# Permanent Weldless Deepwater Repair Strategies

## 1. Abstract

The need for subsea pipeline repair is not always limited to the results of unexpected damage through failure to protect, but can encompass future field/life extensions and subsea bypass during decommissioning. As production extends into harsher and ever deeper environments, new challenges are constantly emerging. These include issues such as pipeline material selection, manufacture and installation, well fluid compositions, along with increasing pressures and temperatures and other infield operational demands. This paper explores these growing technical and commercial strategies that are being adopted within the industry, and illustrate in case studies.

## 2. Introduction

The pinnacle of a pipeline repair is the successful recommissioning test once the repair is concluded. In order to ensure this stage is reached it is vitally important that the foundations of the repair strategy are sound. This means that no aspect of the repair should be assumed until the prior step/assessment is complete. With all pipeline repairs the first foundation stones to be laid includes root cause analysis of the damage, understanding of the location, geography and environment, and assessing the technical requirements of the pipeline system predicting future field life. These items will be briefly addressed in the next section.

When the operator choses to pursue a pipe intervention operation (whether planned or emergency repair) these foundation steps will help assess, critique and select the correct method with which to proceed. It will also lay out key technical requirements that need to be detailed to ensure the solution is fit for purpose. Key solutions include:

- Permanent or temporary
- Welded repair: On deck/subsea/hyperbaric
- Connector repairs: Flange/hub adaptor or pipe-to-pipe coupling
- Clamps repairs: Structural or non-structural
- Leak sealing: Injected epoxy or wrapping
- Diver installed or remotely operated

The following chart provides the basics steps required to complete a pipeline repair, regardless of cause or location.

