of existence, the R.U.P.E. project has grown to at least 22 participants including companies in Australia, Malaysia, Greece, Canada, and the United Arab Emirates. R.U.P.E. maintains an inventory to make pipeline repairs which includes the ability to make two (2) spool piece repairs and two (2) clamp repairs for each pipe diameter covered. To participate in the R.U.P.E. project, operators must purchase a percentage of the inventory based on the size and length of each pipeline eligible for repair. All operating cost are also shared among the co-owners based on percent of ownership. The R.U.P.E project has proven successful with time. Anywhere from 8 to 12 repair devices have been shipped from the R.U.P.E. inventory each year. Many of the shipped items are returned due to false alarms. R.U.P.E. remains open for any company to participate. The more participants, the more likely that inventory will be used and continuously updated. [8]

DeepStar

The DeepStar consortium is a major concerted industry effort in the Gulf of Mexico to address the development of new technology needed for all phases of deepwater development. DeepStar was initiated by Texaco in 1992 as a conceptual study of the feasibility of extended-reach subsea tie-backs. It was proposed that a substantial portion of the deepwater Gulf of Mexico could be covered by a finite number of gathering centers that flowed back 40 to 60 miles to shallow water production facilities.[9] It has become apparent over the last several years that the initial model for deepwater Gulf of Mexico development envisioned in 1992 is much different than what has actually occurred. The number of deepwater production facilities placed on top of compliant towers, spars and mini-tension leg platforms has reduced the required length of actual subsea tie-

[8] Mohr, H.O., "Contingency Pipeline Repair The R.U.P.E. Co-Ownership Project and Deepwater Pipeline Repair", 1997.
[9] World Oil, Deepwater Technology Archive, "Cooperative Efforts Needed for Deepwater Challenges," August 1998.

backs from what was originally anticipated. There are several deepwater subsea developments including Gemini, Pompano, Troika, Popeye, and Diana. However, the Shell Mensa tie-back, at 65 miles, is the only deepwater development that fits the original DeepStar design basis. DeepStar's mission statement is, "To encourage an industry worldwide cooperative effort focused on identification and development of economically viable, low-risk methods to produce hydrocarbons from tracts in up to 10,000 feet + water depth."[10] In order for DeepStar to significantly contribute to any future deepwater developments, they began looking at several different aspect of deepwater development that has expanded today to encompass six major areas with specific short term goals including:[11]

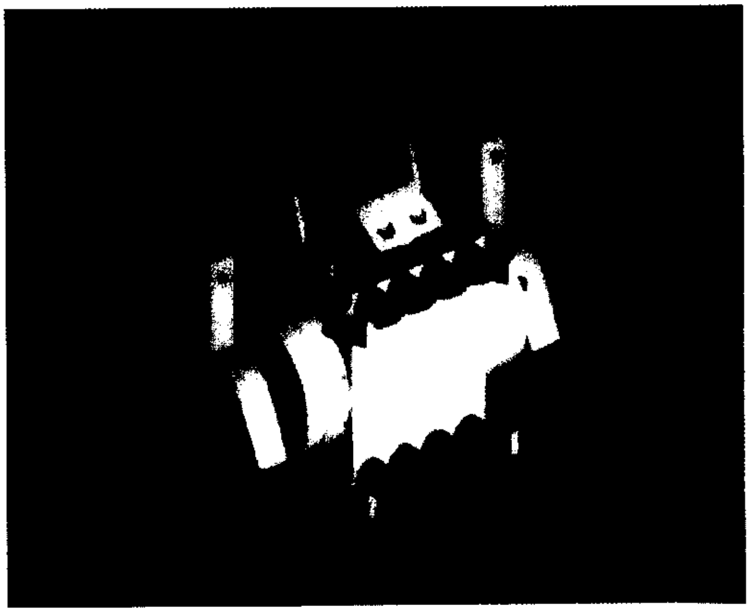
1) Regulatory: Get FPSOs into the Gulf of Mexico
2) Flow Assurance: Achieve bare-pipe extended reach technology capability to predict, prevent and remediate deposition in long offset, deepwater tie-backs
3) Subsea Equipment and Pipelines : Facilities for 60 mile tie-backs from 10,000 feet water depths
4) Vessels, mooring and risers: Floating (moored) drilling and production in 10,000 feet water
5) Drilling and Completions: Ultra-reliable, ultra-deepwater well installations
6) Oceanography: Provide full current data for the Gulf of Mexico

The DeepStar project is addressing deepwater pipeline repair though its Subsea Equipment and Pipeline Committee. The focus of DeepStar in pipeline repair is to provide a document that would allow the formation of a Deepwater Pipeline Repair Consortium with the interest of making diverless emergency pipeline repairs in the Gulf of Mexico. This document provides information such as the scope, likely participants, funding, administration, selection of a repair system, legal agreements, implementation and hurdles to overcome in forming such an alliance. The structure of this proposed alliance is modeled after several precedences including the R.U.P.E. project and lessons learned during trans-oceanic telephone cable repair projects. It is, however, focused on addressing concerns unique to the deepwater pipeline repair industry. The scope of this DeepStar study ends with the proposal of this alliance. It is left to the oil and gas industry to adopt this idea and put it into practice.

DEEPWATER PIPELINE REPAIR OPTIONS:

There are many possible repair solutions to a given deepwater pipeline damage scenario. Factors that influence the best solution in a particular situation include water depth, extent of damage, diameter of pipeline, proximity to end manifolds, risers, structures and other pipelines, geological features, and oceanographic environment. One possible repair solution is to relay the entire pipeline or the portion of the pipeline containing the damaged section. This solution is usually not the most practical since it generally requires a large pipe lay vessel or heavy lift vessel to retrieve the pipeline to the surface. New pipeline end tie-in(s) are also required. Pipeline repair clamps can also provide a repair solution contingent upon the damage area to be sufficiently small to be contained by the clamp. There are repair clamps on the market that can be installed by remote diverless intervention. Operators view repair clamps, particularly in deep

[10] Deepwater Technology, "DeepStar Technology Achievements," August 1999.
[11] Ibid.

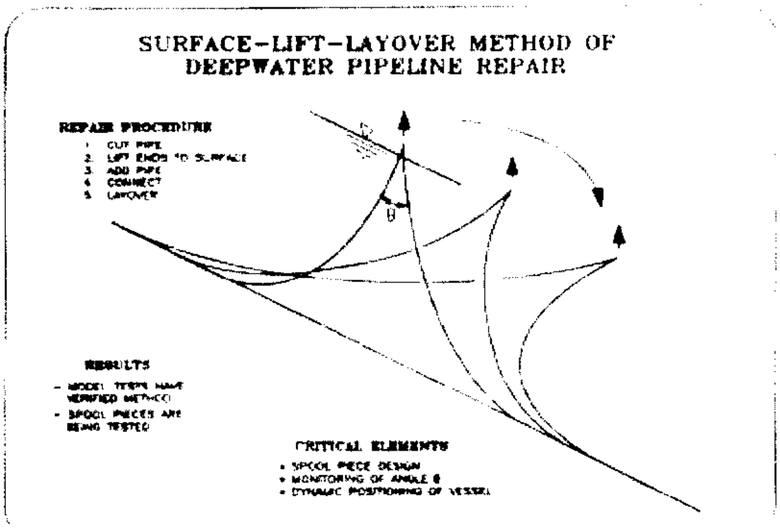


Diverless Pipeline Repair Clamp
(Source: HydroTech, 1999)

water, as a temporary solution to be used until a more permanent repair can be coordinated due to potential reliability and pipeline strength issues associated with repair clamps. Additionally, a repair method called Surface-Lift-Layover has been proposed for small diameter pipeline applications. Among several variations, the underlying concept is based on a mid point tie-in procedure that is adapted to pipeline repair assuming the damage section of the pipeline can be cut out and both resulting ends can be recovered to surface. On the surface, additional pipe is welded as required, the two ends are joined with a welded fitting, and the pipeline is returned to the seabed in a controlled lay over procedure. The resulting repair provides an all welded solution, however a heavy lift vessel is generally required to recover the pipeline ends in deep water.[12]

More sophisticated and potentially more flexible solutions that described above are currently being sought by pipeline operators and construction contractors. The fundamental concept involves removing the damaged section of pipeline and replacing it with a closing spool that is of equal or greater in strength than the pipeline. Many of these techniques have been simulated during dry testing and sea trials. Some of these techniques have been performed during diver assisted repair or surface recovery repair. There have been several diverless on-bottom construction tie-ins performed in the North Sea, but a remote diverless on-bottom repair is yet to be performed. The variations of these more flexible deepwater pipeline repair solutions are described further below.

[12] Langer, C., Presentation, Deepwater Pipeline & Riser Technology Conference, March 1999.



Surface-Lift-Layover Repair Method

(Source: C. Langner, 1999)

All of the deepwater pipeline repair development efforts worldwide from the 1970's until the present resulted in the development of several specific methodologies based around a common philosophy. These methods ranged from diver assisted repairs using manned atmospheric diving suits to completely diverless on-bottom repair. Each of the repair methods have their advantages and disadvantages. No one method is ideal for every situation. The underlying philosophy, however, is common to all methodologies with the universal implementation of highly adaptable modular systems capable of remote operation from the surface. It is also interesting to note how different cultural philosophies shaped the deepwater pipeline repair industry from one major oil producing region to another, namely from the Gulf of Mexico to Europe.

The world wide deepwater pipeline repair industry realizes that if pipeline damage were to occur in ultra deep waters, there are limited resources that could address a remote on-bottom diverless repair. If a pipeline operator, particularly in the Gulf of Mexico, develops no contingency plan with associated hardware on stand by, a worst case field production shut in for up to eight (8) months could result.[13] This is contingent on the fact that the only complete on-bottom diverless pipeline repair systems reside in Europe. The proposed mobilization time to the Gulf of Mexico presuming availability in addition to the time required to engineer, procure connectors and perform the repair are the primary contributors for such a delay. This worst case scenario has not occurred, however there are several Gulf of Mexico pipeline operators that are in partnership to limit the time required to complete a repair to one (1) month.[14]

Most of the deepwater pipeline "firsts" occurred in the Gulf of Mexico, and today, the Gulf of Mexico still has the deepest and largest number of existing and planned deepwater pipelines in the world.[15] The Gulf of Mexico has had many incidences of deepwater pipeline damage to date. There was generally little contingency and preparation done to address repairs for the particular pipelines that were damaged. The repairs were either completed during the duration of the

[13] Riley, J., BP Amoco, Personal Interview, November 1998.
[14] McCalla, J. M., Shell Deepwater Producing Inc., Telephone interview, April 2000.
[15] Mohr, H. O., "Need Organized Capability for Deepwater Pipeline Repair," Offshore, March 1997.

construction project or immediately after, and the repair solutions did not require completely on-bottom repair procedures. Due to these incidences, the oil and gas industry in the Gulf of Mexico have become keenly aware of the risks for potential remote on-bottom repair requirements. This awareness has pushed the industry into the development of more complete repair systems for deepwater pipelines.

The first European diverless pipeline repair system began to appear in the early 1980s, much earlier than in the Gulf of Mexico. There were relatively few deepwater pipelines in Europe as compared to the Gulf of Mexico, and the majority of these pipelines began appearing in the early to mid 1990s. Since the early 1990s, more complete and sophisticated on-bottom diverless pipeline repair systems have existed in Europe, almost a decade before these capabilities were to become available in the Gulf of Mexico.

The early development of these European deepwater pipeline repair systems is related to the heavy dependence on hyperbaric welding performed in the North Sea. Hyperbaric welding is used extensively in Europe in both pipeline construction activities and pipeline repair activities. Hyperbaric welding is used in the North Sea extensively for mid-line construction tie-ins and other construction related activities. European operators prefer the hyperbaric welding tie-in method over flanged tie-ins making it the most technically desired subsea connection by European operators. Additionally the market is competitive enough to support several hyperbaric welding contractors in this region. European pipeline contractors have used hyperbaric welding frequently enough to make this method cost effective.

Hyperbaric welding is a procedure that allows a diver to make an on-bottom weld to a pipeline within a dry habitat constructed around the tie in point. The habitat contains mixed gas at the hydrostatic pressure of the surrounding water to establish and maintain a dry environment on the sea floor. The pipeline ends are prepared and aligned and the diver welds the pipeline. The result is an all welded pipeline with no mechanical connections such as flanges. As the concept of deepwater pipelines was introduced, it became apparent that the depth at which hyperbaric welding could be performed was limited by the requirements of saturation diving and, in some cases, the welding procedure itself. It was realized that pipelines installed beyond the reach of divers would require an alternative to hyperbaric welding to complete an on-bottom repair. Thus the focus of the European deepwater pipeline repair industry was and always has been on a completely diverless on-bottom repair system. Knowing the challenges of developing a system capable of repairing any pipeline size at any water depth, several European pipeline operators including Snam, Statoil, and Norske Hydro have diligently pursued this goal during the last two decades. This pursuit has yielded the worlds first successful diverless on-bottom pipeline repair systems based on mechanical pipeline end connectors. These successes have only come recently and most of the systems have yet to be tested in an actual repair situation.

Shallow water tie-ins and repairs are performed differently in the Gulf of Mexico than in Europe.
Resident Gulf of Mexico contractors have had little experience in performing hyperbaric welded tie-ins. Therefore, most of the midline tie-ins in the Gulf of Mexico were performed by divers using conventional ANSI or API flanged connections welded to pipeline ends after lifting to the surface. Risers were typically installed by the "stalk on" method or by flanged spool pieces using diver assistance. The repair methodology employed by the developing Gulf of Mexico

deepwater pipeline repair systems are modeled after shallow water methodologies. Typical deepwater repair procedures in the Gulf of Mexico rely on pipeline end surface lifts to allow access to the pipe for welding. Various mechanical end connectors or pipeline end skids are welded on to the pipeline end at the surface and connected by diverless intervention. This method has been successfully used in many deepwater pipeline installations as well as some deepwater pipeline repairs. A remote on-bottom repair system is being developed by Shell in a partnership with several Gulf of Mexico pipeline operators. This system is scheduled for completion by August 2000.[16]

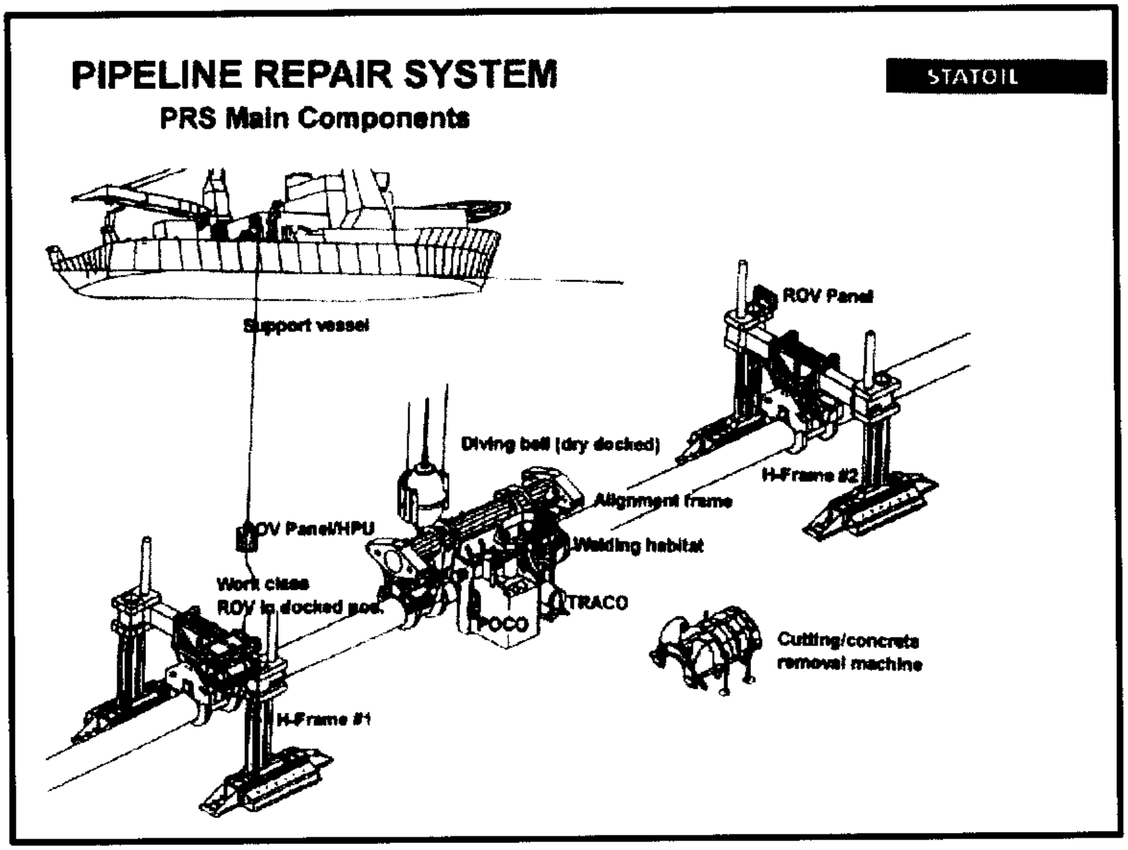
A broad array of deepwater pipeline repair alternatives are becoming available to pipeline operators world wide. Due to the many possible pipeline damage scenarios, there is currently no method of deepwater pipeline repair that is ideal in all situations. This is particularly true in the Gulf of Mexico where, until recently, there was no one company capable of a completely remote on-bottom diverless pipeline repair. The technology fundamental to the support of deepwater pipeline repair systems, such as ROVs and subsea systems, is maturing enough to encourage the rapid development of new repair systems. For example, there are trends with the development of new pipeline tie-in equipment to move away from mechanical connectors and towards simple flange connections. European contractors have begun to integrate pipeline repair equipment with diverless flange tie-in equipment to provide an additional remote diverless on-bottom repair solution.

STATOIL DEEPWATER PIPELINE REPAIR SYSTEM:

Statoil has been involved with the development of a dedicated pipeline repair system since 1987. This original system was designed to cover approximately 1000 km of pipelines that were a part of Norske Hydro's Oseberg Transportation System and Statoil's Statpipe system. This original system was a hyperbaric welding based, on-bottom pipeline construction tie-in and repair system with a water depth limitation of 1,200 feet sea water. This original pipeline on-bottom repair system was comprised of a concrete removal and pipe cutting machine, H-frames for lifting and handling up to 20" diameter pipe on-bottom, and a welding habitat for on-bottom hyperbaric welding. Additional equipment supporting the system include pipeline repair clamps with installation frame, high pressure isolation plugs, a pipeline recovery tool, and excavation system.[17]

As pipelines in the North Sea gradually began expanding into deeper waters, it became apparent that a pipeline tie-in and repair system would be required to address these greater depths. A program was initiated in 1993 to develop a deepwater Pipeline Repair System (PRS). It was realized that the deepwater PRS must be a diverless system. Diverless hyperbaric welding was considered and continues to be investigated to the present. It was realized that a new pipeline end connection system would be required based on diverless mechanical connectors. These mechanical connectors were designed to provide a connection as strong as the pipe and to have a design life of 50 years. Additional requirements for the connector included remote installation

[16] McCalla, J. M., Shell Deepwater Producing Inc., Telephone interview, April 2000.
[17] Styve, K., "Pipeline Contingency Considerations for Pipeline Repair in Deep Water," Deepwater Technologies & Development Conference, November 1999.



