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# Repair methods for damaged pipeline beyond diving depth

Master Thesis / Marine and Subsea Technology

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Spring 2011

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## Preface

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This is a master thesis report under the course MTEMAS-Master Thesis Offshore Technology spring 2011.

I would like to acknowledge:

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|Stavanger, spring 2011

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Keramat Mohammadi

## Abstract

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Mechanical damage of a subsea pipeline is found as one of the most severe concern in management of pipeline integrity. The need to reach and bring the hydrocarbons from the fields located in deep and ultra-deep waters, imposes the need to improve the technologies and techniques in order to repair any unacceptable damage in pipeline. The main objective of this work is to investigate various methods for repairing a subsea pipeline that has been damaged and that is below diving depth. The investigation covers the methods that are applicable for three different water depths of 150, 350 and 1350 meters, two different pipe sizes of 12 and 28 inches and two different length of lines: 5 km (e.g. in-field pipeline) and 500 km (e.g. export pipeline). Since the cause and severity of damage determines the necessity and type of required repair, it is significant to study different scenarios of damage: dent, crack (field joint) and corrosion. For this purpose, the studies and investigations that have been performed so far will be reviewed. Welding sleeves and mechanical couplings provide the main solutions for major damages. High pressure and structural clamps are also repair tools for minor damages. Remote welding concept is under development for deep waters. The repair challenges have been discussed and some ideas are concluded. The idea of Angled-clamp that is presented in this project can be developed for the damaged angled pipes and for spool connection where alignment is hard to achieve.

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## 1 Introduction

### 1.1 Deepwater development

The exploration for new hydrocarbon resources is being extended to the areas that urge new technologies or methods of development and operation. The frontier fields are in the depth of 3000 meters as of 2010 (Figure 1-1). The deepest subsea well is at depth of 2,934 meter in US GoM in Shell's Tobago field where the average depth of the field is 950 meter (Callanan, 2010).

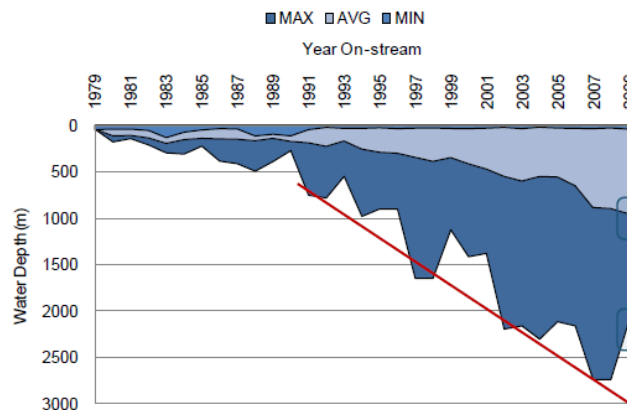


Figure 1-1. Subsea Wells On-stream and Water Depth Trends (Source: Infield Systems)

Further to barriers within the design, construction and installation phases of the development, the challenges with operation, maintenance, modification and repair should be overcome.

The costs with the repair contribute to the Life Cycle Cost (LCC) of a project. For the deep and ultra-deep waters, apart from the costs, the feasibility of the repair is a matter of concern. Normally, a contingency plan is in place and it results in reduction of the operation risks by limiting the consequence of incidents (or even the probability of an incident in the case of preventive maintenance).

Due to the depth, there are challenges in different aspects of a pipeline repair operation:

- Pipeline integrity compensation
- Repair tools/deployment
- Marine operations

The water depth may affect the type of the integrity compensator since the hydrostatic pressure is high and normally the production conditions can be complicated. The environmental risk (Pollution) is also a significant item.

For the shallow water, the traditional diver-assisted repair method is the immediate option. When it comes to the deeper water, employing subsea robots (ROVs) is unavoidable, since the diving depth is

limited to 180 meter in Norwegian Standard (NORSOK U-100). Robotic tools and hydraulic and electrical instruments encounter the challenges in deep and ultra-deep waters.