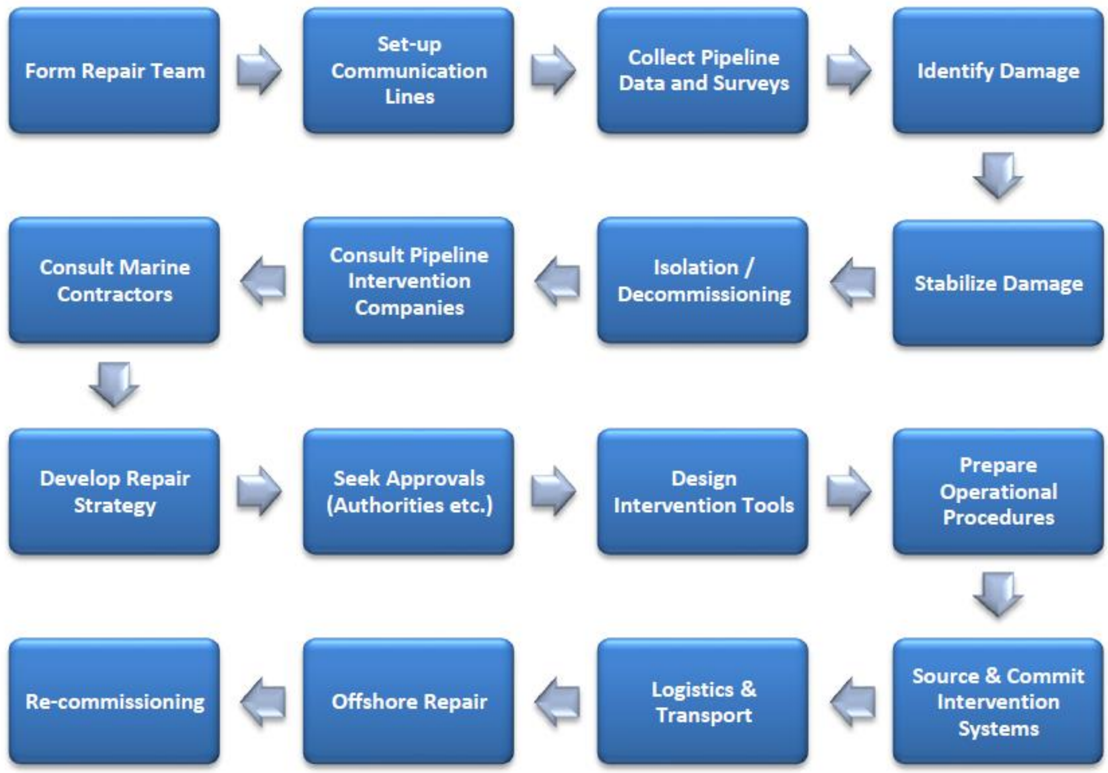



Figure 1: Repair Process (supplied by IRM Systems B.V.)

For the purpose of this paper we will focus on the following key Steps:

- Identifying Damage – Root Cause analysis
- Develop Repair Strategy
- Design Intervention Tooling
- Offshore Repair (Case Studies)

based on the experience of the authors, we will only focus on the strategies concerning permanent weldless remote operated intervention strategies for pipelines and risers. We will class “permanent” as a repair solution that addresses the full structural capacity of the pipeline as well as the secure sealing of the leak. These pipeline repairs solutions and methods are detailed in DNV-OS-F101 (Submarine Pipelines) and DNV-RP-F113 (Repair of pipelines).

# 3. Identifying Damage

## 3.1. Root Cause Analysis

Pipelines are under constant risk of damage. Table 1 below is referenced from DNV-RP-F107: "Risk Assessment of Pipeline Protection" and provides some typical hazards that can cause damage to risers, pipelines and umbilicals.

Table 1. DNV-RP-F107: Risk Assessment of Pipeline Protection

| *Operation/activity* | *Hazard* | *Possible consequence to pipeline* |
|---|---|---|
| Installation of pipeline | Dropped and dragged anchor/anchor chain from pipe lay vessel<br>Vessel collision during laying leading to dropped object, etc. | Impact damage |
| | Loss of tension, drop of pipe end, etc. | Damage to pipe/umbilical being laid or other pipes/umbilicals already installed |
| | Damage during trenching, gravel dumping, installation of protection cover, etc. | Impact damage |
| | Damage during crossing construction. | Impact damage |
| Installation of risers, modules, etc. (i.e. heavy lifts) | Dropped objects | Impact damage |
| | Dragged anchor chain | Pull-over and abrasion damage |
| Anchor handling (Rig and lay vessel operations) | Dropped anchor, breakage of anchor chain, etc. | Impact damage |
| | Dragged anchor | Hooking (and impact) damage |
| | Dragged anchor chain | Pull-over and abrasion damage |
| Lifting activities (Rig or Platform operations) | Drop of objects into the sea | Impact damage |
| Subsea operations (simultaneous operations) | ROV impact | Impact damage |
| | Manoeuvring failure during equipment installation/removal | Impact damage |
| | | Pull-over and abrasion damage |
| Trawling activities | Trawl board impact, pull-over or hooking | Impact and pull-over damage |
| Tanker, supply vessel and commercial ship traffic | Collision (either powered or drifting) | Impact damage |
| | Emergency anchoring | Impact and/or hooking damage |
| | Sunken ship (e.g. after collision with platform or other ships) | Impact damage |

The main causes of failure of pipelines have been researched by the Institute of Petroleum, UKOOA and HSE in their PARLOC 2001/1/ report which provides statistical information on incidents in the North Sea and the Gulf of Mexico.

At the time the report was issued, a total of 1069 carbon steel pipelines were in operation in the North Sea, with over 32,400km of pipeline in the Gulf of Mexico. Corrosion proved to be the most reported fault (27% North Sea, 40% GoM). Between the period of 1971 and 2001 there were a total of 65 reported incidents which resulted in a leakage, the causes of which are illustrated below:

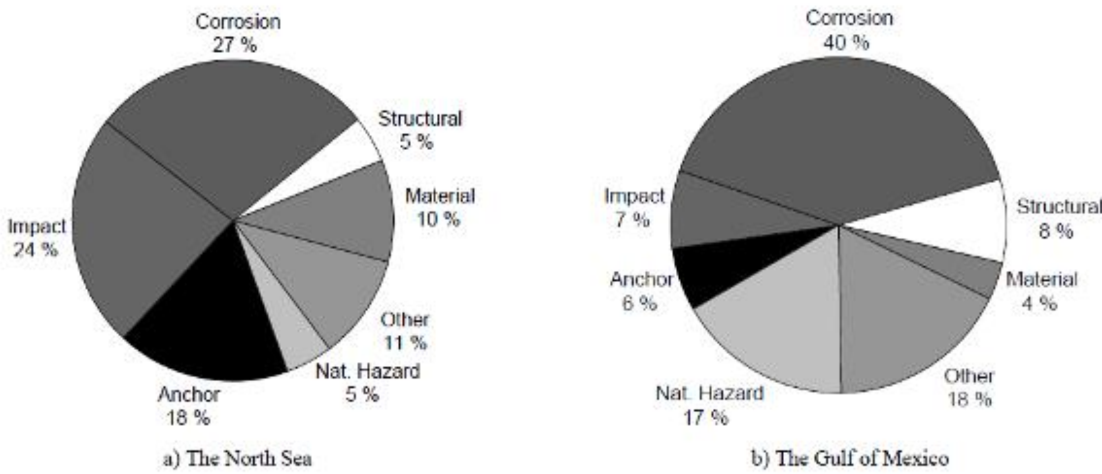
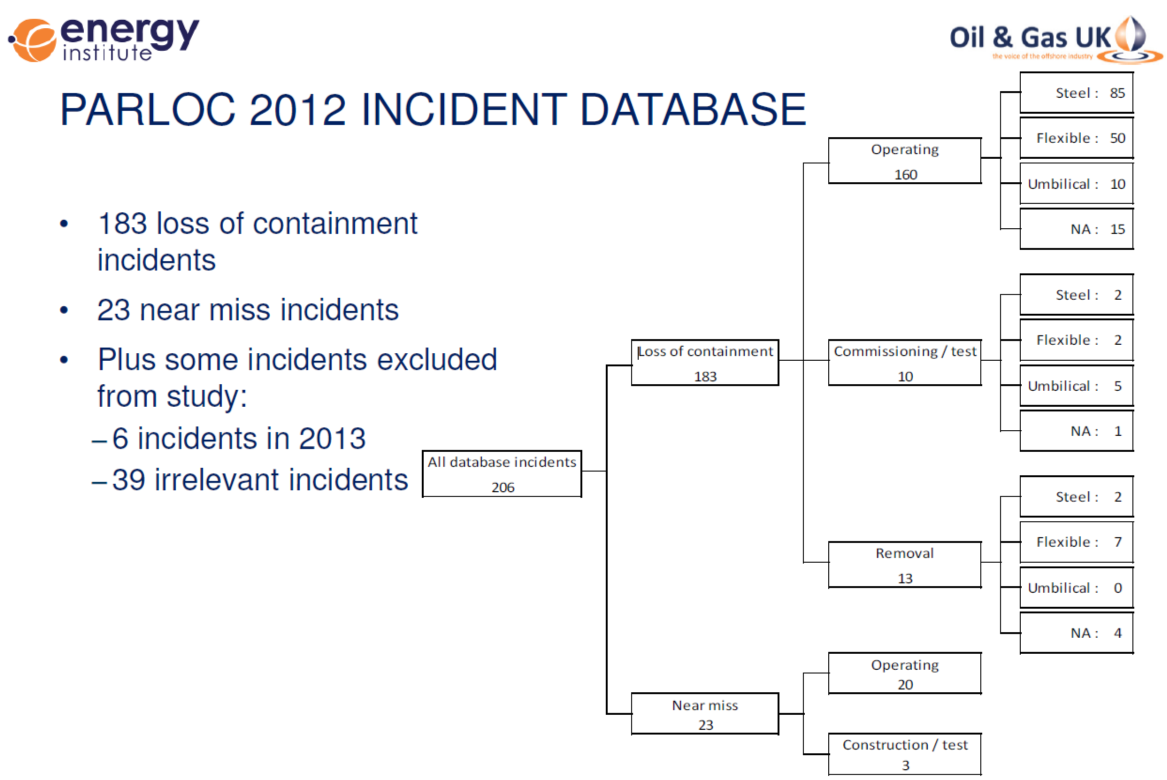