First Statoil Pipeline Repair System (PRS)
(Source: Offshore Pipeline Technology Conference, February 26-27, 1997)

capability and the ability to be installed on-bottom on a bare pipeline end with no special pre-welding preparation requirements. By 1995 a 6 inch prototype and two (2) full scale 16 inch Morgrip diverless connectors were developed by Hydra-Tight, Ltd. In 1996 a 16 inch Morgrip connector was successfully installed during the construction of the Haltenpipe pipeline as part of a diverless mid-line tie-in. The system was limited to on-bottom pipeline tie-ins and repairs in diameters of roughly 20 inches or less. The system was designed for tie-ins and repairs in water depths up to 1,970 feet sea water. By early 1997, Statoil announced that the company will phase out planned diver intervention operations wherever possible. With the North Sea limit of diver intervention at 1,200 feet sea water, Statoil began to further develop diverless technology with the purpose of eliminating planned diver interventions at water depths deeper than 590 feet sea water.[18,19,20]

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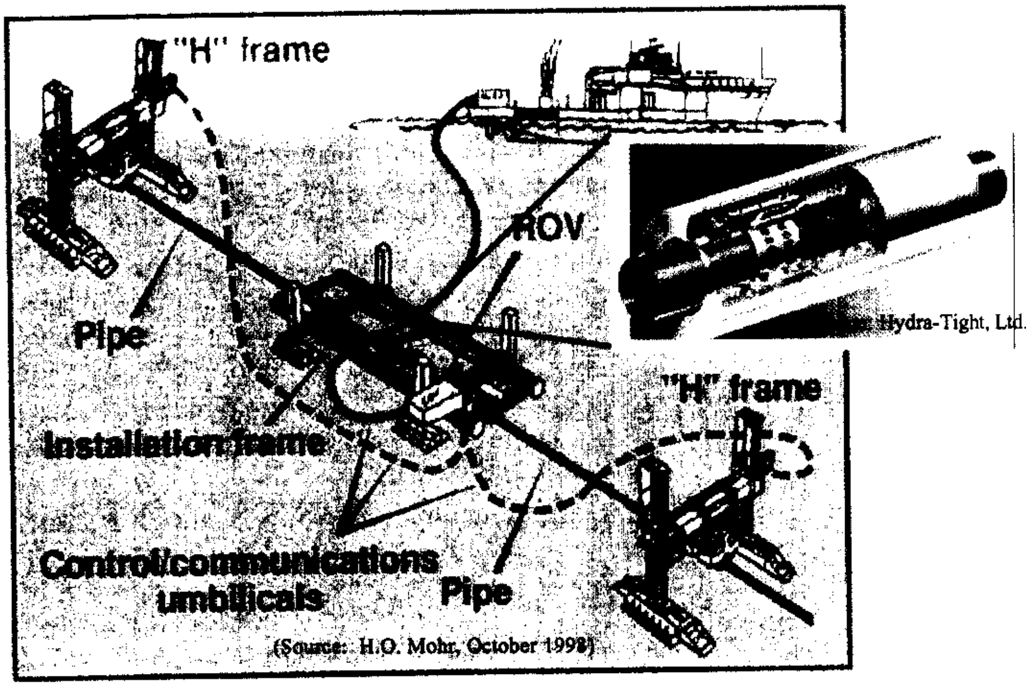
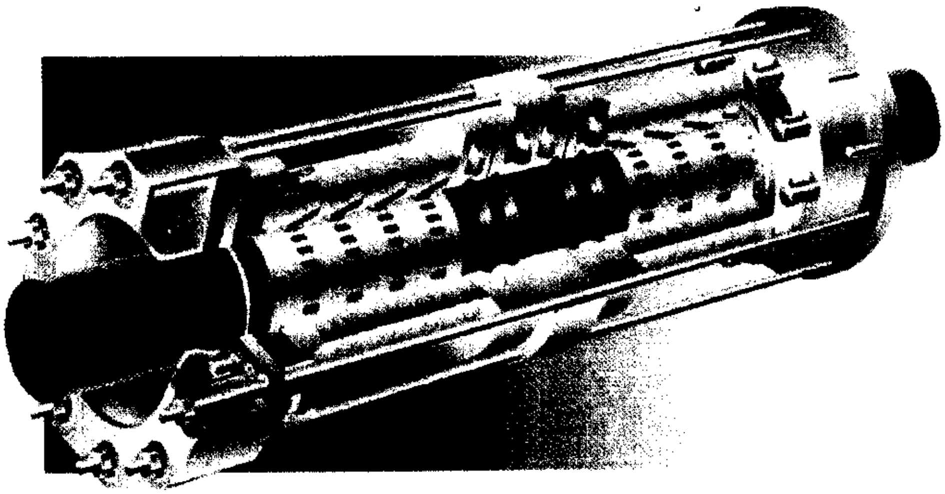
[18] Ibid.
[19] Styve, K., "From Diver Assisted to Diverless Technology," International Gas Union, World Gas Conference, 1997.
[20] Maxted, P., Telephone interview, February 2000.



Current Statoil Pipeline Repair System (PRS) with the First Morgrip Remote Series Mechanical Connector

Since the inception of the PRS, three (3) European companies are participating in the pipeline repair system including Statoil, Norske Hydro, and Phillips Petroleum Company. An approximate total length of 7000 km of pipe is now covered by the PRS. Statoil is currently developing a diverless on-bottom pipeline repair system to handle up to 42 inch pipe in water depths up to 1,970 feet. The new system incorporates all of the components of the existing Statoil system but adds the necessary features to handle the larger diameter pipelines. Hydra-Tight has recently delivered 12 inch, 20 inch, and 42 inch Morgrip connectors for pipeline tie-ins. These connectors are stored and maintained at Hydra-Tight's facilities in the U.K. in a state of constant readiness. Oil States HydroTech has also recently delivered a 42 inch diverless pipeline repair clamp. The major components in the pipeline repair system include two (2) hyperbaric welding habitats, six (6) H-frames for lifting and handling pipe on the sea floor, two (2) Morgrip installation modules, and a high pressure abrasive water jet system for cutting pipe, concrete coating removal, and corrosion coating removal. The H-frames consist of three sets for handling different size pipe or different repair scenarios. There are two (2) very large H-frames each weighing 70 tons that can be used to lift up to 48 inch concrete coated pipe from the sea bed. An additional set of H-frames capable of handling pipe up to 42 inches is recently developed in a more compact, lighter format for more portability and flexibility with installation vessels. The two (2) Morgrip modules also address different size pipe. The original module used on Haltenpipe can handle Morgrip connectors between 10 inch and 20 inch. The new module currently under development will handle Morgrip connectors from 20 inch to 42 inch. Statoil's tool of choice for pipe cutting, concrete coating removal, and corrosion coating removal is the high pressure abrasive water jet system. The system is selected because it is capable of performing these three functions using one tool.

North Sea Pipeline System Covered by the Statoil Pipeline Repair System
(Source: M.Vik, Statoil, 2000)



Morgrip 3000R Mechanical Connector (Smaller and Lighter than Original Remote Series)
(Source: Hydra-Tight, Ltd., 1999)

This system is unique because other pipeline repair systems, particularly in the Gulf of Mexico, rely on two or three distinct tools to perform these tasks[21,22]. Additional tooling including high pressure pipeline isolation plugs, pipeline recovery tools, and pipeline repair clamps are used in conjunction with the pipeline repair system. These tools are used to aid in construction and repair operations. The high pressure isolation plug, provided by Pipeline Integrity International/Tecnomarine, is a pigging tool used to temporarily isolate pressure in one part of a pipeline from the other. The tool resembles an ordinary pig and is deployed and recovered through the pig launching and receiving system of a pipeline. The isolation plug can be used in maintenance situations such as during pipeline valve repair or maintenance, in some cases without disturbing production. Pipeline recovery tools are provided by various suppliers and has been developed for use mainly during pipeline construction as a contingency in the event of a wet buckle. Pipeline repair clamps are regarded by Statoil as a temporary repair used to minimize production loss until a more permanent type of repair, such as hyperbaric welded or mechanically connected spool piece repair, can be planned and executed. It is important to note that each of these tools are pipe diameter dependent which means that a special tool is required for each pipeline diameter to be serviced.[23,24]

[21] Styve, K., Telephone interview, March 2000.
[22] Styve, K., Hamre, S., Vartdal, K., and Milford, G., Personal interview, April 2000.
[23] Styve, K., "Pipeline Contingency Considerations for Pipeline Repair in Deep Water," Deepwater Technologies & Developments, Norway, November 1999.
[24] Styve, K., Email, April 27, 2000, 14:34.

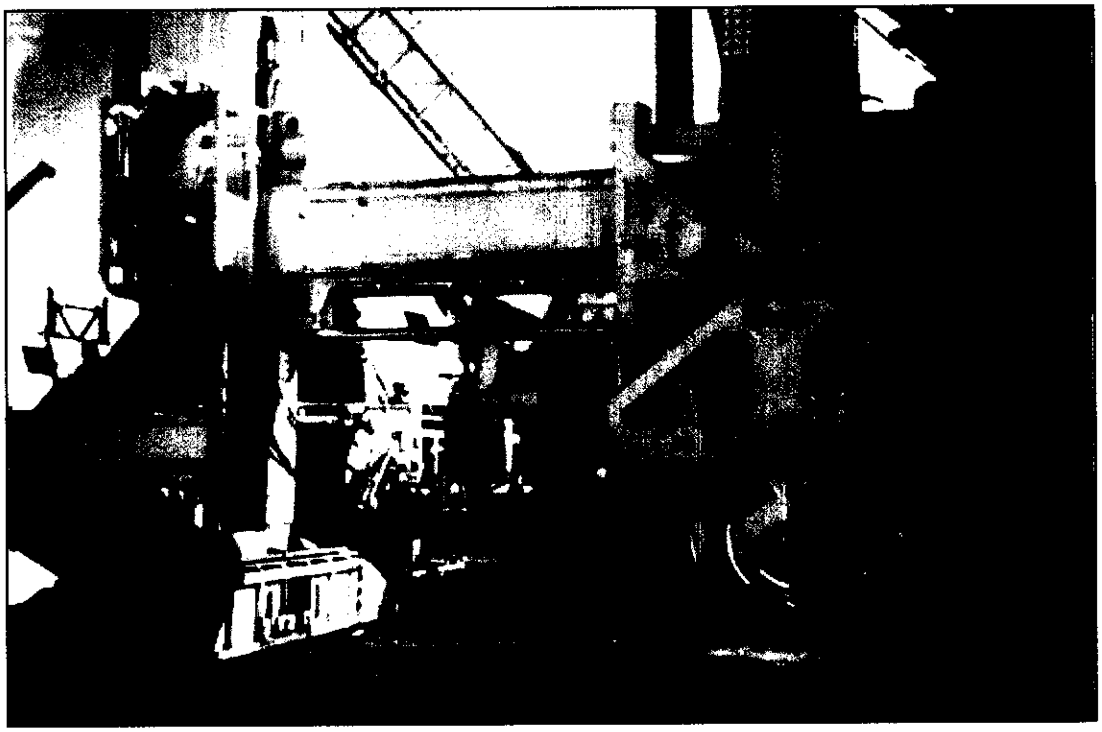
Elevation and End Photograph of 42" Morgrip Connector at Statoil Facility, Haugesund, Norway, April 2000
(Source: PCS Archive Photograph Reprinted by Permission of Statoil, 2000)

There are developments in the North Sea currently planned in water depths from 2,620 feet to 3,940 feet. Statoil realizes the necessity of expanding the capabilities of the pipeline repair system to accommodate these water depths from both a construction and emergency repair standpoint. The Statoil pipeline repair system is currently the only working on-bottom diverless repair system that has been proven in during actual subsea construction. This system also covers the widest range of pipeline diameters which include 10 inch pipelines to 42 inch pipelines. System components are operated on a regular basis since the pipeline repair system is also designed for pipeline construction projects. One of the disadvantages of the Statoil PRS is the size of some of the components such as the H-frames which have limited deployment vessels to only the worlds largest derrick barges. Upon completion of the newer H-frames and other upgrade equipment, due by the end of 2000, the Statoil PRS can achieve additional portability.[25,26,27]

Statoil PRS Components: New 42" H-Frame
(Source: PCS Archive Photograph Reprinted by Permission of Statoil, 2000)

[25] Knott, D., "Diverless Tie-In Tool Gets First Test on Deepwater Line," Oil & Gas Journal, March 24, 1997
[26] Styve, K., Telephone interview, March 2000.
[27] Styve, K., Hamre, S., Vartdal, K., and Milford, G., Personal interview, April 2000.

Statoil seeks collaboration with other oil companies to share in the development of deeper on-bottom diverless pipeline repair technology. The Statoil Pipeline Repair System has been presented at several conferences in Europe and the United States. Statoil has also had meetings with several companies operating offshore in Europe to discuss possible participation in the Pipeline Repair System. Oil companies operating in the deepwater Gulf of Mexico are aware of the Statoil PRS and have considered the system for use. Domestic operators, however, have expressed reservations about participating in the system due to its large, heavy lift vessel requirements and logistical factors required to mobilize the system to the Gulf of Mexico from Europe. Only within the last several months has formidable diverless on-bottom pipeline repair technology become immediately available in the Gulf of Mexico, however most of this technology still remains to be proven. These new repair systems may offset the need for the Statoil PRS for all but the largest pipe diameters in the Gulf of Mexico. [28,29,30]



Large H-Frame with 48" Pipe Handling Capability
(Source: PCS Archive Photograph Reprinted by Permission of Statoil, April 2000)

[28] Styve, K., "Pipeline Contingency Considerations for Pipeline Repair in Deep Water," Deepwater Technologies & Development Conference, November 1999.
[29] Riley, J., Personal interview, November 1998.
[30] Preli, T., Shell Deepwater Producing Inc., Telephone interview, March 2000

SNAM / SONSUB DEEPWATER PIPELINE REPAIR SYSTEM:

Snam, the Italian gas pipeline transmission company of the ENI Group, shared a similar history driving the development of deepwater pipeline repair systems as other European and Gulf of Mexico pipeline operators. The traditional intervention technique to repair subsea pipelines was the use of hyperbaric welded replacement spool pieces. Snam recognized that the maximum practical depth to perform hyperbaric welding is 1,300 feet sea water, beyond which results in compromises in the weld quality. Since qualified welder / divers must perform the complex tasks in completing the hyperbaric weld, further depth limitation is imposed. The maximum safe water depth at which planned intervention can be performed was established at 650 feet sea water within the last few years. The technology of hyperbaric welding also has commercial limitations in that few contractors in the world are capable of performing the procedure. This work can also be relatively expensive in relation to other subsea options. Given these constraints surrounding the use of hyperbaric welding, pipelines that are installed in depths greater than 650 feet must rely on alternate means of repair, maintenance, and construction intervention. Snam is aware of these issues and has been working over two decades on he development of a cost effective, reliable means of deepwater pipeline repair.[31]

Snam looks upon the components of a deepwater pipeline repair system as divided into two major categories: the connection system and the installation system. The connection system consists of all components required to replace the damaged pipeline section and becomes a permanent part of the pipeline upon completion of the repair. The installation system consists of all tooling required to prepare and handle the pipe as well as to install the connection system. The installation system is generally reusable. Connection system components are traditionally mechanical type pipeline end connectors, which have existed well before any diverless installation components became available. The original markets for these connectors include primarily shallow water applications where diver intervention is possible.[32]

Original installation components were developed based on a radically different philosophy than that which exists today. This philosophy was a product of the available subsea technology that existed at the time. During the late 1970's and early 1980's few ROVs were available and they were inspection class vehicles only. The operability and reliability of this new technology did not accommodate pipeline construction project requirements. The first pipeline construction and repair systems were developed as autonomous installation systems in the SAS (Submarine Automatic Station) project, which typically performed primary tasks as well as secondary tasks that, today, are normally performed by ROVs. This repair system consisted of fourteen modules, ten of which operated subsea. These autonomous systems tended to be highly complex, specialized and diameter specific with little possibility of adaptation to other purposes. The high development costs, maintenance expenses, and the relatively few critical deepwater pipelines further inhibited these systems from commercial development through the late 1980s. In the 1990's, ROVs became a formidable pipeline construction and repair force due to increased

[31] Vienna, A., "The evolution of repair systems for deepwater gas transmission sealines," Snam S.p.A, April 1997.
[32] DiNoto, F., Gallazzi, L., and Vienna, A., "A.R.CO.S.: A Diverless Pipeline Repair System Ready to Go Offshore," Offshore Mediterranean Conference, March, 1999.

reliability and the availability of "work class" units. Out of necessity, pipeline repair system philosophy began to evolve from complex autonomous installation/repair systems to simpler discrete ROV operated components. This allowed components to be more flexible and the complete system more adaptable to more varied applications.[33]

The first trans-Mediterranean pipeline system was installed from Tunisia to Sicily in 1978 by the Trans-Mediterranean Pipeline Company (TMPC) a subsidiary of Snam, crossing the Mediterranean Sea in water depths of 1,970 feet. Three 20" gas pipelines were initially installed making these pipelines critical high volume systems carrying gas from North Africa to Europe. In the early 1980's, Sonsub developed the first pipeline repair system. This "first generation" autonomous system provided the deepwater pipeline repair contingency for these pipelines. The entire system of 14 modules was diameter specific to 20" pipe. In 1993 two 26" Trans-Mediterranean gas pipelines were installed near the existing 20" pipelines. A completely new 26" repair system was proposed. A simple scale up of the 20" system to a 26" system produced a design that was roughly twice the weight of a 20" system and did not meet all of the repair system requirements. This realization provided the catalyst to substantially change the philosophy of deepwater pipeline repair methods. The new philosophy developed during this period laid the foundation of the modern pipeline repair systems. Key points included a robust connection system that could take advantage of an installation system based on simple ROV actuated commercially available tools instead of a complex dedicated autonomous installation system. The design of a diverless intervention end connector was considered the most critical item of the connection system. The design of the X-Loc™ connector was based on mechanically forging a connector to the pipeline ends. The connector was designed for diverless installation and actuation. It was fitted on a telescoping spool piece that expanded to meet the pipeline ends. The telescoping joint was locked and sealed with similar water forging technology as the X-Loc™ end connectors.[34]