Marine operation challenges in deep water cover the vessel maneuvering, operation scheduling, lifting/pulling requirements, and so on. Since seabed remote operation needs special tools with a weight in usual range of offshore/subsea installations, therefore for the activities in the vicinity of sea bottom faces fewer challenges.

## 1.2 Pipeline integrity

Pipeline system integrity is defined as the pipeline system's structural/containment function [DNV-RP-F116]. As the main purpose of a pipeline system is the fluid flow, the pipeline is designed, constructed, installed and operated such that the fluid is transported under the required conditions. Any corrective action that shall be done in order to bring back the pipeline into the desired (designed) situations (or one may call it pipeline duty), following any structural deficiency, is defined as pipeline repair. Figure 1-2 illustrates how a threat can lead to failure and how the repair activity can protect the system against the failure. Two main failure modes can be considered for the pipeline's containment/structural function:

- 1) Loss of containment - leakage or full bore rupture.
- 2) Gross deformation of the pipe cross section resulting in either reduced static strength or loss of fatigue strength.

[DNV-RP-F116]

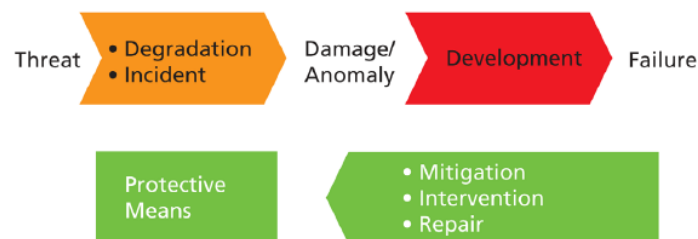


Figure 1-2. From Threat to Failure extension (left to right) and the activities to reduce the likelihood or/and consequence of such extension

[Source: DNV-RP-F116]

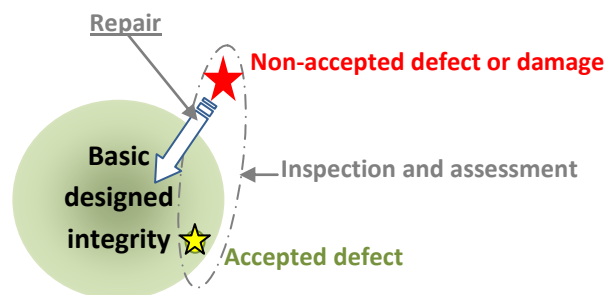


Figure 1-3. The repair brings the system integrity back to the original range of design.



Although the design covers and foresees the probable loads during different phases, the possibility to have any surprise always exists, depending on safety factor. Due to human-side limitations (abilities and cost) and nature-side capabilities, the asset operators should be alerting of threats and prepare the contingencies as responsive as possible (Figure 1-3).

Inspection and/or operation un-stabilities may detect a deficiency in a pipeline. The general inspections are normally the visual methods; using ROV camera. If any further inspection is required it can be done by different methods that normally are known as NDT inspection.

The variety of damage may cover the range of insignificant to a fully buckled or parted pipeline [DnV-RP-F113].

The below list (extracted from the book: Marine Pipelines Braestrup et al., 2005 pg#324) shows the defect and damages that can be detected in the pipeline during the inspection and mapping:

#### Inspection findings

- 1 Mechanical damage to the pipe,
- 2 Buckled pipe,
- 3 Lateral and axial movement,
- 4 Leaks,
- 5 Seabed condition,
- 6 Free spans,
- 7 Corrosion (external, internal),
- 8 Damage in coating, insulation, field joints,
- 9 Anode consumption or detaching.

As the scope of this report is to investigate repair methods for the damages that are most severe, from the above table the first items (1 to 4) are in the area of interest. Generally the pipe defects can be categorized into the following, or any possible combinations of those:

- Grooves, gouges and notches,
- Crack,
- Dents,
- Leaks.