**Figure 2: All reported incidents in percentage for (a) North Sea, and (b) the Gulf of Mexico (DNV-RP-F116)**

The most recent Pipeline and Riser Loss of Containment (PARLOC) report by Oil & Gas UK and the Energy Institute, details incidents over a 12-year period from 2001 to 2012 in the UKCS. It found 183 loss of containment incidents and 23 near miss occurrences across 1,372 steel pipelines and risers and 1,288 flexible pipelines and risers in the UK sector of the North Sea, West of Shetland and Eastern Irish Sea.



## 4. *Develop Repair Strategy*

### *4.1. Geography*

Regardless of what technology exist in the market, the ability to bring that technology to the correct location is key:

- Geographical locations offer many challenges from import and access (trade sanctions) to local skills and service (proximity to manufacturing hubs)
- Geological features can affect the seabed conditions and topography of surface location providing unique challenges (shear strength and surface incline)
- Environmental conditions including water currents, visibility and seasonal changes can change both the repair strategy and schedule

### *4.2. Technical Considerations*

The technology deployed within offshore oils and gas fields is also constantly developing, changing and growing. To make the most of the available fields, subsea assets are required to operate with increased efficiency and at higher temperatures and pressures. The well fluid composition can also change over the life of field introducing issues such as the presence of carbon dioxide ($CO_2$) and hydrogen sulphide ($H_2S$) which can cause severe corrosion problems in both oil and gas pipelines. These challenges have led to many Operators evaluating and deploying a variety of engineered pipeline solutions, including corrosion resistant alloy (CRA) Clad and Lined Pipelines, Pipe-in-Pipe (PiP) systems, Stainless Steel, Duplex and other exotic pipeline materials. To further magnify the challenges faced in a pipe intervention operation, Operators may also need to consider risers (both Steel Catenary, Flexible and hybrid).

### *4.3. Identifying the Solution*

The root cause of the repair, location and extent will determine whether the solution needs to be a weld, clamp, wrap or a mechanical connector. The extent of damage and future field life (or the operational plan) will determine whether the repair needs to be permanent or temporary. The geographical location will determine whether a fully remote system, an ROV operated system or a diver operated system can be used.

In any case, early engagement with the Original Equipment Manufacturers (OEMs) or third party design houses to assess potential solutions on the market are essential from the early stages to ensure that all potential repair options that are available are to be considered.

### 4.4. Ensuring Integrity

Once the Operator has a preference for the repair solution, consideration for the installation requirements can then be addressed. To mitigate operation risk the key interface points between the repair products and the original assets must be addressed. These include:

- Pipe manufacturing tolerances (straightness, roundness, ovality, etc)
- Pipe Coating Removal
- Pipe cutting and end preparation (bevelling)

In situations where the data is not available or cannot be confirmed through inspection, the design basis for the equipment needs to be broadened to cover a greater bandwidth.

The repair products should undergo a full Factory Acceptance Test (FAT) prior to mobilisation. The FAT should encompass both a Hydro/gas test at a test pressure defined through industry codes, and if possible the testing should take place on a like-for-like test spool.

Load testing may also be carried out if the pipe system requires it.

Site Integration Tests (SIT) are not required, but recommended to ensure the integrity of the complete system. This testing encompasses all supporting equipment to help prove the operational steps and procedures.