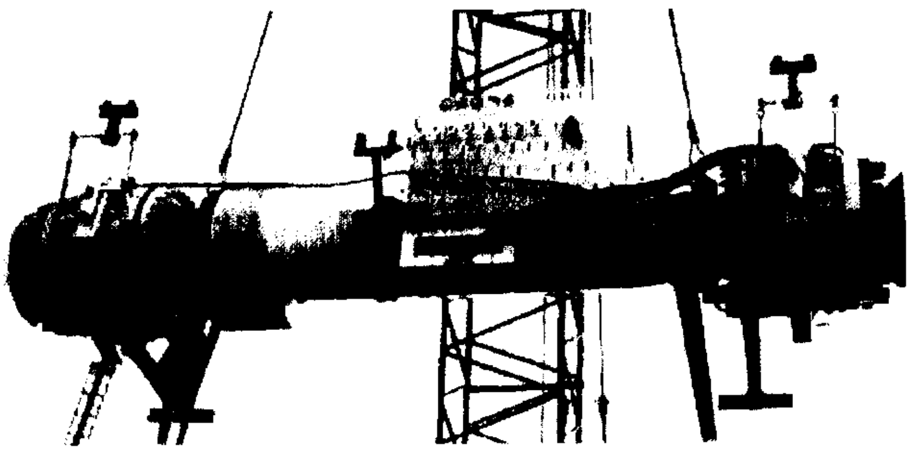
A system of ROV actuated subsea pipeline repair tools called AROWS or Advanced Remotely Operated Work Systems, was developed by Sonsub to perform the tasks required to prepare the pipeline ends and install the telescoping closing spool piece. The main components of the AROWS consist of two (2) H-frames for on-bottom pipe manipulation, water inflatable jacking bags for initial pipeline elevation, pipe support trestles, underwater winches and bollard clump weights for manipulation of pipe and AROWS component manipulation, air bags for repair spool buoyancy, pipe cutting equipment, end preparation equipment, and an excavation system to provide access for tools under the pipeline. The key component of the original system was the X-Loc™ connector around which much of the AROWS tooling was focused. The first sea trials for the 20" / 26" system occurred in 1993 off the coast of southern Italy on a short section of 26" O.D. x 1" W.T. pipe laid in 980 feet sea water. These initial sea trials revealed problems in multiple system components including subsea winch systems and water inflatable jacking bags. The problems encountered during these early sea trials were primarily the result of internal directives not to test individual system components before sea trials commenced and lack of lead time to procure the proper components. The results of these sea trials, although not completely successful allowed Sonsub to proceed with the development of the "low force" pipeline repair

[33] Vienna, A., "The evolution of repair systems for deepwater gas transmission sealines," Snam S.p.A, April 1997.
[34] Venzi, S., Brambilla, M., and Gallazzi L., "Diverless pipeline line repair system passes early trials", Pipe Line Industry, June 1993.

system concept. This continued development led to the later D.S.R.S. (Diverless Sealine Repair System) and A.R.CO.S. concepts.[35]

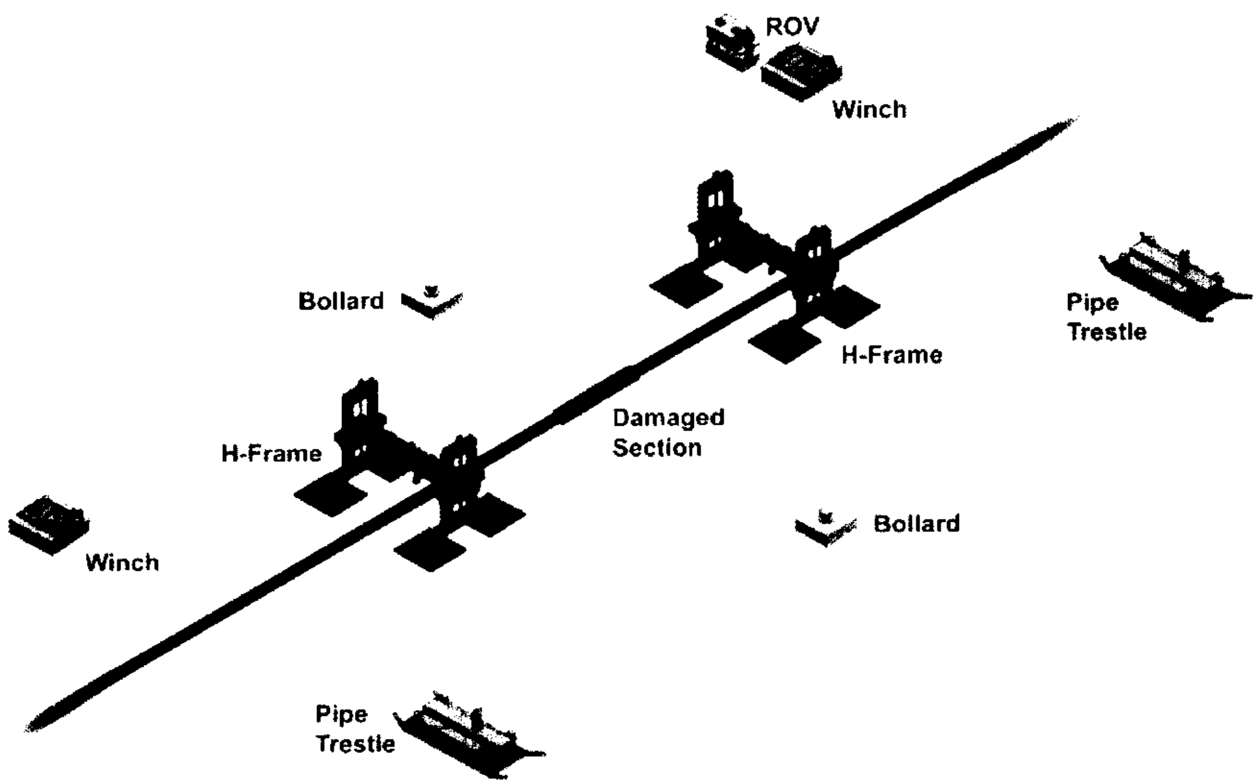
The D.S.R.S., Diverless Sealine Repair System, first appeared under this name in 1995. The system underwent shallow water trials offshore southern Italy in 1995 and in Stavanger, Norway in 1997. These shallow water trials resulted in further improvements to the pipe lifting components and spool installation module of the D.S.R.S. The components that make up the D.S.R.S. continue the AROWS philosophy of ROV operated low force tooling to complete a deepwater pipeline repair by diverless on-bottom remote intervention. The D.S.R.S. was developed to address the repair contingency for the 20" and 26" Trans-Mediterranean pipelines using the intervention of work class ROVs. The system was originally designed around the X-Loc™ mechanical pipe connectors that were mechanically forged to the pipeline ends. A telescoping spool piece that mated to the X-Loc™ connectors provided the closing spool to make the repair. The typical repair scenario that the D.S.R.S. is designed to handle is based on an isolated section of pipeline being damaged. The D.S.R.S. is designed to remove the damage section and replace it with a spool piece that is equal in strength to the pipeline. The typical sequence of this type of repair is described as follows:[36]

The pipeline damage is first located with ROVs that use visual cameras for exposed pipeline and pipe trackers for buried pipelines. The damage section of the pipeline is excavated as required to allow access for repair tooling. Then repair equipment is lowered to the sea floor and positioned to begin repair tasks. The damaged section of pipe is then cut out using a diamond wire cutting machine. The pipeline ends are then prepared by removing concrete coating, corrosion coating and preparing the pipe end bevels as required. Mechanical end connectors are installed onto the prepared pipeline ends, and measurements between the ends are taken for closing spool fabrication dimensions. Once the closing spool is fabricated to the proper dimensions, the spool piece is installed and tested. The tools are then recovered from the work site.



Sonsub D.S.R.S. X-Loc Spool
(Source: G. D'Aloisio and B. Lådegard, Sonsub, 1998)

[35] Ibid.
[36] True, W.R., Deepwater pipeline-repair system deployed to Mediterranean, Oil and Gas Journal, November 16, 1998.



Sonsub DSRS Components
(Source: G. D'Aloisio and B. Lådegard, Sonsub, 1998)

All on-bottom pipe handling is accomplished through the use of H-Frames, subsea winches, and subsea bollards. The H-frames are designed to lift up to 36" concrete coated pipe with a vertical lifting capacity of 30 tons. The H-Frames are capable of a vertical stroke of 7'-6" and a horizontal stroke of 8'-2". The H-Frames are used to lift the pipe off the sea floor and position the ends for connection with the repair spool. The weight of the H-frames in air is 16 tons each. The subsea winches are capable of horizontal pull of up to 5 tons and have a weight in air of 13 tons. These winches are designed to horizontally position the pipeline on the sea floor as well as position installation equipment on the sea floor as required to make the repair. Water inflatable pipe trestles are used to assist the H-Frames in lifting of the pipeline and to provide the proper break-over alignment required for spool piece installation. The pipe trestles have a vertical lift capacity of 22 tons.[37]

[37] Chiesa, G., Baldini, G., Hettinger, F., and Peterson, J., Personal interview, October 1998.

Sonsub D.S.R.S. H-Frame
(Source: G. D'Aloisio and B. Lådegard, Sonsub, 1998)

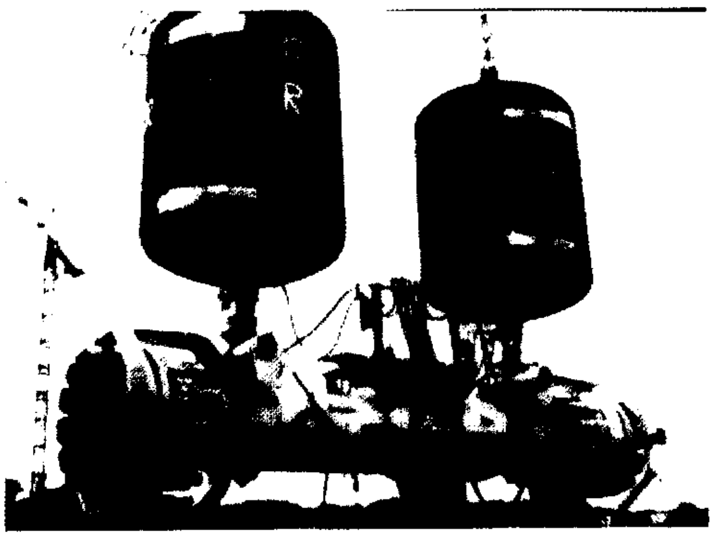
The diamond wire cutting machine is designed to cut pipe on-bottom up to 36" in diameter. The cutter is ROV operated and relies on a single diamond wire to cut the pipe. Once the pipeline is cut, pipe end preparation tools are used to prepare end bevels and the pipe surface to allow proper installation of a mechanical pipeline end connector. A dedicated metrology tool based on the taut wire method is used to determine the relative position and orientation of each pipeline end with respect to each other. The tool is capable of an accuracy of 8 inches linear and 0.5 degrees angular misalignment. The repair spool piece replaces the damaged section of pipeline cut out by the diamond wire cutter. The spool piece consists of a telescoping joint and two misalignment ball end connectors that mate the pipeline end connectors together. The spool end connectors are capable of up to 7 degrees of misalignment. As the spool piece is installed, the telescoping joint is extended to allow mating of the pipe hubs and spool end connectors to complete to the repair.[38,39]

The A.R.CO.S. (Attrezzature per la Riparazione di Condotte Sottomarine – Equipment for Sealine Repair) system is an integration of the diverless connection system developed by Snam and D.S.R.S. installation tooling developed by Sonsub and Saipem. The same "low force" philosophy from D.S.R.S. is applied to the A.R.CO.S. system. The tasks of an on-bottom diverless pipeline repair are broken down into simple activities that can be accomplished using ROV actuated tooling. The tools are designed such that they can be operated for different tasks

[38] Ibid.
[39] True, W.R., "Deepwater pipeline-repair system deployed to Mediterranean," Oil and Gas Journal, November 16, 1998.

independently from the rest of the system. The advantage of this approach allows for future improvement of individual tools without requiring a redesign of the whole system as with the early autonomous on-bottom systems. The A.R.CO.S. system uses the concept of cold forging mechanical connectors onto the pipeline ends subsea and using the telescoping spool piece as the closing spool.

The A.R.CO.S. system underwent sea trials in Stavanger, Norway in May 1998. The trials were successful enough to claim the availability of a reliable diverless on-bottom pipeline repair system. The A.R.CO.S. system was designated as the permanent stand-by pipeline repair system for the Trans-Mediterranean sealines, which now include three 20" and two 26" pipelines.[40,41,42,43]



Telescoping Spool Piece with Snam Connection System
(Source: G. D'Aloisio and B. Lådegard, Sonsub, 1998)

The Innovator ROV is a work class ROV designed by Sonsub for use with the D.S.R.S./A.R.CO.S. installation and connection systems. The major systems and subsystems of previous designs have been upgraded to improve performance and reliability. The main improvements of the Innovator include the increase power output water depth rating. The hydraulic power output of the Innovator is upgraded to 150 horsepower, which is a 75% to 100% increase from its work class predecessors. The Innovator is rated for 11,500 feet sea water, down from 3300 feet sea water. The primary water depth limiting factor is the buoyancy material which consists of syntactic foam and macro-alloy spheres.[44]

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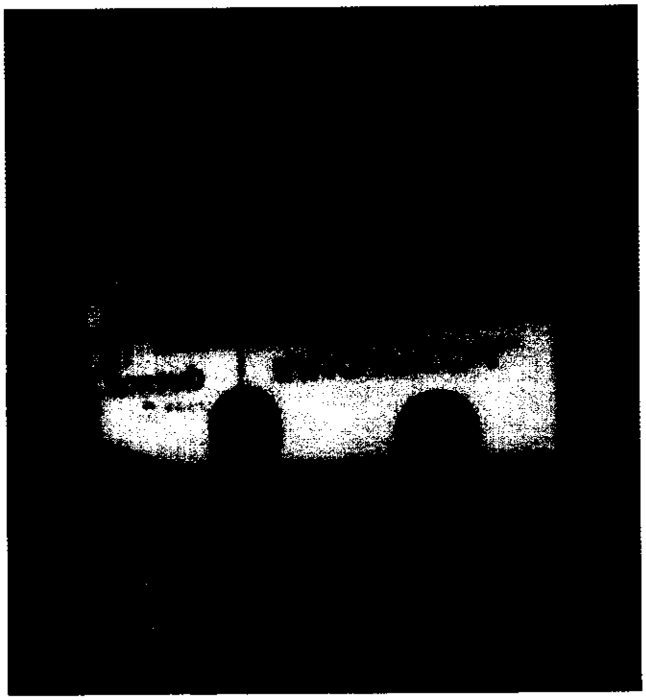
[40] Abadie, W. and Anderson, C., Sonsub, Personal interview, April 2000.
[41] Lådegard, B. I. E. and D'Aloisio, G., Sonsub, Personal interview, April 2000.
[42] Corbetta, G., Sonsub, Personal interview, April 2000.
[43] DiNoto, F., Gallazzi, L., and Vienna, A., "A.R.CO.S.: A Diverless Pipeline Repair System Ready to Go Offshore," Offshore Mediterranean Conference, March, 1999.
[44] McCavanagh, G. and Sclocchi, M., "Deepwater Development: A New Generation of Deep-Water Construction Class ROVS," Offshore Mediterranean Conference, March 1999.



Innovator ROV
(Source: Sonsub, 2000)

Snam and Sonsub now offer the components of the D.S.R.S./A.R.CO.S. repair system to outside markets. As mentioned in the Shell deepwater pipeline repair system section above, Shell integrates many of the D.S.R.S./A.R.CO.S. system components into its repair system philosophy. These components include a new concrete, corrosion coating removal and pipeline end preparation tool, diamond wire pipe cutting tool, the pre-measurement metrology tool and subsea hydraulic power supply. The D.S.R.S./A.R.CO.S. system was also offered as a repair system for the Blue Stream pipeline scheduled for installation in 2000. The Blue Stream pipeline will be a 24" gas transmission system from Russia to Turkey across the Black sea. The pipeline will traverse a maximum water depth of 6,560 feet. Sonsub acknowledges that significant upgrade of some D.S.R.S./A.R.CO.S. system components would be required to operate in 6,560 feet sea water.[45]

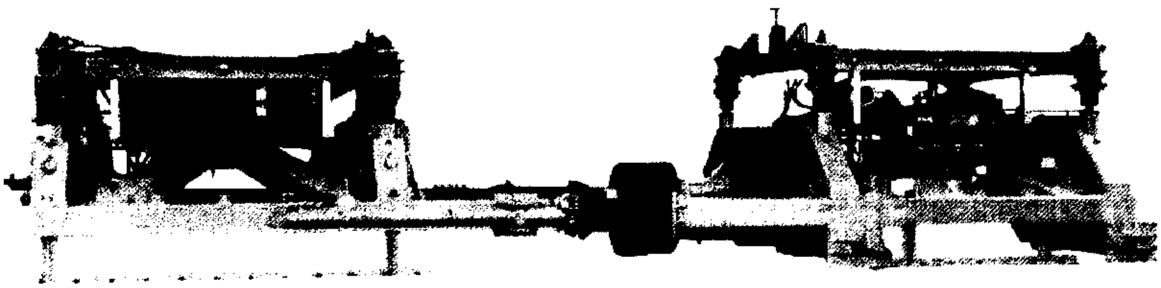
BRUTUS Diverless Pipeline Tie-In System

The latest development from Sonsub is the BRUTUS diverless pipeline tie-in system. The BRUTUS system was developed from the Sonsub DFCS (Diverless Flowline Connection System) and from the experience gained during the BP Foinaven project. The principles behind the BRUTUS system are based on the subsea construction tasks required to make a bolted flange connection using diverless intervention. Sonsub performed its first commercial remote flange tie-in in 1997 during the BP Foinaven project on 8" and 10" pipelines in the North Atlantic, West of Shetlands, in 1,500 feet sea water. The connection used Destec compact flanges and used

[45] Ibid.

project specific tooling developed by Sonsub. The BRUTUS system is adding the capabilities of diverless tie-in of a 16" ANSI 1500 Class flanges in 1000 feet water depth for a June 2000 installation.[46]

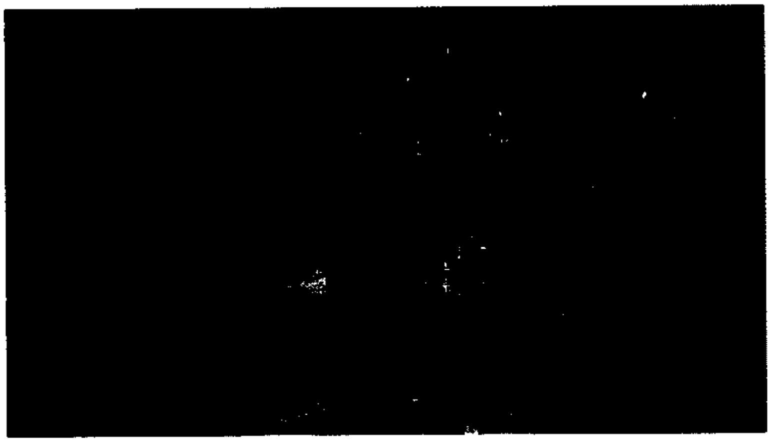
The BRUTUS system incorporates this diverless flange make-up technology with the ability to make up connections using commercially available flanges or mechanical connector technology. The BRUTUS system is composed of three major tools that perform all the tasks required to make up a diverless flange connection: the Axial Force Tool, the Reaction Tool, and the Flange Connection Tool. The tools were designed to minimize the amount of permanently installed subsea equipment left on-bottom upon completion of the flange connection. The tool also eliminates the requirement of using a pipeline end skid or tie-in porch structures in most cases. These design criteria simplify the complexity and reduce the cost of installation, eliminate the requirement of complex mechanical connectors, and provide a reversible connection allowing for future repairs or upgrades.[47]



Sonsub BRUTUS
Reaction Tool (Left) and Axial Force Tool (Right) Engaged to Align Flanges. The Flange Connection Tool Is Not Shown.
(Source: Sonsub, 1999)

The Axial Force Tool and Reaction Tool are ROV operated tools that each clamp to the pipe behind the mating flanges. The Axial Force Tool is typically installed by an ROV onto the spool piece end, and the Reaction tool is installed onto the pipeline end. The Axial Force Tool engages docking receptacles in the Reaction Tool and pulls in and aligns the flanges for bolting. The Axial Force Tool reacts against a prefabricated thrust collar that is welded to the spool pipe near the flange. The Reaction Tool uses a thrust collar that reacts against the rear of the pipeline flange. These tools together are capable of forced positioning of the pipe in the axial and lateral (vertical and horizontal) directions to align the flanges for bolting.[48]

[46] Abadie, W. and Anderson, C., Sonsub, Personal interview, April 2000.
[47] Corbetta, G. and Cruden, R., "BRUTUS, A New System for Diverless Tie-Ins of Rigid Lines: Integration Tests Report, Offshore Mediterranean Conference, March 1999.
[48] Ibid.