A repair assessment shall be performed to check if the operational condition (particularly the pressure and temperature) are maintained with the present defect/ damage (PDAM: THE PIPELINE DEFECT ASSESSMENT MANUAL) and also to study the remaining life of the pipeline, considering the fatigue and cyclic loadings at the defect. Based on assessment results, the corrective action might be the pipeline mechanical/structural repair, changing the operation strategy (operate in a limited margin of internal pressures) or both. This can be lead to any of following:

- no action is required,
- no repair is needed, but the operation condition shall be changed (lowered) (while the pipeline still meets the purpose),
- temporary repair is needed with the limited operation condition,
- permanent solution is required,
- pipeline shall be replaced.

For the cases where intervention is required, the repair strategy is also depending on number of factors, further to the type of defect (Braestrup, et al., 2005):

- the pipe material,
- pipe dimensions,
- location of defects (depth, slope, nearby distance(safety class)),
- load conditions.

The pipeline repair is to compensate that part of pipeline integrity which has been weakened due to damage.

Below figure (1-4) shows a general algorithm chart for monitoring the pipeline integrity.

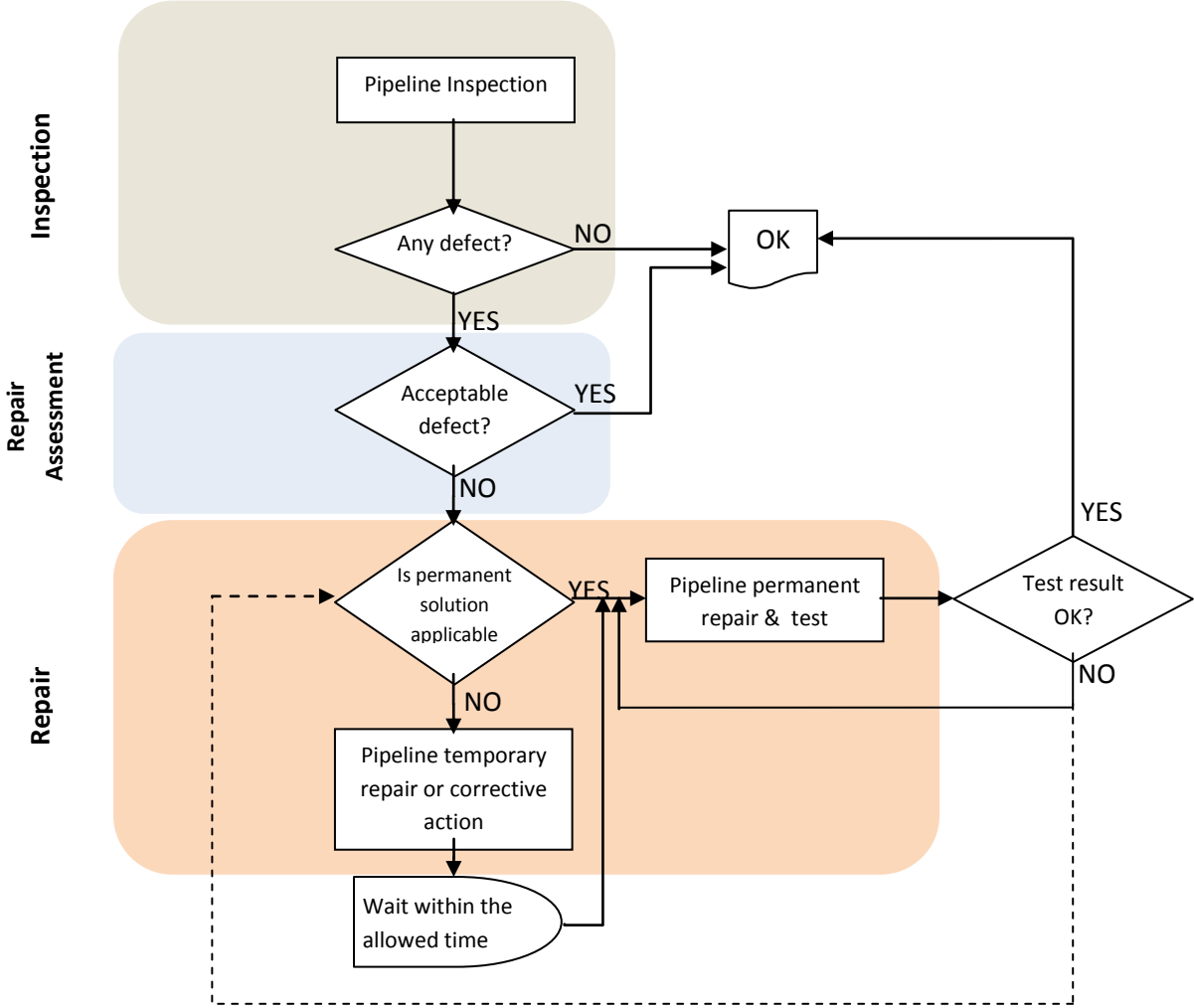


Figure 1-4. The integrity management system diagram to inspect, assess and repair (if required).

### **1.3 Pipeline damage scenarios**

The damage scenarios can be expressed by categorizing pipeline damages as follows (ABS Guide for Building and Classing Subsea Pipeline Systems, 2006):

- Internal Damage
  - Corrosion damage due to corrosivity of the pipeline service and flow conditions. Corrosion damage happens more likely at pipe low points, bends and fittings.
  - Internal erosion damage occurs through abrasion by the pipeline flow, generally at bends, trees, valves, etc. Erosion may be a primary cause of corrosion too.
  