## 5. Design Intervention Tooling

There are a number of basic steps that need to be carried out to enable a pipeline repair. To illustrate how the complexity of these steps increases with water depth, the table below provides an overview of the process for divers vs. the process for ROV/ Remote systems.

| Step | Diver Installed | Remote Installed |
|---|---|---|
| **Static pipeline needs excavated/ exposing** | Trenching/ excavation<br><br>Buoyancy | Remote/ ROV Trenching/ excavation<br><br>Remote pipe handing frames |
| **Remove coating** | Water pressure lance | ROV pipe coating removal tool |
| **Pipe Cutting** | Subsea pipe cutting tool | ROV pipe cutting tool |
| **Inspect seal surface** | Visual Inspection | ROV Pipe inspection tool |
| **Aligning connector** | Diver handling with airbag support | Hydraulic controlled positioning system |
| **Installing connector** | Diver handling with airbag support | Hydraulic controlled positioning system |
| **Verifying connector position** | Visual Inspection | Sensors with electronic feedback to surface |
| **Activate connector** | Standard Subsea Tensioners | Remote Operated Subsea Tensioners |
| **Seal verification test** | Diver handling + Hydratight tools | Remote operated hydraulic test system |
| **Recover installation equipment** | Diver handling | ROV operated disengagement system |

### 5.1. Pipe Handling Frames

Remote or ROV operated handling frames must be designed to accommodate the soil, ground conditions and incline at the repair location.

To increase the value of the handling frames, the functionality can be increased to enable movement and positioning of the pipe. Using the pipe handling frames as a means of alignment build robustness into the system while enabling simpler functionality on other intervention tooling.

**Figure 3: Remote pipe lifting frames supplied as part of the Petrobras CRD pipelines repair system. Rated up to 2000m, have been used in over 700 free span correction operations**

### 5.2. Coating Removal

Given that all remote repair solutions are designed specifically for the exact pipe dimension, material and tolerance - It is imperative that the coating of the pipe is completely removed without any damage to the parent material. Mechanical or water jetting methods may be used to cover a variety of coatings including FBE and concrete weight coating. Often each tool is calibrated for a specific coatings so in some instances multiple tools may be required.

Although it may be tempting to increase the functionality by using the same tool on a variety of coatings, as the operation bandwidth increases it is likely that the effectiveness will decrease. This will increase the risk of the key interface between pipe and repair tool being out of design tolerance.

Figure 4: Coating Removal Tool with buoyancy

Rather than reduce the tooling, it is worth deploying a secondary tool to verify the wall thickness, straightness, end bevel and coating removal.

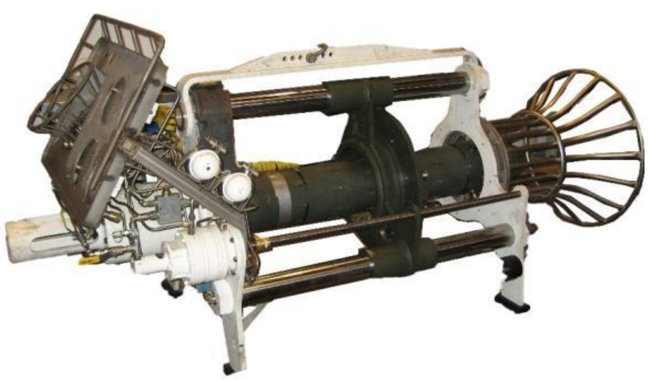


Figure 5: Pipe End Preparation Tool

### *5.3. Connector Alignment, Installation & Activation*

Once the pipeline is prepared the repair solution must be aligned, installed, activated and tested (usually through a 1.1 x Design Pressure, back seal test). These systems vary on the pipeline size and location (horizontal to vertical) but can be grouped into 3 catagories:

1) Horizontal Installation Frame (goes over the pipe)

2) Horizontal Installation Trolley (goes under the pipe)
3) Vertical Installation System (hands from the riser)

All three systems have a degree of variation to cover +/- 15% incline from vertical or horizontal, covering the majority of pipelines in operation.