BRUTUS Axial Force Tool Mounted on Flanged Pipe End
(Source: PCS Archive Photograph Reprinted by Permission of Sonsub, April 2000)

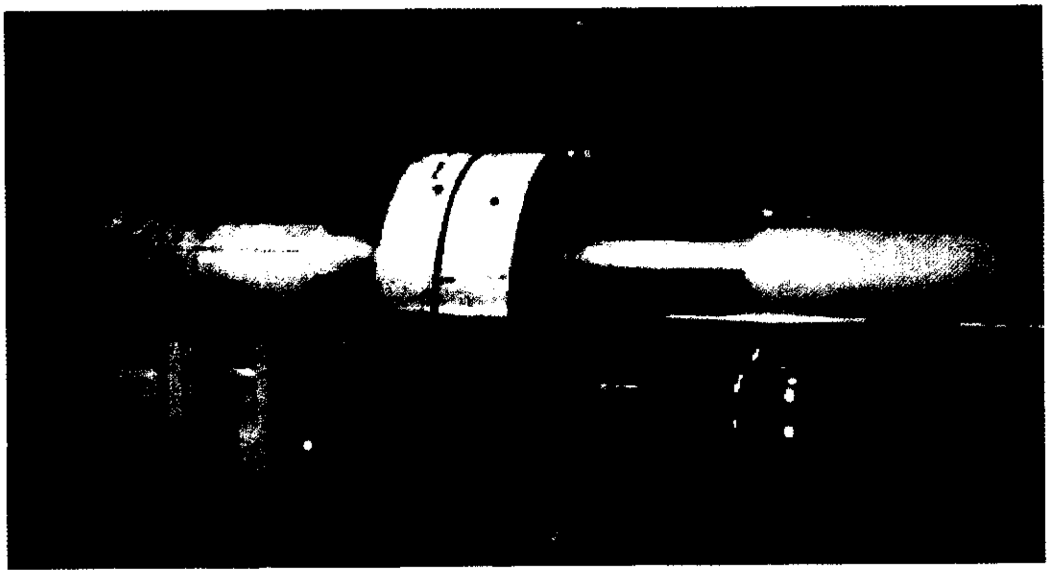
BRUTUS Reaction Tool
(Source: PCS Archive Photograph Reprinted by Permission of Sonsub, April 2000)

The Flange Connection Tool is made up of two ROV operated tools that perform the bolt insertion, flange closure, bolt tensioning, and nut running operations. The Flange Connection Tool is installed at the flange connection between the Axial Force Tool and the Reaction Tool to perform the tie-in operation. The two components of the Flange Connection Tool are the Nut Magazine and the Bolt Insertion and Tensioning Tool. These tools are self aligning with respect to each other and the flange bolt holes assuming a conventional swivel ring flange / weld neck flange connection. The bolts with preinstalled nuts on one end are inserted into the bolt holes of the swivel ring flange. Upon installation of the flange seal ring, the tools and bolt holes are aligned using the swivel ring flange. The nuts are installed onto each bolt and 50% of the studs are tensioned to close the flange gap. The remaining 50% of the bolts are then tensioned. The tensioning cycle continues three times. Once the bolt tensioning is complete, all tools are recovered to the surface leaving only the flange connection on-bottom.[49]

[49] Ibid.

BRUTUS Bolt Insertion and Tensioning Tool with Preinstalled Studs (Red)
(Source: PCS Archive Photograph Reprinted by Permission of Sonsub, April 2000)

BRUTUS Nut Magazine with Preinstalled Nuts (Red) and Buoyancy
(Source: PCS Archive Photograph Reprinted by Permission of Sonsub, April 2000)



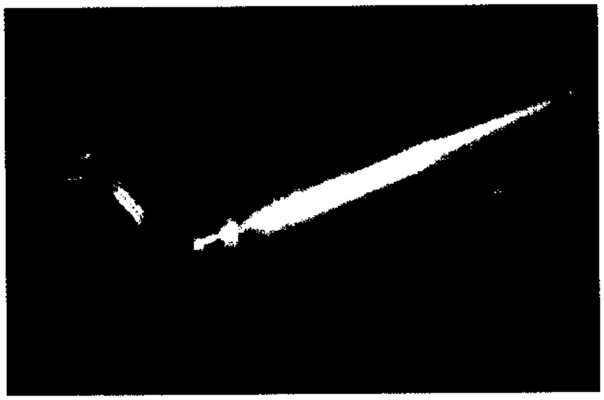
Completed BRUTUS Flange Connection
(Source: PCS Archive Photograph Reprinted by Permission of Sonsub, April 2000)

Integration of the D.S.R.S. and BRUTUS

Although BRUTUS is primarily designed as a pipeline construction system, it is suitable to perform connections necessary for the repair of deepwater pipelines. Several pipeline repair options are supported by BRUTUS by virtue of its capability to connect conventional flanges and diverless mechanical connectors. This allows a pipeline operator the flexibility of a surface lift repair for welding conventional flanges or a complete on-bottom repair scenario using diverless mechanical connection systems.[50,51]

The BRUTUS system is supported by an extensive array of existing subsea technology provided by the D.S.R.S. BRUTUS and the D.S.R.S. can be integrated into a complete pipeline repair system that is capable of providing all the tasks required to make a remote diverless intervention deepwater pipeline repair. The D.S.R.S. provides all pipe handling, end preparation, and connection equipment such as H-frames, pipe trestles, subsea winches, flange/hub cleaning equipment, inspection tools, and metrology systems. BRUTUS provides the installation of a spool piece with the option of using bolted flanged connections eliminating the dependency on telescoping spool pieces as currently used in the D.S.R.S./A.R.CO.S. repair system. BRUTUS also provides the opportunity to use several types of pipeline end connectors in addition to weld neck flanges in the event that a diverless on-bottom repair is necessary. Suggested connectors include flanged slip-on connectors (cold forged onto cut pipe ends), Morgrip connectors, and Framo PD Connectors.[52,53]

[50] Ibid.
[51] Corbetta, G. and Cruden, R., "A New Approach to Capex and Opex Reduction: An Integrated System for Remote Tie-Ins and Pipeline Repair," Offshore Technology Conference, May 1-4, 2000.
[52] Ibid.



Framo PD Connector
(Source Framo Engineering AS)

The following is an outline of the basic procedures required to use the integrated BRUTUS/D.S.R.S. for a bolted flange repair. The procedure assumes that flanges are mechanically forged onto each pipeline end using the water forging Hydro-Lok tool:[54]

- Two H-frames are positioned on either side of the damaged section and powered by an ROV.
- The diamond wire cutter is deployed to cut out the damaged pipeline section which is removed from the work area with an ROV positioned diverless pipe clamp.
- The cut pipeline ends are prepared to accept the slip on mechanically forged flanges by removing concrete, corrosion coating, and pipe weld seam, as required.
- The pipeline end connectors are deployed and forged onto each pipeline end
- Metrology is performed to establish relative position and orientation between the two pipe ends to determine the fabrication dimension(s) of the spool piece.
- The spool piece is lowered to the work area using buoyancy and a ROV for manipulation
- The BRUTUS Reaction Tool and Axial Force Tools are deployed an flown into position by the ROV.
- The Axial Force Tool docks into the Reaction Tool and pulls in and aligns the flanges; the Bolt Insertion and Tensioning Tool and Nut Magazine are operated to install the seal ring and close the flange.
- The BRUTUS modules are repositioned on the other end of the spool and the sequence is repeated.
- The equipment is recovered to surface once all bolts have been properly tensioned.

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[53] Corbetta, G., Personal interview, May 2000.
[54] Corbetta, G. and Cruden, R., "A New Approach to Capex and Opex Reduction: An Integrated System for Remote Tie-Ins and Pipeline Repair," Offshore Technology Conference, May 1-4, 2000.

The BRUTUS system is scheduled to be first used on the Statoil Norne/Heidrun Project in the Norwegian Sector of the North Sea in the summer of 2000. The project includes the diverless tie-in of a 16" Taper-Lok weld neck to swivel ring flange connection in 980 feet sea water. The BRUTUS system does push the conventional limits of ROV technology since it relies heavily on ROV intervention. The experienced gained during upcoming projects will continue to enhance this type of pipeline tie-in and repair technology. The BRUTUS system is designed primarily for horizontal on-bottom tie-ins. Vertical tie-ins for subsea equipment and risers are possible, however BRUTUS has a limited forced alignment capability when operated in the vertical.[55,56,57]

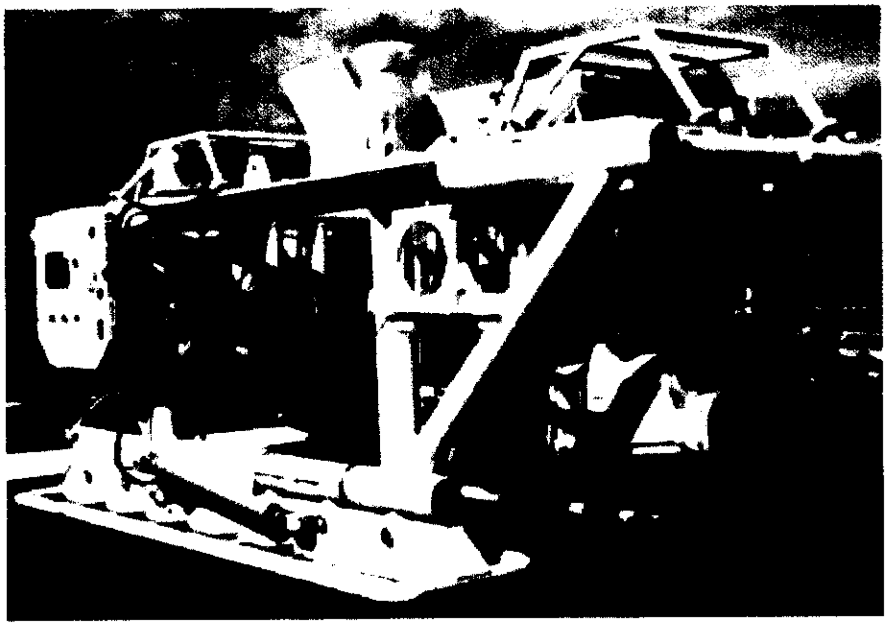
SKETCH OF D.S.R.S. / BRUTUS INTEGRATED SYSTEM
(Source: Sonsub, April 2000)

[55] Stalker, G., E-mail, April 21, 2000, 09:35.
[56] Corbetta, G., and Cruden, R., "A New Approach to Capex and Opex Reduction: An Integrated System for Remote Tie-Ins and Pipeline Repair," Offshore Technology Conference, May 1-4, 2000.
[57] Abadie, W. and Anderson, C., Sonsub, Personal interview, April 2000.

STOLT OFFSHORE MATIS BASED PIPELINE REPAIR SYSTEM:

Stolt Offshore has developed a deepwater pipeline repair system around their MATIS (Modular Advanced Tie-In System) diverless remote pipeline tie-in program. The MATIS system was designed to address the depth limitations of hyperbaric welded tie-ins. The system was developed around the ability to make up an ordinary bolted flange connection using remote, diverless intervention. Pipeline construction was the initial focus of the system, however once the system was proven on a construction application, it was evident that the system could be expanded to diverless pipeline repair applications.

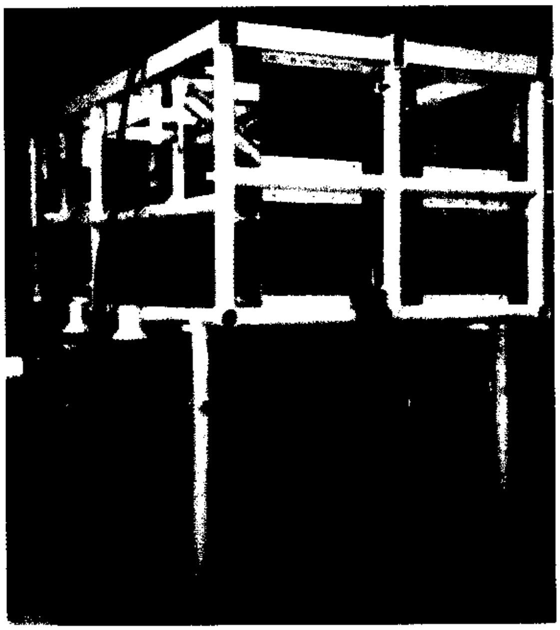
Unlike hyperbaric welded pipeline tie-ins with depth limitations of 1,200 feet sea water, the Deep MATIS system currently under development will be capable of making both horizontal and vertical pipeline tie-ins on 12" diameter and smaller pipe using remote intervention in water depths down to 9,850 feet sea water. The system was proven effective in June 1999 when it completed the first commercial diverless bolted flange tie-in using a standard 8" gas pipeline flange as part of the Statoil Loke project in 260 feet sea water in the North Sea.[58]



Flange Alignment Frame Used on Statoil "Loke"
(Source: PCS Archive Photograph Reprinted by Permission of Stolt Offshore)

[58] "Matis Pipeline Connection Loke Project," Video, Stolt Comex Seaway, 1999.

The Deep MATIS system is currently under development and will be first used for the Elf Angola Girassol project. The Deep MATIS system will be used exclusively to perform all sub-sea pipeline tie-ins on the Girassol project located off the coast of West Africa in 4,600 feet sea water. The MATIS system was selected by Elf to perform the 82 diverless subsea pipeline tie-ins required during subsea construction, 16 of these being vertical connections at the bottom of the riser towers. The use of MATIS allowed the selection of standard flanges for Girassol, which produced a more cost effective approach than standard jumper / mechanical collet connector tie-ins. In addition, the selection of standard flanges allowed the project team increased flexibility with respect to the selection of the vendor and supply of the connectors. Stolt will perform deepwater trials on the Girassol connections in the North Sea in June 2000. Construction of the Girassol project using the MATIS system is scheduled for November 2000.[59,60,61]



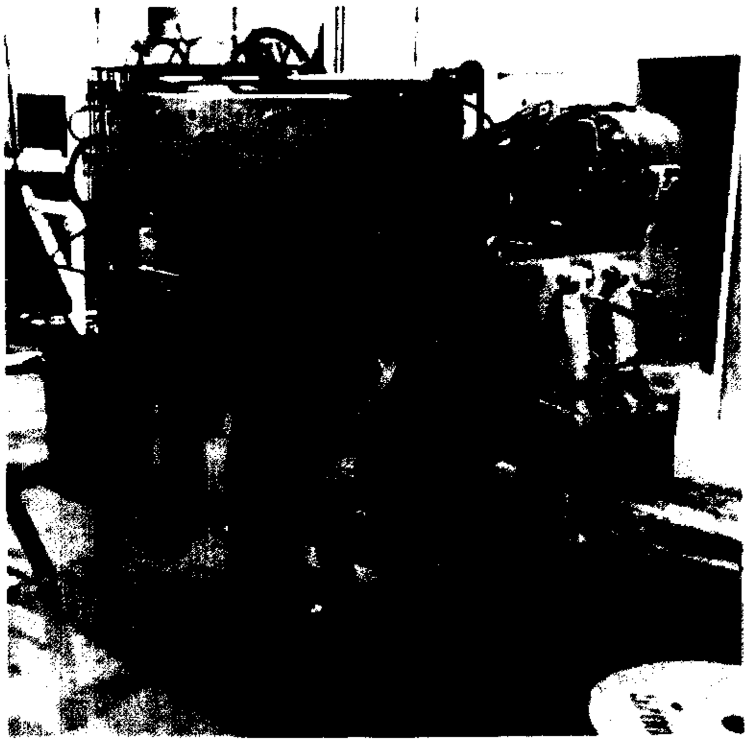
Deep Matis Module
(Source: PCS Archive Photograph Reprinted with Permission of Stolt Offshore)

Stolt performed the first commercial diverless flange connection on the Statoil Loke project in the Norwegian Sector of the North Sea. This connection was made during the construction of the pipeline, however pipeline repair procedures using this system would be similar. One end of a premeasured flanged spool piece was preinstalled to a manifold, the other end of the spool piece was left unconnected to its mating pipeline end. The operation was performed from a diving support vessel (DSV) which indicates its portability, cost effectiveness, and its ability to use a vessel of opportunity unlike the larger vessel dependent systems.