- External Damage
  - Dropped objects due to activities on or surrounding a nearby installations like platform, drilling units, etc.,
  - Abrasion between cable or chain and the pipe outer surface,
  - Damage caused by direct hit, snagging or dragging due to anchoring or trawling,
  
- Environmental Damage
  - Severe storms and excessive hydrodynamic loads (e.g. Hurricanes),
  - Earthquake,
  - Seabed movement and instability
  - Seabed liquefaction
  - Icebergs and marine growth

Corrosion is the most frequent pipeline damage scenario, specially when it comes to deeper waters where anchoring and trawling less probable. The environmental damages are also common for some areas like in Gulf of Mexico. In the next section historical statistics for different scenarios is presented.

### 1.4 The damage statistic

There are some survey reports that present the statistic figures for damaged pipes. One can plan a contingency strategy based on the data: type, frequency,... of damages.

#### 1.4.1 CODAM & PARLOC reports for North Sea

CODAM (pipeline damages- Damages and incidents, Petroleumstilsynet Norway) and PARLOC (The update and loss of containment data for offshore pipelines, HSE UK) are two references for the North Sea cases. Figure 1-5 illustrate the summary of the PARLOC2001 report. From the figure, about 40 percent of pipeline incidents lead to leakage. This report divides the incidents for pipelines and fittings separately since the survey focuses on the containment leakages due to incidents. The report also tabulates the data for different size of diameters. The tables show that in the most cases the small sized pipelines (< 10”) are exposed to the risk of incidents. Trawl impact and corrosion are the main causes of incidents (PARLOC2001, table 4.2). Weld defect is being reported as the main cause for the larger sized pipelines. PARLOC does not list the incidents based on water depths which is the interest of this thesis.