Figure 6: Statoil Coupling Installation Frame (CIF) with integrated pipe handling suitable for 6" - 30" pipelines

# 6. Offshore Repair Case Studies

## 6.1. Hybrid Riser Repair, 4" gaslift riser at 1300mwd

Two 4" gas lift risers at the base of a hybrid riser system were damaged during the original deepwater installation operations in the Atlantic Ocean, Offshore Angola. To ensure future production, it was essential that the damaged sections were bypassed.

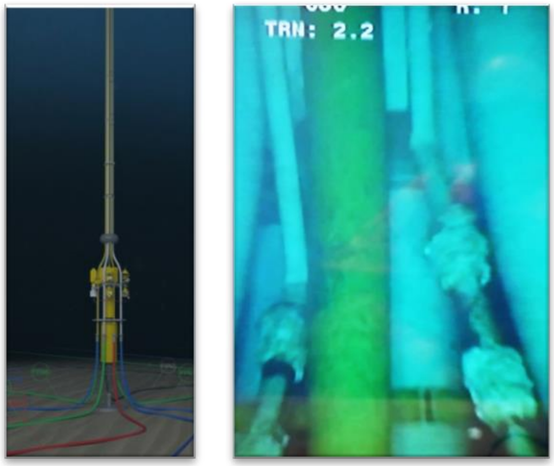



Figure 7: Location of damage

Located in water depths varying between 1,200 meters and 1,500 meters, the damage to the risers was at 1,300 meters making this one of the deepest repairs ever attempted and with the risers secured in the bundle near the base of the tower, would require a completely new repair strategy implementing a solution deployable in a restricted environment, 50m above the seabed.

The solution had to be permanent (in accordance with DNV F101/F113), of proven technology (TR6 or above in accordance with API 17N) and suitable for confined space envelopes. Remote Mechanical Connectors are a field proven method of repairing pipes in deepwater, so the challenge lay not with the design of the permanent repair method, but the means of installation without support from the surface or the seabed.

In order to deploy a connector repair, the damaged pipe would have to be released from the riser bundle, the coating would then have to be removed and the correct cuts made. Without overstressing the riser, the connector would then have to be aligned, installed, activated and tested allowing the new flexible jumper bypass to be attached.

To support the completed repair, a high-load structural clamp would have to be permanently fixed to the riser bundle, providing a means to limit the motion of the new repair spools. All work would need to be conducted by ROV in 1300mwd, approximately 50 meters above the seabed.