The first step of the tie-in was to lower the MATIS pipe handling frame over the pipe on the seabed. This handling frame provided rough alignment and support of the pipeline end roughly 30 feet away from the flange connection to be made. The Flange Alignment Frame complete

[59] Frazer, I., "Stolt MATIS System," Email, April 6, 2000.
[60] Osborn, R. and Jared, P., Stolt Offshore, Personal interview, February 2000.
[61] Gibb, S., E-mail, May 1, 2000, 16:33

with Flange Alignment Tool was then lowered over the pipe on the seabed. The pipe was lifted from the seabed and flanges were aligned by the combination of the Pipe Handling Frames and Flange Alignment Frame. Once the flanges were aligned, the flange faces were brought together. Gasket insertion can be performed with a dedicated MATIS gasket insertion tool. However, the preferred method, which was used on the Loke project, is to preinstall the gasket into one of the flange faces. After the flange faces were brought together, the bolt holes on the swivel ring flange were aligned with the bolt holes on the weld neck flange with the Flange Alignment Tool. The flange connection was then preloaded in compression by the Flange Alignment Frame and the MATIS bolting unit inserted the studs into the flanges where they were remotely tensioned and nutted. The pipe alignment frame and flange alignment frame were based on proven designs used with hyperbaric welding spreads. The MATIS system was developed around this proven technology which provides the most reliable and proven subsea pipeline alignment method and guarantees the accuracy of the flange alignment required for the bolting unit to be successful.[62]



MATIS Flange Alignment Tool
(Source: PCS Archive Photo Courtesy of Stolt Offshore, April 2000)

The pipeline repair procedure follows the same basic procedure as a pipeline construction tie-in. Additional equipment is required to address repair specific tasks. The pipeline repair system is

[62] "Matis Pipeline Connection Loke Project," Video, Stolt Comex Seaway, 1999.

being designed for pipeline diameters ranging from 6" to 24" in diameter. The current application of the system requires that the pipeline ends be recovered to the surface for welding on flanges. This may limit the use of the system to damage scenarios that do not require diverless on-bottom repair methods. Stolt is, however, developing a complete on-bottom repair system based on a modified Morgrip connector fitted with a flange face.[63,64]

Stolt Offshore has developed a variety of subsea tools to support the MATIS on-bottom repair system for a deepwater pipeline repair. The tools are designed to perform preparatory, repair specific tasks that the basic construction system does not provide. A detailed description of the deepwater pipeline repair tools is provided below.[65]

Stolt is developing a leak detector tool using a suite of sensor technology to detect fluid ingress or egress from a damaged pipeline. This will allow the leak detector to sense different modes of pipeline leakage with a variety of fluid types. The leak detector tool is to incorporate several methods of leak detection including acoustic, passive fluorescence and fluorometer based instruments to detect active hydrocarbon leaks out of and seawater leaks into a pipeline. The sensor platform is also being designed to support the entire array of sensors proposed during the preliminary design effort.[66]

Stolt Offshore has several existing concrete removal tools that have been successfully used to remove weight coating from subsea pipelines. The tools use diamond saws and hydraulic wedges to make radial and longitudinal cuts into the concrete weight coating. The operation of the cutting saws and hydraulic wedges are specifically designed to avoid damage to the corrosion coating and the pipe steel by only penetrating the concrete to 70% of the thickness.[67]

A FBE corrosion coating removal tool under development is being designed to clean pipe to a white metal finish (SSPC-SP5). The methods under consideration include wire brush, grit blast, rotary scraper, and mechanical stripping tools. This tools is being developed for a future contingency of a complete on-bottom diverless repair system.[68]

Stolt Offshore has experience with a variety of subsea pipeline cutting tools including diamond wire cutters, guillotine reciprocating cutters, grinding disc cutters, diamond saw cutters, and grit blast cutters. Stolt plans to evaluate which cutter best suites their requirements based on the following requirements: neutral buoyant, robust, high advance rate, low jamming potential, minimal change out time, reliable attachment mechanism, low risk to base metal.[69]

A pollution containment system is being developed by Stolt Offshore to minimize the release of hydrocarbons to the environment during a deepwater pipeline repair operation. Stolt Offshore is currently looking at a system comprised of several different containment methods to be applied

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[63] Gibb, S., Telephone interview, March 2000.
[64] Gibb, S., E-mail, May 1, 2000, 16:33
[65] Lomax, P. and Mackintosh, M., "The Development of a Cost Effective System for the Repair of Deep Water Pipelines," ETCE/OMAE, February 2000.
[66] Ibid.
[67] Ibid.
[68] Ibid.
[69] Gibb, S., "Stolt Offshore Deepwater Pipeline Repair," Notes, March 2000.

during different phases of a repair operation. A containment tent has been evaluated as the most effective means of pollution control during the initial location of the leak and cutting of the damaged section. Once the damaged pipe has been removed and access to the pipeline bores has been established, internal packing plugs are being considered as the pollution control method of choice until the closing spool is ready for tie-in. Stolt acknowledges that the damage scenario has the most impact in dictating the optimal pollution control system.[70]

Stolt is proposing a metrology tool based on acoustic (EHF) and taut wire measurement technologies. Correlation of measurements from these measurement techniques can result in the highest subsea measurement accuracies possible. It is believed that a linear accuracy of 1/32" and an angular misalignment accuracy of 1/2 degree can be attained with a linear repeatability on the order of 1 inch. Stolt is particularly concentrating on efforts to develop angular misalignment error compensation techniques to attain these new levels of accuracy. Stolt has noted the use of EHF only systems in the North Sea and will investigate further when this solution is the most practical for a given repair scenario.[71]

A pipe uncovering/deburial system is required if the pipeline becomes buried or partially buried over time. Deburial is required to allow access for the pipe lifting tool so the pipeline can be raised off of the seabed. The pipeline deburial system is based on the proven Stolt Talon concept. The Talon system is a subsea pipeline burial system that is self powered and operated by an ROV. The Talon system uses a track machine that straddles the pipeline to provide a completely subsea pipeline burial system. Since the proposed deburial machine would be ROV operated the possibility of using magnetometer based ROV equipment to track the pipe during jetting operations is being investigated.[72]

Hydrate detection systems are being evaluated including density measurement, temperature measurement, hoop strain, and volumetric methods. Stolt is giving consideration to incorporating the hydrate detection tool into the pipeline uncovering tool. Such a combined tool would allow the simultaneous operation of pipeline deburial and hydrate plug detection. This combination of the two operations can potentially save large amount of offshore spread time, thus reducing cost of the total repair operation.[73]

Several pipe lifting tools have been developed by Stolt Offshore for the purpose of raising the pipeline off of the seabed to accommodate repair tooling. These tools have primarily been based on surface deployed steel frame structures. Other approaches continue to be considered as well including inflatable lift systems.[74]

Typical Deepwater Pipeline Repair Scenario

To perform a repair, a leak detector device first locates pipeline damage. Once located, pipe handling frames are lowered to the sea floor to lift the pipeline off the seabed to allow access for

[70] Ibid.
[71] Ibid.
[72] Ibid.
[73] Ibid.
[74] Ibid.

pipeline repair tools. Concrete weight coating and corrosion coating equipment is then lowered to the seabed to prepare the damage section for cutting and to prepare the severed pipeline ends for the pipeline recovery device. The damage section is then cut and removed from location. A recovery tools is attached to the pipeline ends and in turn, the pipeline ends are raised to the surface for welding of conventional flanges. Once the flanges are welded to the pipeline ends, they are lowered to the seabed with bolted laydown heads with acoustic transponders for the metrology operation. Metrology is performed to determine the required dimensions for the pipeline repair spool. Once the repair spool is fabricated to the required dimensions, it is lowered to the seabed and connected to each pipeline end by a method similar to that described in the construction tie-in description above.[75]

Mechanical End Connectors

Stolt Offshore is investigating the future possibility of a complete on-bottom diverless repair system. This investigation is in response to both customer needs and the continued internal efforts to globally expand the company. Diverless subsea pipeline mechanical connectors remain the key component around which a diverless on-bottom repair system must be designed. Big Inch Marine Systems (BIMS) is a U.S. subsidiary of Stolt Offshore and has a diverless mechanical connection system that can be potentially applied to diverless on-bottom pipeline repair operations.[76,77]

The BIMS Remote Articulated Connector (RAC) is a mechanical pipe connection device that combines the technologies of hub in clamp connection and BIMS misalignment ball connection. The installation of the RAC system can be completed by divers or by diverless intervention such as ROVs. The connector allows up to 5 degrees of angular misalignment.[78]

The RAC consists of two sealing surfaces. One sealing surface is spherical and accommodates the articulating ball section of the connector. The other sealing surface is comprised of an AX type seal ring used on similar hub in clamp connectors to provide a seal against the mating hub. Each of these seals are metal to metal with elastomeric back up. The connector can be installed with an ROV in a completely diverless operation.[79]

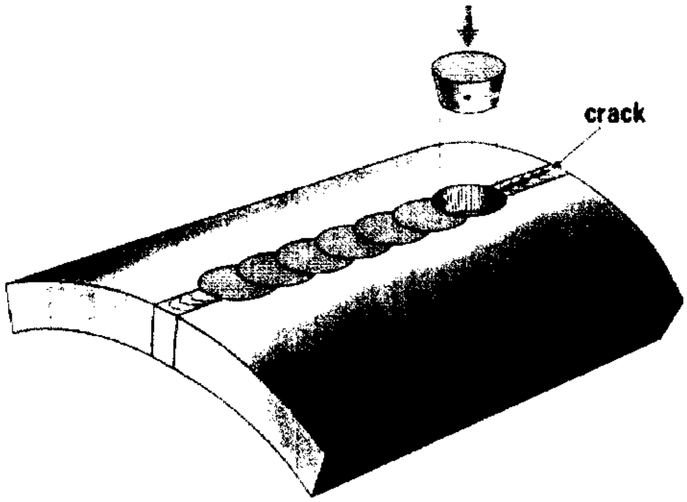
[75] Ibid.
[76] Ibid.
[77] Gibb, S., Stolt Offshore, Telephone interview, March 2000.
[78] Gibb, S., "Stolt Offshore Deepwater Pipeline Repair," Notes, March 2000.
[79] Ibid.

BIMS Remote Articulated Connector
(Source: Stolt Offshore, April 2000)

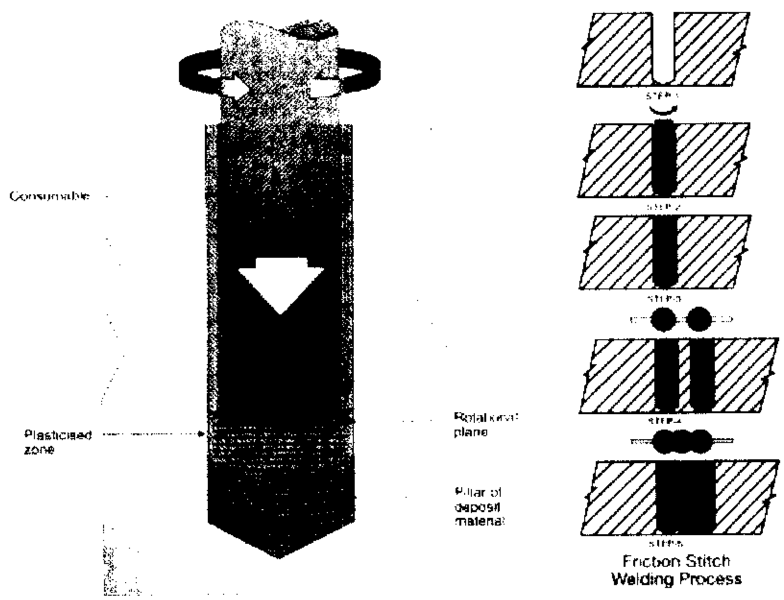
Wet Friction Welding

There is a new type of pipeline connection system being developed. It is aimed at providing a welded alternative to diverless bolted flange connections and mechanical connectors. This system is based on Tapered Plug Welding, which is a wet welding process developed at The Welding Institute (TWI), Cambridge, England in collaboration with Chevron. A related welding technique called Friction Hydro Pillar Welding was later developed in a TWI Group Sponsored Project on which Stolt Comex Seaway was a sponsor along with major pipeline operators such as Shell, BP, and Chevron. An additional project, titled BRITE ROBHAZ, has been initiated by The National Hyperbaric Centre, a subsidiary of Stolt Offshore, sponsored by the European Commission, and includes GKSS, a German research center that is responsible for the development and characterization of welded joints. The project goal is to develop an underwater robotic repair system for repairs to offshore steel structures, FPSO's, ships and nuclear power plants. The project is scheduled to run until May 2000.[80]

[80] Gibson, D., National Hyperbaric Centre, Personal interview, April 2000.

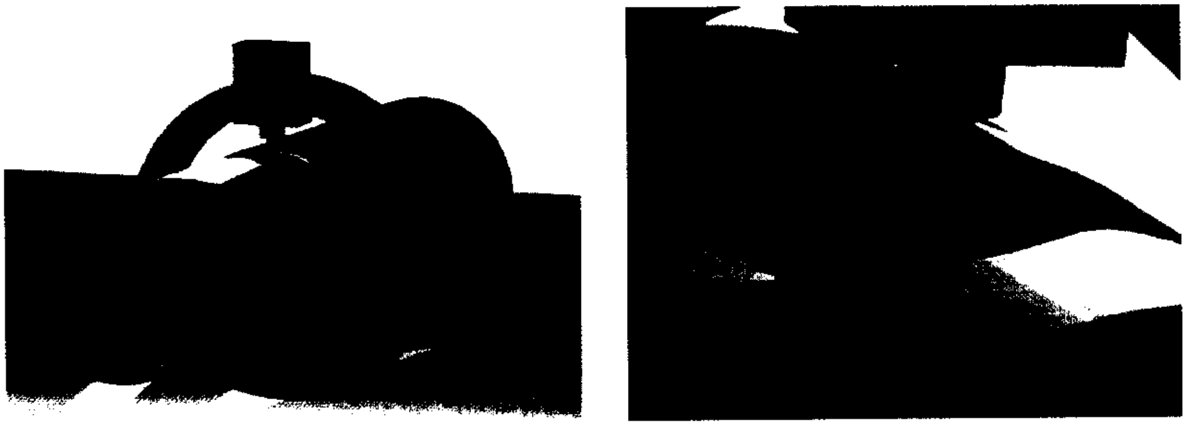


Taper Plug Welding
(Source: S. Gibb, Notes, 2000)



Friction Hydro Pillar Processing / Application to Friction Stitch
(Source: D. Gibson, ROBHAZ, 2000)

The application of this welding process to submarine pipelines is called friction stitch welding. The process involved friction welding overlapping plugs around the circumference of a pipeline to produce an all welded connection.[81] The process is a solid phase welding process that uses friction and pressure to produce a plasticized zone that allows metal to flow into the joint and form a metallic bond to the parent material. Friction Stitch welding is a fully mechanized process and ideal for use as a method for deep diverless pipeline repair. It does not require a dry habitat as with hyperbaric welding, and it is not sensitive to water depth. This makes the process ideal for diverless on-bottom pipeline repair that is required in deep water. Additional applications proposed for friction stitch welding include diverless hot tapping and diverless welded tie-ins of subsea pipelines.[82,83]



Friction Stitch Welding Process
(Source: D. Gibson, ROBHAZ, 2000)

A cost comparison between friction stitch welding and diverless mechanical connectors was proposed. Assuming the average cost of a typical mechanical connector was $300,000. If two sets of connectors for 12 different pipeline diameters, the pipeline operator would need to invest $10 million to purchase the required connectors. This excludes the cost of connector storage, maintenance, and the cost of special installation equipment required to install each connector. It is proposed that a friction stitch weld repair can be performed at a small fraction of this cost. There is a definite advantage in the use of the diverless friction stitch welding system since the system could be provided on a contract basis as typical with other pipeline construction equipment.[84]

Stolt Offshore and GKSS have initiated a project to assemble and demonstrate a prototype system for pipeline, tie-ins and repair. The main objective is to develop the procedures and

[81] Gibb, S., "Stolt Offshore Deepwater Pipeline Repair," Notes, March 2000.
[82] Ibid.
[83] Gibson, D., Personal interview, April 2000.
[84] Osborn, R. and Jared, P., Personal interview, February 2000.

parameters for friction stitch welding of deepwater pipelines. This project is supported by the EC THERMIE program and will involve the transfer of technology from the BRITE ROBHAZ project. Stolt Offshore is inviting other pipeline operators to participate in the development of the friction stitch welding program The project will build a prototype module for friction stitch welding of underwater pipelines. The module will be designed to operate with the deepwater pipeline repair equipment already developed by Stolt Offshore for diverless flange connection (MATIS). It is the ultimate goal to completely replace hyperbaric welding with friction stitch welding.[85,86]

Current and Future Development Goals

Stolt Offshore is actively pursuing deepwater pipeline repair technology as evidenced through the development of the MATIS deepwater pipeline repair system, continued development of diverless mechanical pipeline connectors, and further research into diverless friction stitch welding technology. Stolt is using the experience derived from deepwater pipeline construction projects such as the Statoil Loke Project and current Elf Angola Girassol Project to further develop and prove the MATIS system for deepwater pipeline repair applications.

A drawback to the current application of the MATIS system for deepwater pipeline repair is the surface lift requirement. This requirement further reduces the applications of the MATIS system particularly when an on-bottom pipeline repair solution is required. Stolt Offshore has proposed the use of diverless mechanical connectors such as the Morgrip to be used in conjunction with MATIS, however this combination has not been proven in testing or field applications. Hydrate detection tooling is also an area in the pipeline repair system that apparently requires further development before practical application can be pursued as part of the deep water pipeline repair system. Friction stitch welding technology, although in its infancy, has the potential of changing pipeline repair operations, equipment, and procedures and could have a profound effect on the entire subsea pipeline construction industry. This potential will ultimately depend on the mechanical properties, repeatability, and reliability of this new welding process.[87]

The availability of diverless on-bottom horizontal flange tie-in to the pipeline construction industry is a significant development milestone for deepwater pipeline repair technology. The availability of both the BRUTUS and MATIS systems offer pipeline operators more flexibility with regards to diverless pipeline repair options. The horizontal flange tie-in system offers both construction and repair alternatives to vertical connection systems. The vertical connection systems using inverted U-shaped jumpers and collet connectors are the primary means of performing diverless pipeline tie-ins in the Gulf of Mexico. Vertical connection systems do rely on fairly simple installation equipment, require minimal ROV interface, and allow provisions of performing external leak tests. These connection systems also require extensive subsea structure such as pipeline end skids, to support installation and operation of the jumper spool and upward looking male hubs. The subsea structure requires additional lay barge time to install. A high level of accuracy is required in the metrology system, particularly in short jumper connection, since the collet connectors and spool flexibility must account for all measurement and fabrication

[85] Gibb, S., "Stolt Offshore Deepwater Pipeline Repair," Notes, March 2000.
[86] Gibson, D., Personal interview, April 2000.
[87] Ibid.

errors. Collet connectors are significantly more expensive and require greater lead time to procure than conventional flanges causing an operator to invest a large amount of capitol to stockpile the require connectors for each line size to be covered. The installation of the jumper is also highly weather dependent due to the use of guidelines from the surface to control spool installation. The flange tie-in system requires no subsea structure at the pipeline end, reducing lay barge requirements, relies on only moderate measurement and fabrication tolerances, and is less dependent on weather conditions. The major drawbacks of the flange tie-in system include the complex subsea equipment required as well as high dependence on ROVs to perform most of the tie-in functions. The bottom time required to perform the tie-in operations is substantially longer than for vertical jumper installation, however a typical DSV spread can provide all of the support required for the tie-in. The economic advantages of the DSV spread outweigh vertical jumper requirement of pipeline end skid fabrication and installation using a pipe lay barge or derrick barge.