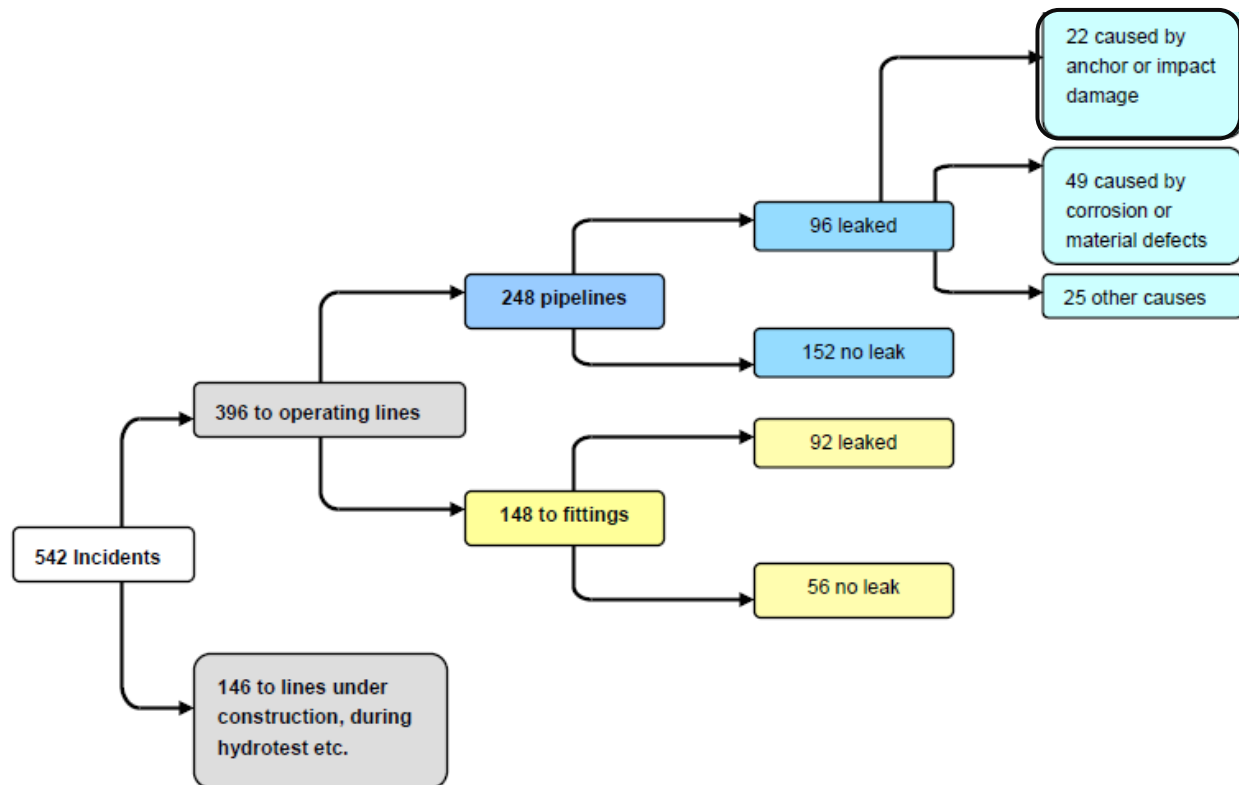


Figure 1-5. Damage report summary shows the distribution of damage type and causes [source: PARLOC 2001].

#### 1.4.2 DnV MMS report (448 14183) for Gulf of Mexico

DNV Minerals Management Service issued a report regarding the pipeline damage assessment from Hurricanes Katrina and Rita in the Gulf of Mexico. This report broadly investigates the damaged pipelines where obviously the main cause was the environmental extreme conditions. However the

survey gives a sensible overlook of pipeline system robustness against the overloading cases. The pipelines being damaged due to storms direct or indirect effects; the platform end displacement; the construction anchor drag and so on. Figure 1-6 illustrates the pipelines which were being affected by both Hurricanes Katrina and Rita (in red). The different categories of damages are shown in Figure 1-7.