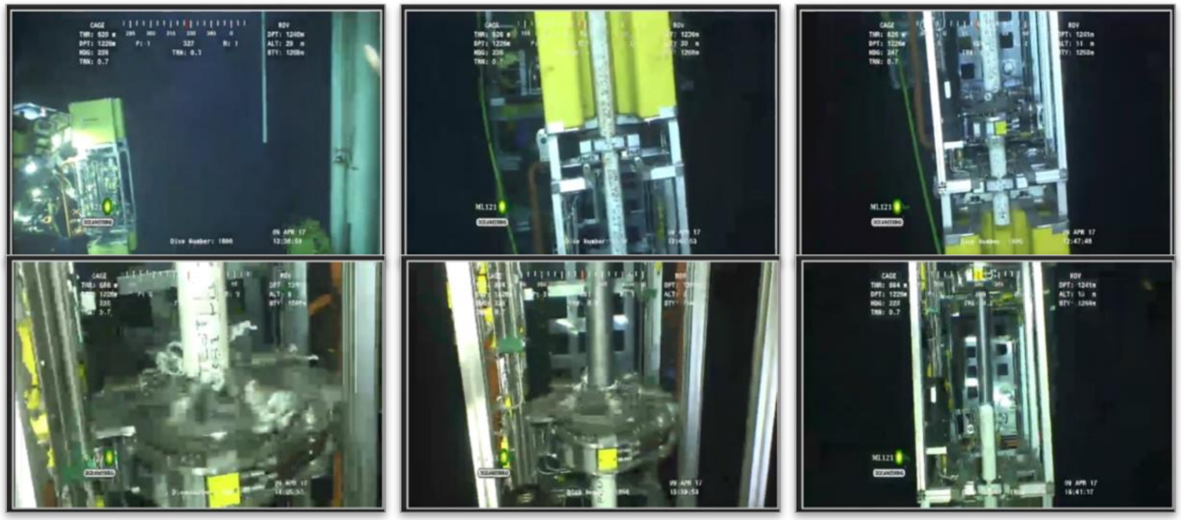


Figure 8: Coating Removal

The solution was to have a removable, low-weight installation system hang off the existing riser. Controlled from the ROV, the system would allow the installation of a Mechanical Connector. Through supplying both the connector and the installation system under the same contract, the collaboration between Hydratight and Connector Subsea Solutions was able to develop the systems alongside one another—ensuring that the key interface points were carefully managed to reduce operation risk and increase the level of assurance provided to the project.

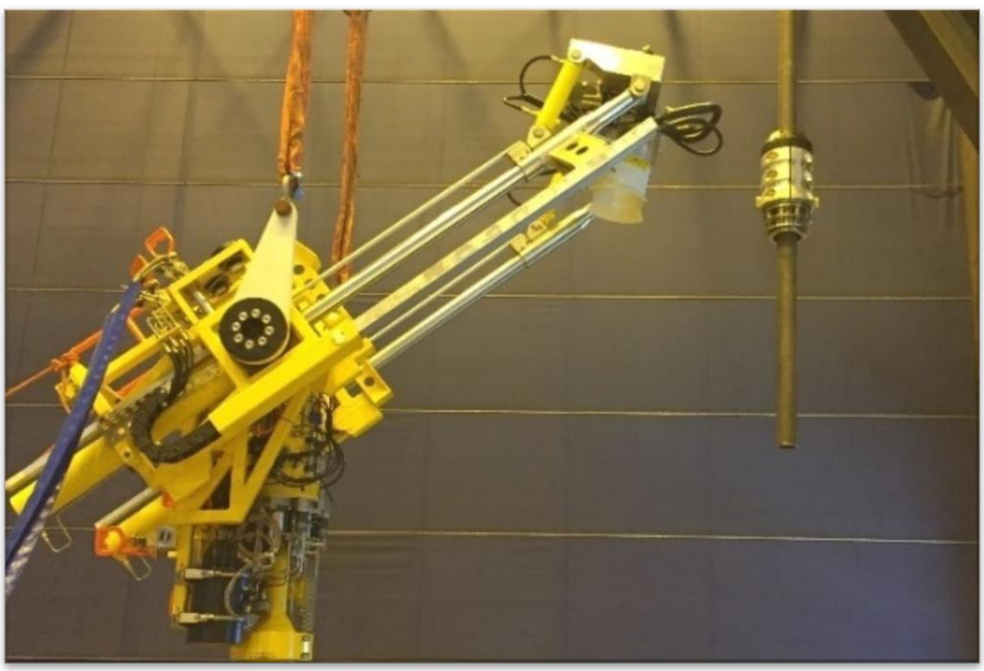


Figure 9: Vertical Installation, Alignment & Activation Frame (VIAA) with the mechanical connector mounted

The full tooling included the high load clamps and remote clamp installation tools, the coating removal tools, a 3D buoyancy milling tool, the connectors and the alignment and installation frames.

All equipment had to be ROV compatible and supported with an ROV skid and control systems.

The Operator and partners had to be convinced of the permanency of the repair solution, which took detailed analysis, extended testing, documented and video evidence as well as various levels of technology (TRAP) review. The use of a metal graphite composite seal was a key differentiator as it has been proven superior to an elastomeric seal.

The project required an eight-week Extended Factory Acceptance Testing (EFAT) program at an independent facility. This stage included 12 pipe activations, hydrotests, gas tests, temperature/pressure cycling and external load application. The connectors then travelled to Norway for site integration testing. The final stage was shallow water testing involving the use of an ROV to remotely activate and hydrotest the complete system.