SHELL DEEPWATER PIPELINE REPAIR SYSTEM:

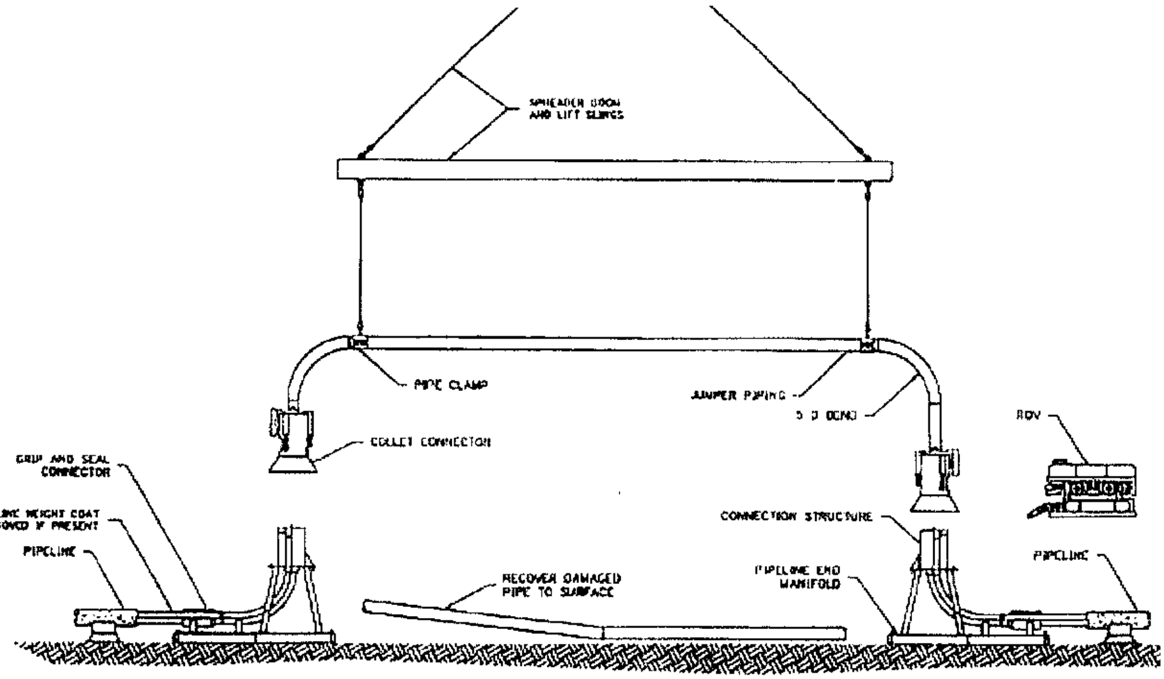
At present Shell operates approximately 60% of the deepwater pipeline mileage in the Gulf of Mexico followed by ExxonMobil at about 20%.[88] Shell recognizes the significant loss of revenue that could occur if a deepwater export pipeline is shut in due to damage. As deepwater production contributes more to Shell's total Gulf of Mexico production, Shell recognizes the increasing risk of damage to their deepwater pipelines. Shell has already experienced damage to several of their deepwater pipelines, the most notable is the damage to the Mensa tie-back during construction with repairs performed in 5,300 feet water depths.[89] Recognizing the increasing risk of deepwater pipeline damage with the increasing number of deepwater pipelines being operated, Shell Deepwater Producing, Equilon Enterprises and Coral Gas Transmission have entered into an agreement to develop a deepwater pipeline repair system. The goal of the Shell deepwater pipeline repair system is to minimize the downtime associated with deepwater pipeline damage to one (1) month. The philosophy of a repair system includes all activities require to perform a deepwater pipeline repair, commission the pipeline, and insure uninhibited flow upon start-up.[90]

The Shell deepwater pipeline repair system was initially focused on surface lift methods, which meant bringing the pipeline to the surface for preparation and welding of end connectors. The surface lift repair option may not be available for all pipeline damage cases. Physical damage scenarios, risk, or equipment availability may preclude a surface lift repair method. To address this issue, Shell expanded their repair system to have diverless on-bottom repair capabilities.[91]

The Shell repair system covers the following line sizes of 12", 14", 16", 18" and 20" representing the deepwater pipeline sizes operated by Shell. The surface lift and on-bottom repair systems both consist of an inverted U-shaped or M-shaped jumper connecting repaired pipeline ends. The pipeline ends and jumper are connected via upward looking male hubs

[88] Ayers, R., "Deepwater Pipeline Repair Alliance," DeepStar IV – CTR 4306, November 1999.
[89] Preli, T.A., Shell Deepwater Producing Inc., Telephone interview, March 2000
[90] Preli, T.A. and McCalla, J.M., "Deepwater Pipeline Repair System," Deepwater Pipeline & Riser Technology Conference, March 7-9, 2000.
[91] Ibid.

mounted on skids on the ends of the pipeline. Collet connectors are attached on the jumper ends.[92]



Schematic of Inverted "U" Shaped Jumper Mating to Upward Looking Male Hubs
(Source: H.O. Mohr, 1998)

In a surface lift repair, the damaged portion of the pipeline is first cut out. A heavy lift vessel is required to retrieve the pipe to the surface. The pipeline end is then prepared on the surface by removing concrete weight coating and corrosion coating as required to install pipeline end skids. The upward looking male hub connectors are then welded on to the pipeline ends and the pipe is then lowered to the sea floor. The position and orientation of each upward looking male hub connector relative to each other are measured using a diverless metrology tool. The jumper can be fabricated based on these measurements for a proper fit. The jumper is then lowered to the sea floor where it is connected to the upward looking male hubs on the pipeline ends to complete the repair.[93,94]

The surface lift repair has several advantages that include accessibility to the pipeline bore for remediation of hydrate plugs and the ability to weld male hubs onto the pipeline ends. The surface lift repair method is hindered by the requirement of a vessel with heavy lifting capabilities to lift a flooded pipeline the surface in deep water. Such vessels in the Gulf of

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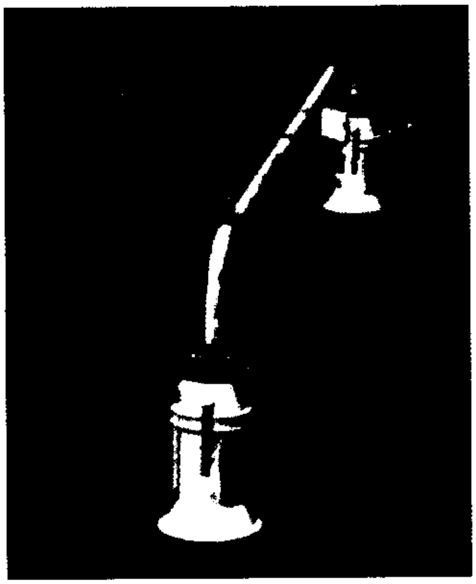
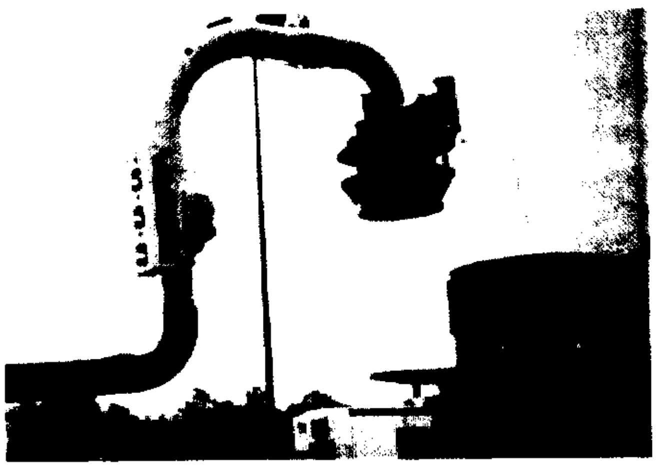
[92] Ibid.
[93] Langner, C., Carl Langner and Associates, Personal interview, April 1999
[94] Preli, T.A. and McCalla, J.M., "Deepwater Pipeline Repair System," Deepwater Pipeline & Riser Technology Conference, March 7-9, 2000.

Mexico are few and are generally unavailable on short notice. Delays in contracting a vessel increases the lead time required to perform the repair, further delaying production. The remote on-bottom repair scenario allows all of the tasks required to make the repair to be performed on the sea floor without the need for surface access to the pipe or diver intervention. The on-bottom repair system is comprised of tools that can elevate the pipeline above the surface of the seafloor, cut out and retrieve the damaged section of pipeline, remove coatings, prepare pipe ends to accept grip and seal mechanical connectors welded to an elbow with upward looking male hubs, and install the grip and seal connectors. On-bottom measurements, jumper fabrication, and jumper installation then proceeds as in the surface lift repair. The advantage of an on-bottom pipeline repair is that it eliminates the need for a heavy lift vessel and can be performed off of a more readily available large Diving Support Vessel or Multi Service Vessel of opportunity outfitted with an ROV. In addition, an on-bottom, diverless repair capability can address a wider range of damage scenarios then a surface lift repair.[95]



Offshore Installation of Inverted "U" Shaped Jumper
(Source: Oil States HydroTech, 1999)



Integration Test of "M" Shaped Jumper
(Source: Oceaneering Intervention Engineering, 2000)

[95] Ibid.

As part of the pipeline repair system project, Shell has funded the development of a variety of components and ROV operated tools for both the surface lift repair procedure and on-bottom repair procedure. The key elements of the Shell repair system are the Oil States HydroTech pipeline end and jumper end connectors. Shell is employing the use of sleeving to reduce the high capital equipment costs in purchasing connectors for each individual line size. Sleeving allows the use of one size collet connector for all sizes covered by the deepwater pipeline repair system, eliminating the need to buy a collet connector for each pipe size. Both collet connectors and grip and seal type connectors are being procured to address both surface and on-bottom solutions. Oil States HydroTech is also supplying on-bottom lift frames (H-frames) and pipeline end manifolds (PLEMs). Existing lifting frames from a previous Shell deepwater project are being adapted for use as part of the repair system. The PLEMs are being fabricated to fit the entire range of pipe sizes under consideration for this repair system.[96,97]

Diamond Wire Pipe Cutter Supplied by Sonsub
(Source: Sonsub 1999)

Additional equipment to support the Shell deepwater pipeline repair system is being procured from Sonsub including a diamond wire cutting machine, a concrete weight coating and FBE removal tool and a pipe end preparation tool. The diamond wire cutter is used to make subsea cuts in the pipeline to remove damaged sections of pipe. The cutter uses a diamond wire for the blade that is capable of cutting any pipeline diameter under consideration. The concrete weight coating and FBE removal machine and pipe end preparation tool prepares pipe for the installation of the grip and seal connectors on the pipeline end. The combination concrete weight coating removal and FBE removal tool being developed by Sonsub is a new technology that is scheduled for delivery by the summer of 2000.[98,99,100]

The hydrate detection tool and discharge containment tent are being procured from Oceaneering. One of the two primary metrology tools is Oceaneering's PMT (Pre-Measurement Tool), which is a taut wire system that Shell already owns from a past project. The other metrology device, the JMT (Jumper Measurement Tool) acoustic system, will be leased from Fugro/Chance. The discharge containment tent acts to catch any liquids that may leak from the pipeline during the

[96] Ibid.
[97] McCalla, J.M., Shell Deepwater Producing Inc., Telephone interview, April 2000.
[98] Preli, T.A. and McCalla, J.M., "Deepwater Pipeline Repair System," Deepwater Pipeline & Riser Technology Conference, March 7-9, 2000.
[99] McCalla, J.M., Shell Deepwater Producing Inc., Telephone interview, April 2000.
[100] Abadie, W. and Anderson, C., Sonsub. Personal interview, April 2000.

repair operations. The tent can also be used as a first response unit to contain any leakage from a damage pipeline before a repair can be performed. The discharge containment tent works by gathering production liquids and diverting them into one end of the tent where they can be pumped to secondary containment for proper disposal. Hydrates are addressed with deepwater pipeline repair because of the potential of hydrate formation during pipeline damage. The detection tool consist of a sled that can be pushed along the pipeline by an ROV that detects variations in density caused by blockages using a low strength radioactive source. Once a plug is detected, it can be removed using case specific procedures. Shell intends to own part of this system, however the required radioactive source will be a rented item.[101,102]

Shell is developing agreements with contractors and service companies and creating a pipeline repair manual addressing the use of the deepwater pipeline repair system tools, connector design and installation, fabrication of jumpers, remediation of hydrates, as-built alignment sheets of pipelines covered, and deepwater pipeline repair system maintenance. All testing performed on the repair system is being included in the manuals for reference.[103]

Shell is also soliciting support and participation in the deepwater pipeline repair system from other operators. A draft agreement modeled after the R.U.P.E. agreement has been written as a model as to how the system can be administered.[104] There is currently no company beside Shell Deepwater Producing, Equilon Enterprises and Coral Gas Transmission signed on to the repair system. Shell believes that other operators are skeptical until actual hardware is completely developed and tested. The target schedule to have the DPRS fully operational is summer 2000. Shell believes that this deepwater pipeline repair system, once fully operational, will reduce the estimated 30 to 40 week lead time required to procure equipment and services to perform an on-bottom diverless repair. The system does not specifically address the repair of steel catenary risers, insulated and pipe-in-pipe deepwater flowlines, and pipelines with pressures higher than 6000 PSIG MAOP. Shell does intend to address these issues with regards to the deepwater pipeline repair system in the future.[105,106,107]

OCEANEERING PIPELINE REPAIR SYSTEM:

Oceaneering has performed and has been involved in several deepwater pipeline repairs in the Gulf of Mexico over the past several years. The most notable of these repairs was on Mariner Energy's Dulcimer and Pluto pipelines. These repairs were performed below the practical range of saturation diving using Oceaneering's WASP Atmospheric Diving System assisted by a work class ROV. The Dulcimer repair in particular was one of the first repairs performed completely

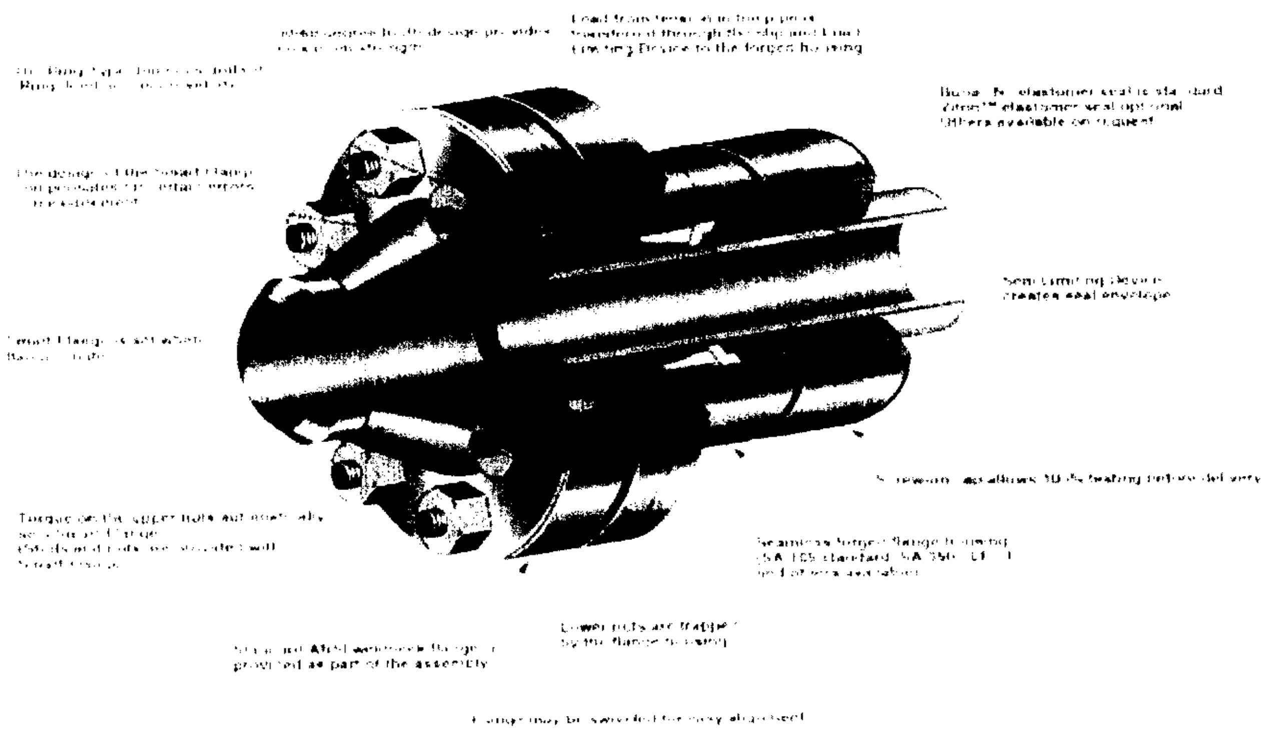
[101] Preli, T.A. and McCalla, J.M., "Deepwater Pipeline Repair System," Deepwater Pipeline & Riser Technology Conference, March 7-9, 2000.
[102] McCalla, J.M., Shell Deepwater Producing Inc., Telephone interview, April 2000.
[103] Preli, T.A. and McCalla, J.M., "Deepwater Pipeline Repair System," Deepwater Pipeline & Riser Technology Conference, March 7-9, 2000.
[104] Ayers, R. "Deepwater Pipeline Repair Alliance," DeepStar IV – CTR 4306, November 1999.
[105] Preli, T.A. and McCalla, J.M., "Deepwater Pipeline Repair System," Deepwater Pipeline & Riser Technology Conference, March 7-9, 2000.
[106] Preli, T.A., Shell Deepwater Producing Inc., Telephone interview, March 2000
[107] McCalla, J.M., Shell Deepwater Producing Inc., Telephone interview, April 2000.

on-bottom in the deepwater Gulf of Mexico. Mechanical grip and seal Smart Flange Plus connectors were used on the prepared pipeline ends to avoid lifting the pipe to the surface for welding conventional flanges. The system was portable enough to be deployed from a multi-service vessel making it a relatively accessible and cost effective system for use in Gulf of Mexico applications. This may be the Gulf of Mexico's first deepwater on-bottom repair system in use. The system, however, is not truly a remote diverless system since a pilot is required to operate the WASP ADS at repair depth. This factor imposes depth limitations of 2,300 feet on the system, rendering it ineligible for repairing the increasingly deep pipeline mileage in the Gulf of Mexico. Deepwater pipeline operators have also expressed some reservations concerning the safety of the WASP ADS system in the wake of the August 1999 incident in the Gulf of Mexico. Though this system is not a universal on-bottom deepwater repair system, there are many applications where this system would be considered a preferred solution.

WASP Atmospheric Diving System Installation of Smart Flange Plus Connectors during Dulcimer Repair
(Source: J. Charalambides, Underwater, 2000)

Oceaneering has a formidable deepwater pipeline repair program with equipment in development and use that follows the same concepts of the larger deepwater repair systems proposed by Shell and currently operated by Statoil. The Oceaneering system is on a smaller scale than these other deepwater pipeline repair systems, has diameter limitations of 14" pipe, and has not been proven to be a completely remote diverless on-bottom repair system. The systems components proposed for a diverless on-bottom system do have a good track record in regards to diver assisted installations and reliability. Oceaneering has performed underwater pipeline construction and repair operations using their Smart Flange Plus technology around the world since the late 1980's. The Smart Flange Plus technology was developed by Oil Industry Engineering, Inc.

(OIE), which later became a division of Oceaneering in the early 1990's. These connectors are designed for permanent installation or repairs. They are installed by sliding onto a properly prepared bare pipe end and mating to a standard ANSI class flange. Hydraulic Smart Connectors were developed based on the proven technology of Smart Flange Plus in the early 1990's. The Smart Flange Plus and the Hydraulic Smart Connectors use the same grip and seal technology. The major difference between the two connectors lies in grip and seal actuation. The Smart Flange Plus connectors are actuated by the normal tightening sequence used in making the flanged connection. The Hydraulic Smart Connector is actuated with external hydraulic pressure. Once activated both of these connectors become permanently installed onto the pipe ends without the need for continuous tension or pressure from bolts or hydraulics. These connectors both have been used in both shallow and deepwater installations and repairs.[108,109]

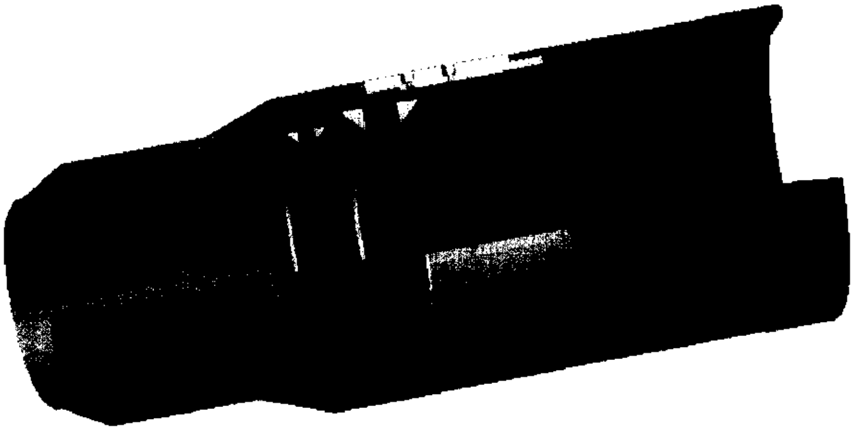


Oceaneering Smart Flange Plus Connector

(Source: Oceaneering Intervention International, Inc., #1025)

[108] Charalambides, J., Oceaneering, Telephone interview, March 2000.