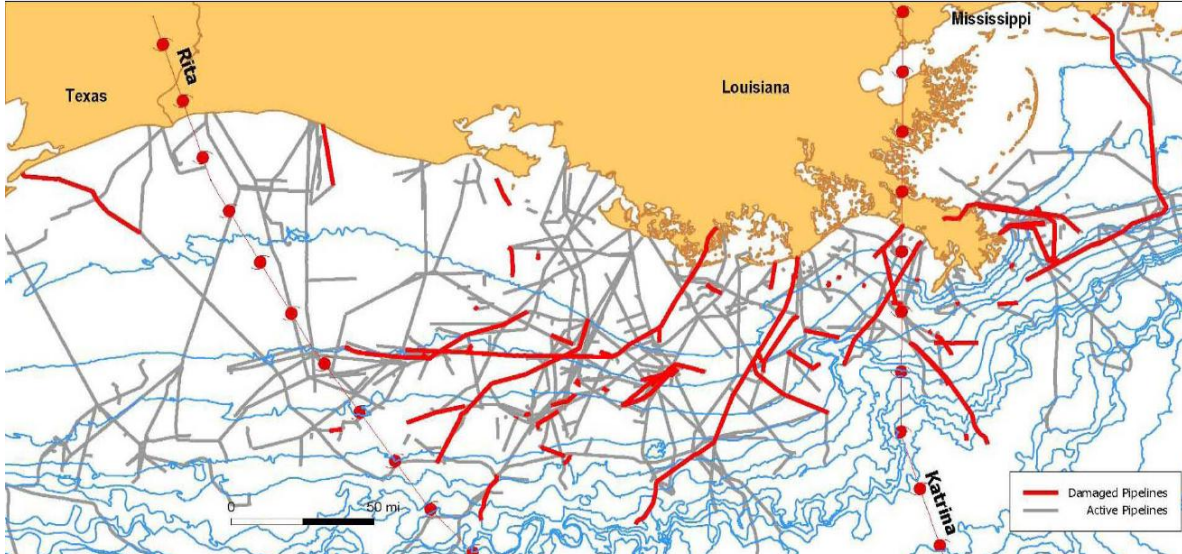


Figure 1-6. All reported pipeline damage due to both Hurricanes and Rita (Source: DNV MMS Report).

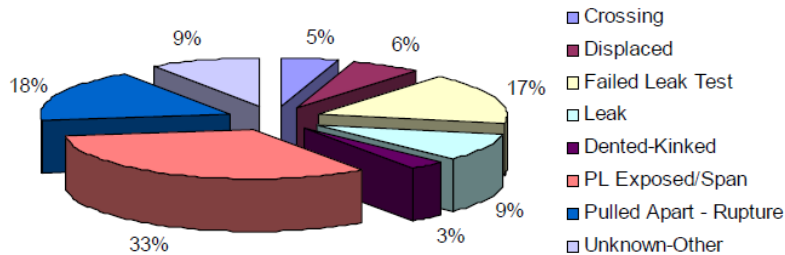


Figure 1-7. Damage categories contribution for both Hurricanes-Katrina and Rita.

The report results for the Hurricanes damages, refer most of damages to the small size pipelines, as illustrated in below graph.