The regulatory process from the operator and industry bodies required a stringent Technology Readiness & Acceptance Process (TRAP) to ensure the technology was mature. Video animation was provided to detail each step of the repair process and showcase the planned operations to mitigate any risks at an early stage.

Once in location, the system was deployed over a one month timeframe during favourable weather windows, leading to the successful repair of both risers - an innovation milestone for the industry.


Figure 10: Completed installation of remote connectors

## 6.2. Horizontal 4” 400bar MEG line at 830mwd

A major NOC experienced a deepwater pipeline fracture offshore Western Australia which required urgent repair. A fracture was detected on a 400bar four-inch MEG line, located at 830m. The Operator required a permanent, field - proven repair on a minimal lead time. Due to the location and environment the entire project had to be carried out remotely, using ROV compatible tooling. Furthermore the weight of the repair had to be minimal so as to not overstress the pipe.

The need for a high pressure repair conflicts with the requirement for a low weight solution. Typically in order to achieve a high seal pressure the seal needs to be put under a very high load stress. The load it typically transferred through bolting – the higher the load, the larger the bolting and the surrounding material to react from.

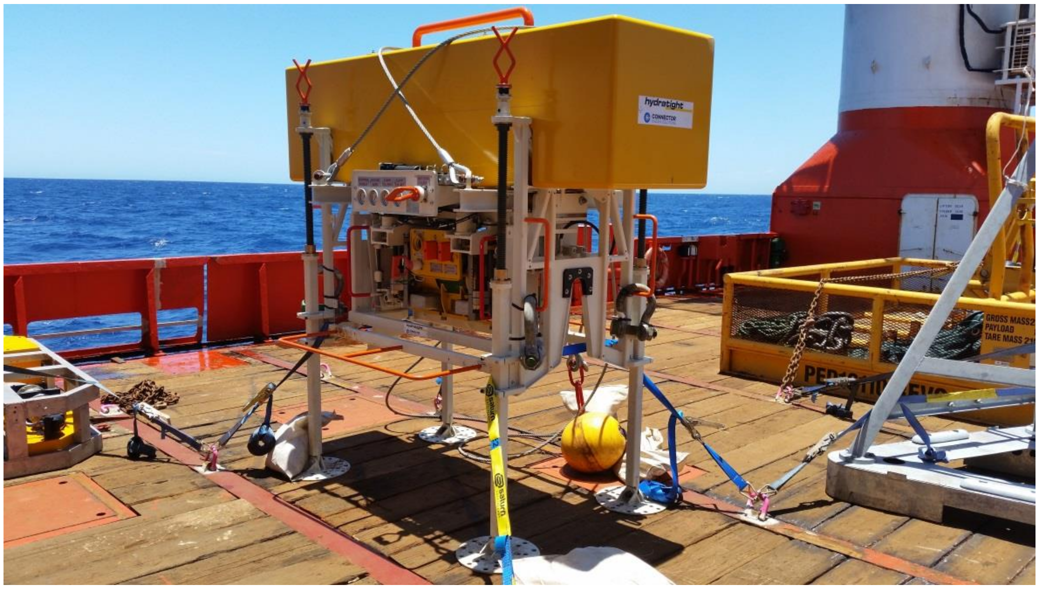


Figure 11: Remote boltless clamp with external activation tool

A clamp was custom-fabricated for the specific requirements. All activation system technologies and hydraulics were within a separate retrievable tool, to reduce weight, fatigue and cost. It would ensure that the fracture was repaired rapidly and with minimal impact on the underwater environment. A high-performance ROV-based Coating Removal Tool was also supplied to ensure the interface between the pipe and clamp was as required, removing all sea-growth, debris and the original protective coating to provide a clean surface for the repair.

Once in location, the system was deployed leading to the successful repair of the pipeline - an innovation milestone for the industry.