[109] Pre-Qualification for Flowline/Pipeline Subsea Connectors & Jumpers, Oceaneering Intervention Engineering, January 19, 2000.

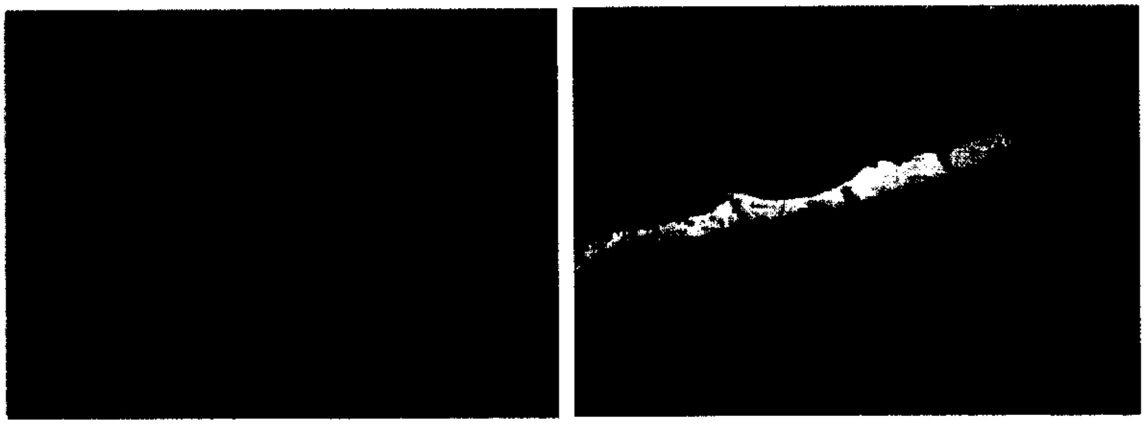


Oceaneering Hydraulic Smart Connector
(Source: Oceaneering Intervention Engineering, 2000)

Oceaneering Repair Experience:

In mid 1999, Mariner Energy's two (2) Dulcimer 4" flowlines were damaged before commissioning by a pipeline in bottom tow. The bottom tow wore similar elliptical holes in the top of both 4" flowlines. The damage was discovered during hydrotest when it was noticed that the pipelines would not hold pressure. The pipelines were located in the Garden Banks Area in approximately 1,100 feet water depth. This water depth was beyond the practical limits of saturation diving so an alternative solution was required. The solution was to perform the pipeline repair in the following sequence using the WASP ADS in conjunction with an ROV. The damage section of the pipeline was cut out and replace by a flanged pipe spool. The pipe spool was fitted with standard ANSI flanges. The flanges mated to Smart Flange Plus flanges that were installed on the prepared pipeline ends after the damage section was removed. The repair procedure was not completely diverless, however this was the first completely on-bottom deepwater pipeline repairs made in the Gulf of Mexico. This repair was performed from a 243 foot Multi-Service Vessel (MSV) Ocean Intervention. [110,111,112]

[110] Gorman, N. and Ellis, M., "The Dulcimer and Pluto Pipeline Repair Projects," Deepwater Pipeline & Riser Technology Conference, March 7-9, 2000.
[111] Charalambides, J., "Deepwater Pipeline Repair Oceaneering and Mariner Energy Push the Envelope," Underwater, Summer 1999.
[112] Huber, D.S., Weser, R., and Gorman, N., "On-Bottom Flowline Repair in 1,000 feet Water Depths," Offshore, June 1999.



Dulcimer Flowline Damage in 1,100 Feet Sea Water Before Commissioning
(Source: J. Charalambides, Offshore, 1999)

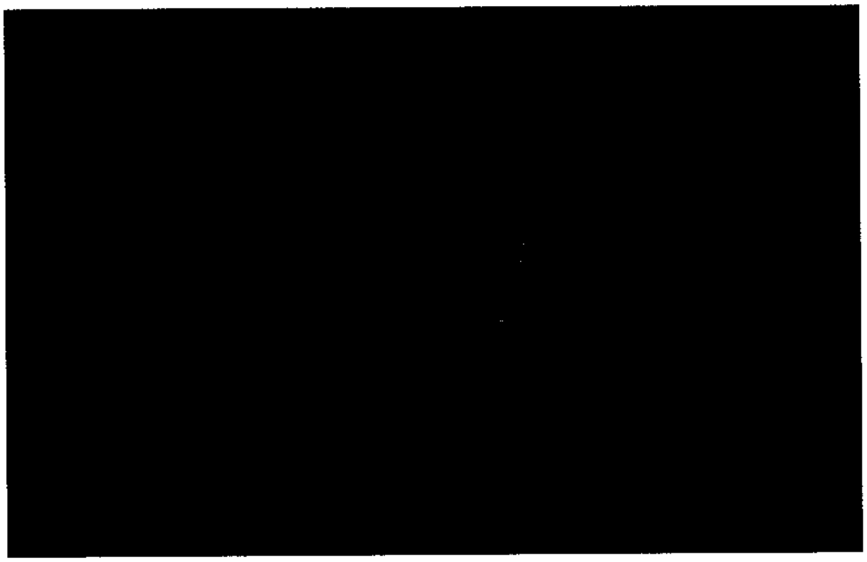
The Mariner Energy Pluto 8" deepwater pipeline repair was made in October 1999. The pipeline repair was made in the Mississippi Canyon Area in 2,150 feet water depth. The leak was discovered before commissioning during the pipeline hydrotest. An ROV located the leak at a weld seam. The pipeline repair was made by having the pipe lay contractor lift the severed pipeline ends to the surface after Oceaneering performed the pipe cut. Conventional ANSI flanges were then welded onto each pipeline end to be lowered and later joined by a conventional flange connection. A WASP ADS was employed to make up the flange connection subsea. The subsea work for the repair was performed by a WASP ADS in conjunction with a work class ROV from the MSV Ocean Intervention. Oceaneering built four (4) subsea pipe handling frames to provide complete access to the ROV and WASP ADS to the repair site and to allow for proper alignment of the pipeline ends for flange make up with the spool piece. The pipeline lay contractor used a pipe lay barge to lift the severed pipeline ends to the surface for welding.[113]

Oceaneering has been involved in several additional deepwater pipeline repair projects including the Shell Mensa 12" gas pipeline repair in 5,300 feet water depth in mid 1998, and the BP Amoco Troika 24" carrier pipe repair in 1,500 feet water depth in early 1999. Oceaneering provided ROV support and associated tooling support to help carry out the repairs on both projects. HydroTech collet connectors were used at Mensa to repair damage due to construction of the pipeline. A HydroTech repair clamp was used by Oceaneering to perform the repair on the Troika pipeline.

Oceaneering has several tools used as part of the deepwater pipeline repair system. Oceaneering utilizes a WACHS guillotine hydraulic saw, essentially acting as a subsea power hacksaw, to cut out sections of pipeline as part of a repair. The WACHS saw has proven to be an effective tool for cutting subsea pipelines. It completely cut the Shell Mensa 12" pipeline in 90 minutes during

[113] Gorman, N. and Ellis, M., "The Dulcimer and Pluto Repairs Project," Deepwater Pipeline & Riser Technology Conference, March 7-9, 2000.

the repair in 5,300 feet sea water.[114] The WACHS saw can jam when the pipe is put into certain stress configurations, therefore there may be some repair scenarios where this saw may be unsuitable.[115]

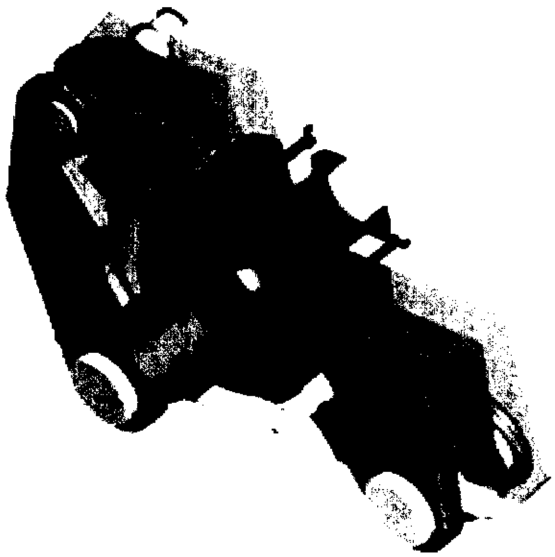


WACHS Guillotine Saw
(Source: D. Huber, R. Weser, and N. Gorman, Offshore, 2000)

A tool originating from OIE is the Pre-Measurement Tool (PMT), a taut wire metrology device used to measure pipeline end alignment for fabrication of a jumper or pipe spool that replaces the damaged pipeline segment. Based on the measurements performed by the PMT subsea, the jumper spool or pipe spool is fabricated to exacting dimensions to allow proper make up of the end connections. The on-bottom pipe handling systems consists of a set of A-frame supports with hydraulically manipulated pipe clamps.

In addition, Oceaneering has established a working agreement with Reflange, Inc. who produce the A-Con Variable Alignment Connector a remote hub-in-clamp type misalignment connector. This connector was designed for 10 degrees of misalignment from centerline and to be diverless installed in water depths up to 10,000 feet. This type of connection has the potential of offering more misalignment compensation and a cheaper alternative to traditional collet connectors. History with subsea hub and clamp connectors indicates that there have been problems in large diameter applications, which may pose a diameter limitation on the effectiveness of these types of clamps.[116]

[114] "Deepwater Pipeline Repair Intervention Techniques," Oceaneering International Inc., March 2000
[115] McCalla, J.M., Shell Deepwater Producing Inc., Telephone interview, April 2000.
[116] Charalambides, J., Oceaneering, Telephone interview, March 2000.



Reflange Remote A-Con Variable Alignment Connector
(Source: Oceaneering Intervention Engineering, 2000)

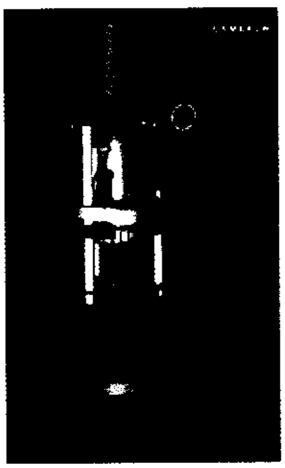
Oceaneering is able to offer deepwater pipeline operators a variety of tools and capabilities for the repair of deepwater pipelines. They have performed several industry firsts in the Gulf of Mexico including the first completely on-bottom deepwater pipeline repair. Oceaneering has currently proven their diverless on-bottom deepwater pipeline repair capabilities with the WASP ADS, which has a maximum working depth of 2,300 feet. Pipe handling capabilities of Oceaneering's equipment for on-bottom repair is limited to 14" pipe and smaller which limits repair capability to in-field flowlines and smaller diameter export pipelines. A comprehensive diverless on-bottom system must be capable of water depths for all current deepwater pipelines is currently in development. Oceaneering is taking a proactive role in developing tools to make a diverless on-bottom repair in any water depth using diverless pipeline repair tools based on Hydraulic Smart Connector technology. In February 2000, Oceaneering completed an order for BP Amoco including two (2) sets of Smart flange plus and two (2) sets of Hydraulic Smart Connectors each for the 10" and 14" Marlin project. These connectors were provided with WASP ADS and diverless field installation procedures for the Smart Flange Plus and Hydraulic Smart Connectors. The procedure for the Smart Flange plus was proven on the Dulcimer flowline repair. The procedure for the diverless Hydraulic Smart Connector installation has yet to be proven or full scale tested.[117]

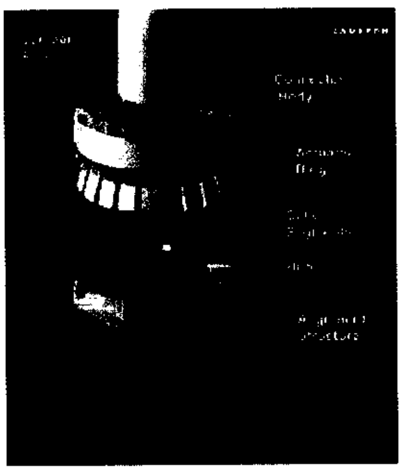
[117] Charalambides, J., Oceaneering, Telephone interview, April 2000.

OTHER DEEPWATER PIPELINE REPAIR, OPERATION, AND MAINTENANCE SYSTEMS:

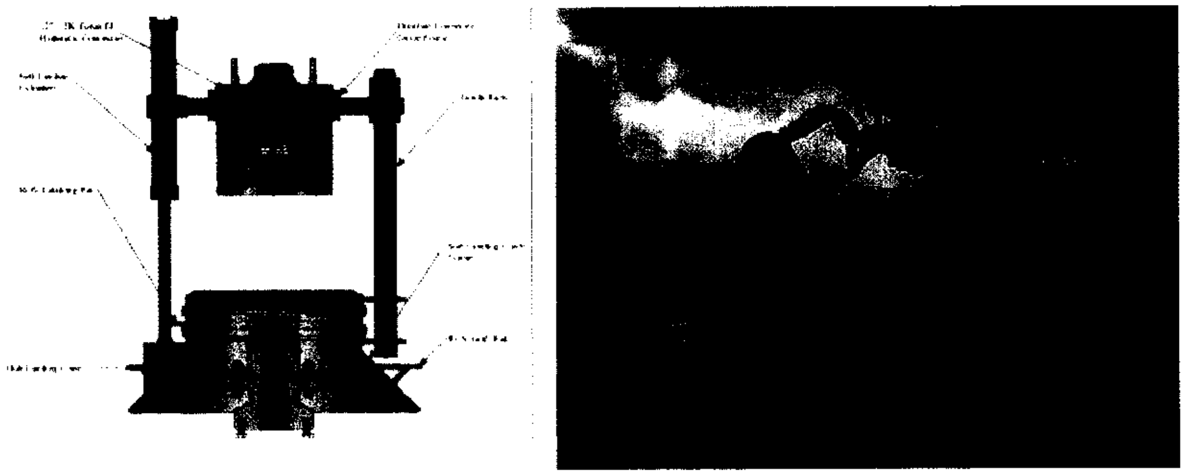
In addition to the major pipeline repair systems described above, there have been other approaches to address the deepwater pipeline repair challenge such as a flexible pipe system developed by Petrobras. The Petrobras system is known as the Vertical Connection System (VCS). This is a variation of the vertical jumper / collet connection system used primarily in the Gulf of Mexico. The VCS uses a length of flexible pipe connected to the end of a pipeline. The flexible pipe can either be attached prior to pipe lay down, or can be attached after pipeline installation by recovering the pipeline end to the surface. The flexible pipe is connected to a collet connector via a "goose neck," and the collet connector is attached directly to an upward looking male hub on a pipeline end skid or manifold. The use of flexible pipe only requires one (1) collet connection per jumper instead of the two (2) collet connections as required with "hard" pipe. This type of flexible pipe system can be less expensive than a typical "hard" pipe vertical jumper / collet system depending on flexible pipe requirements. The flexible pipe system does raise some reliability issues with many pipeline operators and in some cases cannot be used due to technical constraints. A splice repair of flexible pipe can also be risky depending on the nature of the damage. The use of flexible pipe does offer a viable alternative to the traditional method of pipeline repair.

Additionally, there are several mechanical connector manufacturers such FMC, Oil States HydroTech, Coflexip Stena, Vector International and Cameron who manufacture deepwater pipeline construction and repair components. FMC, Oil States HydroTech, and Cameron offer mechanical collet type connectors for diverless installation. These types of connectors offer varying degrees of misalignment and have been proven on numerous projects. These type of connectors are used most extensively in the Gulf of Mexico for deepwater construction projects. Oil States HydroTech provides a variety of mechanical subsea pipeline repair devices including collet connectors, repair clamps, pipeline isolation tools, and diverless recovery tools. HydroTech has been involved with the Shell and Statoil pipeline repair systems as discussed in the above sections. FMC has provided mechanical connectors to deepwater pipeline project worldwide since the 1980s including projects for Petrobras, Amoco Liuhua, Shell, Texaco, and Oryx. The most notable deepwater Gulf of Mexico projects include Shell Mensa and Texaco Petronius. FMC produces collet connectors that are typically used in vertical jumper construction applications.





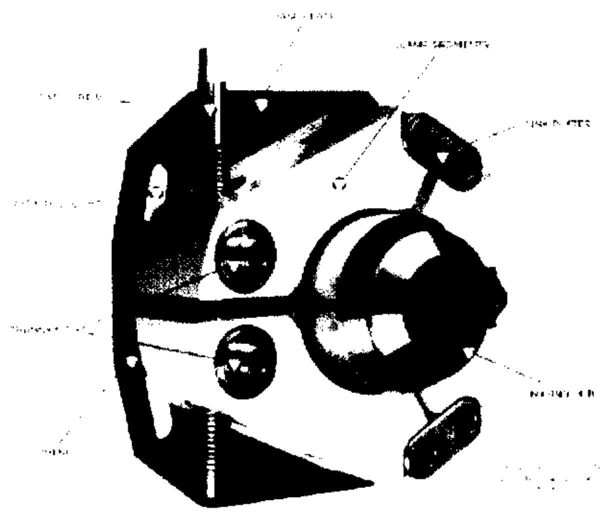
Cameron Vertical Collet Connector
(Source: Cameron, 1999)



FMC Torus III Hydraulic Connector with Soft Land Assembly
(J. Fitzgerald, 2000)

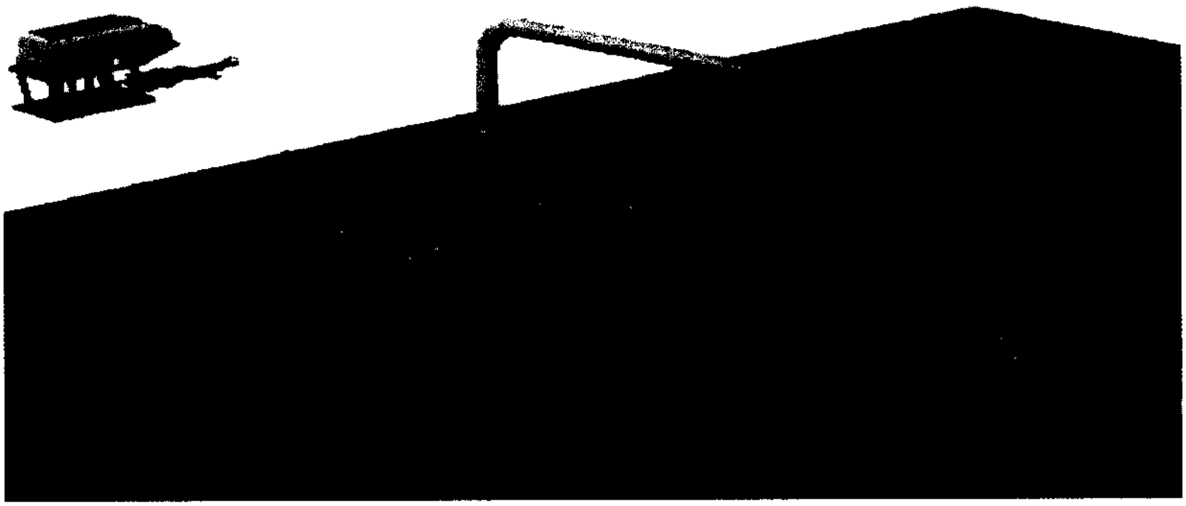
Vector International offers a diverless hub-in-clamp type connector capable of up to 5 degrees of angular misalignment and up to an API 15000 service rating in up to 10,000 feet sea water. This type of connection system would be applicable for small, high pressure flowlines originating from deepwater well equipment. The Coflexip Stena Flexconnect system connects pipelines, umbilicals, and bundles up to 19 inch diameter. The system is diverless and requires surface installation of hardware into the pipeline or umbilical ends. The development of this system was partially funded by the EC and the French government.[118]

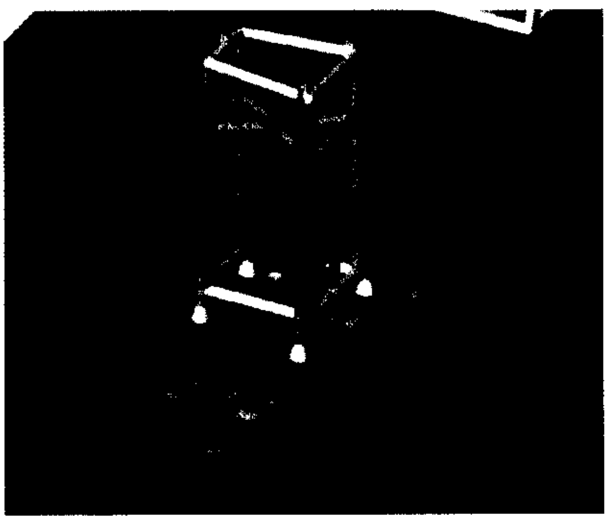
Vector International Optima™ Subsea Connector
(Source: K. Leaning, 1999)



[118] Leaning, K., "Vector Optima Subsea ROV Connector," Letter and Brochure, April 11, 2000.

Williams Field Services is sponsoring a JIP including Oceaneering, T.D.Williamson and Oil States HydroTech Systems. The JIP is focused on developing a diverless hot tap system. The design basis includes the accommodation of up to 20" ANSI 1500 systems in up to 8,000 feet sea water. A diverless hot tap would open up a variety of possibilities for deepwater pipeline operators including unplanned expansion of pipeline system in deep water and an alternative method for the remediation of hydrate plugs. The JIP started planning in 1997 with completion scheduled for 2000.[119]





JIP Sponsored by Williams Field Services: Diverless Hot Tap Concept
(Source: J. Charalambides, Oceaneering International, 2000)

[119] "Williams Designing Equipment for Deep-Water Pipeline Connections," Press release, October 27, 1999.

Technology originating from disciplines other than pipelines is providing further initiative for deepwater pipeline operators to escalate the development of deepwater projects. A variety of operations and support equipment is continually being developed to ease the transition of the industry into deeper waters. Some of this equipment includes subsea processing systems capable of processing oil and gas on the seabed, subsea pig launching for deploying pipeline cleaning and inspection devices subsea, subsea pipeline leak detection systems, and through wall pig location systems. A deepwater pipeline anode retrofit system was introduced by Deepwater Corrosion Services in early 2000. This device provides a reliable contact between pipeline and anode and can be installed with an ROV.

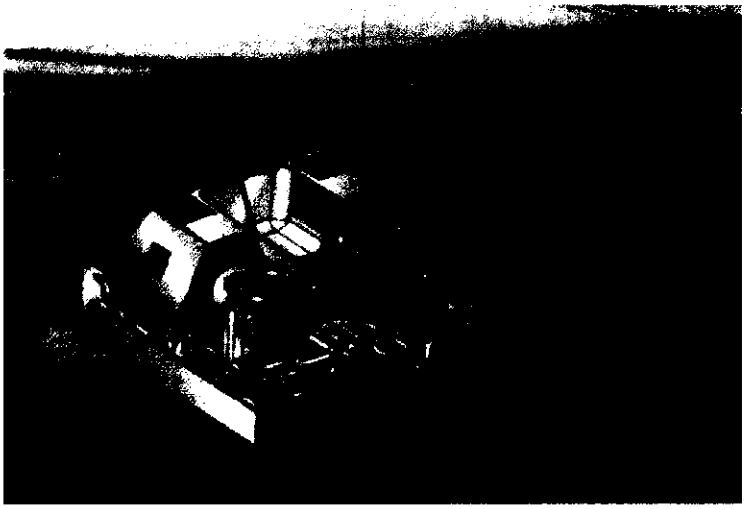
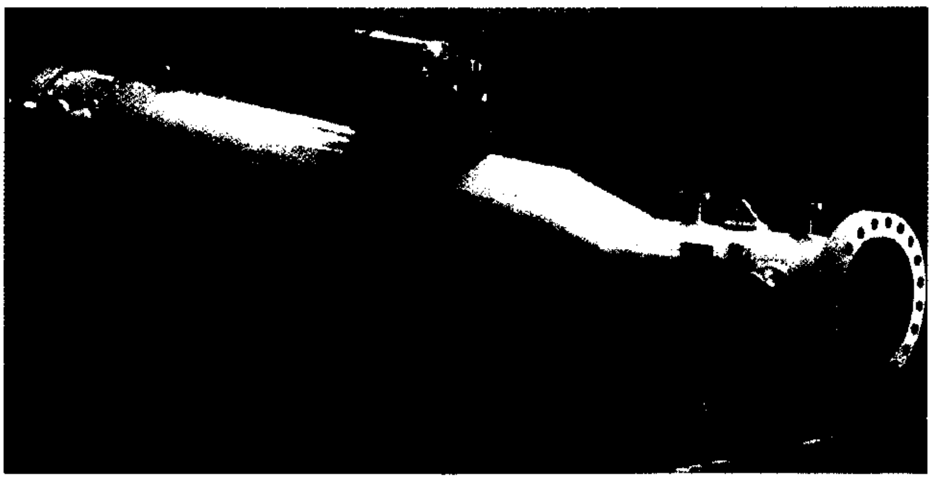
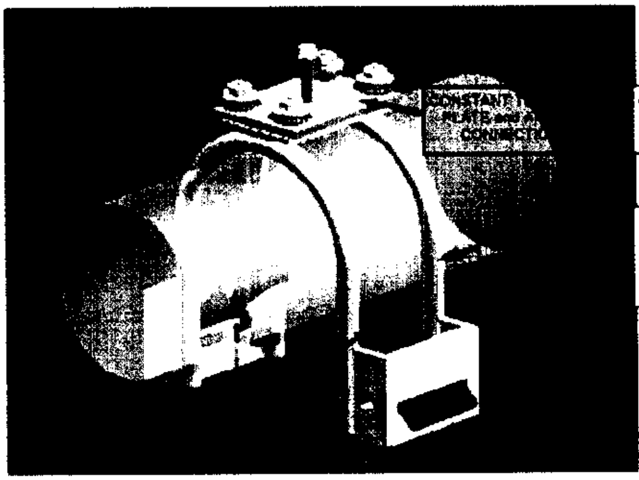


ABB Subsis Subsea Separation and Reinjection Equipment
(Source: Offshore Engineer, 1998)



Subsea Sphere Pig Launcher
(Source: Pipeline & Gas Industry, November 1996)




Retro-Clamp Pipeline Anode Contact System
(Source: Deepwater Corrosion Services, May 2000)

CONCLUSION:

Pipeline operators have funded research and development of deepwater pipeline repair systems for almost three decades. It has been in the last ten years that successful deepwater pipeline repair systems have appeared on the market. Recent deepwater pipeline activity in the Gulf of Mexico including construction related damages to several deepwater pipelines have intensified the development of repair systems. One operator in the Gulf of Mexico is currently developing a complete deepwater pipeline repair system that will be ready by the third quarter of 2000. JIPs and consortiums have provided much insight to the development of deepwater pipelines. In Europe, JIPs allowed the development of the first pipeline repair system components which served as the basis for the modern diverless on-bottom repair systems available today.

Funding for the first deepwater pipeline repair systems was provided by pipeline operators to ensure the reliability of their deepwater fields. Now that methods of deepwater pipeline repair have been tested or proven, there is a trend indicating that pipeline construction contractors are taking on an increasing role in repair system development. This development is taking place mainly in conjunction with pipeline construction projects later adapted for repair specific applications. Examples of this are the BRUTUS and MATIS pipeline tie-in systems. This evolution seems to be beneficial for both parties since the pipeline operator reduces construction cost, and the pipeline construction contractor receives incentive to develop equipment that can be used for future installation and repairs.

The high cost of deepwater development requires operators and contractors to pool both their financial and technical resources together. The deepwater pipeline repair system development problem has produced cooperation within the entire pipeline industry and among direct competitors in some cases. JIPs and other partnerships have encouraged the transfer of technology to provide world wide benefit. Now that systems are in place, all system developers are encouraging participation in existing systems from other operators. This participation allows the oil and gas industry to push further into deeper waters, and it will allow the repair system developer to defray some of the cost of system development and maintenance.

The industry worldwide has not seen a critical worst case deepwater pipeline failure to date, therefore experience with completely remote intervention, on-bottom systems has been acquired only during sea trials or construction projects. These systems have not been proven in the deepwater pipeline repair scenario, therefore is difficult to speculate on the effectiveness of existing equipment without further track record. There will be, however, several projects occurring during the middle to end of 2000 that will begin to push the limits of current technology. One of which is the Elf Girassol project that will prove diverless flange make up equipment in deep water.

As more pipelines are installed in deep water it is more likely that damages will occur. Overall, the industry has produced formidable pipeline repair equipment that continues to improve. By the end of 2000 the Gulf of Mexico will have world class deepwater pipeline repair equipment that will be able to address a more comprehensive set of damage scenarios than currently possible. Shell and its partners, Equilon and Coral Gas Transmission, will be looking for participants to buy into these systems. A model agreement for the administration of a repair system has been drafted in a DeepStar committee, which is largely based on the proven R.U.P.E. model. The effectiveness of this agreement structure if applied to larger scale deepwater pipeline repair systems is uncertain. It will be left to the non-participating deepwater operators to either buy into these systems and participate in their administration and maintenance or develop independent repair capabilities.

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APPENDIX 1
EARLY DIVERLESS REPAIR SYSTEMS
(Source: H.O. Mohr, 1996)

Ref. No.	Company	Type/Participants	Date	Scope	Status/Remarks
1	Exxon sponsored (performed/managed by HydroTech)	JIP - 16 participants	1973/1976	Repair 36-inch concrete coated pipe to 4,000 ft. water depth	Final report submitted 1976/1977 - No further work done and system not built. The repair system was based on HydroTech hydraulically activated mechanical connectors, and all pipe preparation done by large ROV's that were concepts and non-existent at the time.
2	Shell sponsored and managed by Shell	JIP - 6 participants	1974/1977	Repair 36-inch concrete coated pipe to 3,000 ft. water depth	Final reports submitted 1977. No further work done and no components built. The system consisted of a large catamaran type vessel that was deballasted and sunk on bottom and over the repair piece. It carried all work tools, repair devices, spool pieces, etc.
3	Hydro Tech/Oceaneering 1,500 ft. repair system	Funded by Statoil	1977	Repair 36-inch concrete coated pipe to 1,500 ft. water depth	Discontinued before completion. Statoil had commissioned several approaches by general contractors to develop alternate systems to repair pipes. HydroTech designed and built a special subsea manipulating frame that could apply mechanical connectors to make a repair - operated subsea by Oceaneering's one atmosphere diving suit. Project discontinued by Statoil for reasons unrelated to HydroTech/Oceaneering project.
4	Gulf Oil sponsored	JIP - 4 major participants	1981/1983	Repair pipes to 8,000 ft. water (size unknown)	Phase I and II performed through preliminary design. Phase III for fabrication drawings not funded. Project executed by 6 participating contractors. System based on used of existing equipment, large ROV's, and mechanical connectors.
5	SNAM Modular Repair System. Partially funded by THERMIE	Detail design and some construction of equipment by Snamprogetti	Mid 1980's	Replace a 40 ft. spool piece on 20-inch pipe at 2,000 ft. water depth for the 20-inch Trans-Mediterranean pipeline	Hardware constructed - none on standby. System consisted various frames and modules that were lowered over the pipe to perform various functions separately such as pipe cutting, concrete removal, etc. Connections were made using an expanding cold forging system.
6	HydroTech/Sonsub/Diverless Systems formed JV	JV called: Deepwater Pipeline Repair, Inc.	1988/1990	Repair 20-inch pipe to 2,000 ft. water depth	Attempted to form a JIP to study the concept and develop a stand-by repair capability. Industry not receptive to investing in repair capability. JV was dissolved. The system was based on using ROV's, mechanical connectors, and bottom manipulating equipment.
7	Partially funded by THERMIE and managed by Sonsub	Sonsub, Saipem, and Snamprogetti	1992/Present (Active)	Initially to repair 26-inch pipe to 3,000 ft water dept; being upgraded to 10,000 ft. water depth.	Some ROV operated equipment currently available from Sonsub. The system applied ROV's to perform all functions such as pipe cutting, coating removal, end preparation, etc. A mechanical connector (X-loc system) was used for connections. Field tested on a 550 ft. Long spool piece of 26-inch pipe in 1,200 ft. of water in Italy. Tests were inconclusive. Now being upgraded to 10,000 ft. water depth and shallow water trails in Norway by summer '97.
8	Statoil/Norsk Hydro	Funded by Troll Oil Pipelines and Haltenpipe	1994/Present (Active)	Initially to repair pipes up to 24-inch in 2,000 ft. water depth.	Field tested -- considered successful. System uses ROV's perform various tasks such as coating removal, pipe cutting etc. Connection made using mechanical connectors. A system that could make a 16-inch diverless is reportedly on stand-by.
9	Hydro Tech	Inventory owned by a major deepwater pipeline operator	1995/1996 (Active)	Stand-by repair capability using diverless repair clamps. Connectors not on stand-by.	HydroTech has designed, constructed, tested and placed in their inventory on stand-by, 3 diverless repair clamps in sizes up to 18-inch. Clamps can be installed by ROV's. Remotely operated mechanical connectors tested.
10	Texaco sponsored DeepStar project	JIP - 18 participants	1992/Present (Active)	Repair any size pipe at any depth in which it can be layed.	In progress - Concept is to cut pipe and retrieve ends to surface and weld on ends, lower to bottom and make connection with jumper system. This phase completed. Currently studying pollution minimization. No equipment constructed.
11	Snam/Saipem	Internally funded	1996/Present (Active)	Repair 20-inch/26-inch pipe to 3,300 ft. water depth	The connection system (connectors, cold forging tools and spool piece) will be built and tested by mid 97. The complete repair system that will also use many commercial tools (cutting, clean, H frames, etc.) will be tested at the beginning of 1998.

APPENDIX 2
MODERN DEEPWATER PIPELINE REPAIR SYSTEMS

	Shell	Oceaneering	Statoil	SNAM / Sonsub	Stolt Offshore
Title	Shell Deepwater Pipeline Repair System	Oceaneering Pipeline Repair System	Statoil PRS	D.S.R.S. / BRUTUS	MATIS
Concept	Surface lift repair supported by ROVs using vertical collet connectors and U/M shaped jumper; ROV supported on-Bottom repair capable using grip and seal connector hubs to join PLEM to pipeline ends; Surface lift 12", 14", 16", 18", 20" capable to 5,325 feet	WASP Atmospheric Diving System based repair supported by ROV using Smart Flange Plus flange connectors	Hyperbaric welding repairs to 1,200 fsw 10" - 42" diameter capability; ROV supported Diverless, on-bottom tie-ins to 2,000 fsw using Morgrip to connect horizontal spool piece to pipe end: 8" - 20" diameter capability	D.S.R.S.: 20" and 26" complete pipeline repair system to 2000 fsw supported by ROV(s) using telescoping horizontal spool piece; mechanical forge pipe end hubs and telescoping joint; horizontal collet connectors; suite of subsea tools available for pipe preparation and handling	Diverless modular flange tie-in system supported by ROV for up to 12" pipe in 10,000 fsw; suite of pipeline preparation and handling tools
Advantages:	Surface lift and on-bottom capable; both concepts use proven equipment and tooling; sleeving allows the use of one collet connector size for all diameters covered	Repair system capable of being deployed from small DSV	Diverless on-bottom repair system; tested during pipeline construction	Diveless on-bottom repair system; suite of subsea pipe preparation and handling tools fit up to 26" pipe diameter	Portable; capable of being deployed from DSV; ultra-deep water capable
Limitations:	Covers five pipe diameters	Limited to 2,300 feet water depth; applicable to pipe diameters 14" and smaller	Large diameter specific components; not as portable as other systems; requires diameter specific Morgrip connectors on standby	System limited to two pipe diameters 20" and 26	Limited to small diameter pipelines; modules are diameter specific
Operator/Partners	**Shell**; Equilon; Coral Gas	**Oceaneering**	**Statoil**; Norske Hydro; Phillips Petroleum	**Snam / Sonsub**	**Stolt Offshore**
Phase of Development	Scheduled to be fully operational by Summer of 2000	WASP Atmospheric Diving System fully operational; diverless/on-bottom repair system capable using Hydraulic Smart Connectors or other Mechanical connectors 14" diameter and smaller	Lighter, more portable system under development; 20" - 42" diameter capability will be fully operational by Summer 2000	BRUTUS diverless flange tie-in/connector pull-in system under development; up to 26" diameter capability; fully operational by Summer 2000; integration of D.S.R.S. / BRUTUS proposed as a repair system	New system "Deep Matis" scheduled for sea trials in June 2000; scheduled for construction project offshore West Africa in November 2000
Project Experience	Surface lift repairs to 5,300 feet water depth	On-bottom WASP assisted repair; surface lift WASP assisted repair; ROV support on several diverless repair operations; No diverless repair experience		D.S.R.S. underwent last sea trials in 1998; diverless flange tie-in perform on an offshore pipeline construction project in 1997	Performed 8" mid-line construction tie-in on the Statoil Loke Project in June 1999 in 260 fsw
Location/Availability	Gulf of Mexico	Gulf of Mexico	North Sea; 12", 20", and 42" Morgrip connectors and 42" diverless repair clamp in stock for emergency diverless repair	D.S.R.S - Mediterranean Sea BRUTUS - North Sea	North Sea
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