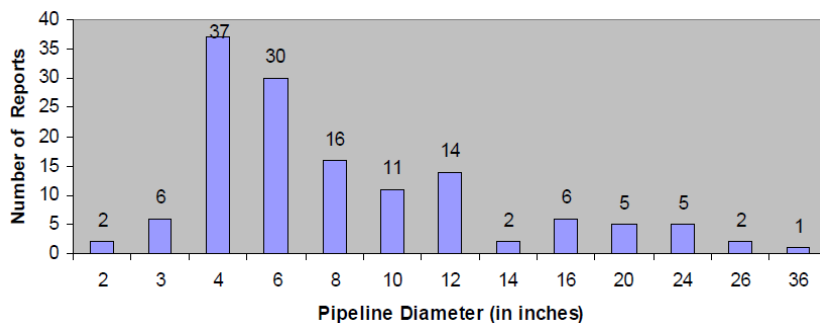


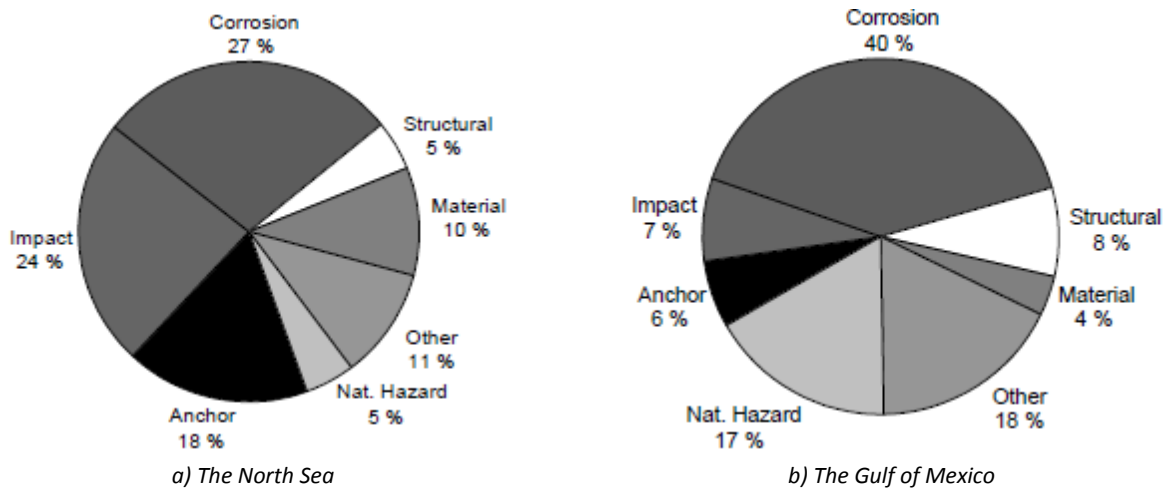
Figure 1-8. Damage diameter size distribution

In this report also the water depth is not addressed for the damages.

### 1.4.3 Results for North Sea and Gulf of Mexico

Studying the incident reports for North Sea and Gulf of Mexico for the incidents with and without the leakage (Figure 1-9) shows that the corrosion (internal and external) is the most important cause of damage for both areas. The second important cause is the anchor and impact damage and natural hazard (Hurricanes) for the North Sea and Gulf of Mexico, respectively.

Figure 1-10 shows the distribution of the corrosion types for both NS and GoM.



a) The North Sea b) The Gulf of Mexico  
 Figure 1-9. All reported incidents in percentage for a) North Sea and b) the Gulf of Mexico  
 [Reference DNV-RP-F116 Appendix A]

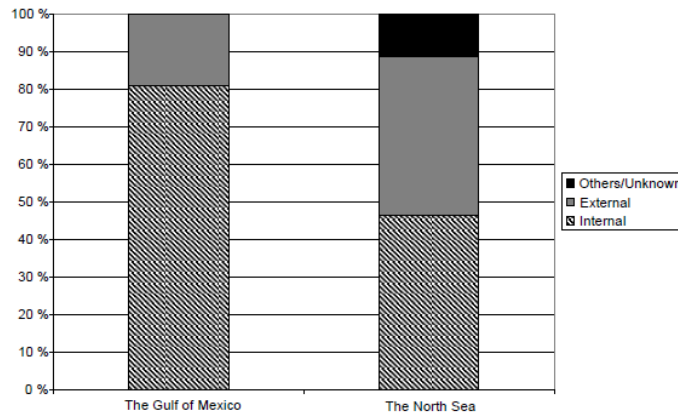


Figure 1-10 Distribution of different types of corrosion damages without leakages  
 [Reference DNV-RP-F116 Appendix A]

The results give some ideas for repair contingency planning for different areas. For the North Sea the plan should be based on the anchor and impact damage more than for natural hazard or internal corrosion. When it comes to the deep water pipelines corrosion dominates.



## 2 Repair: integrity compensation

Any damage can lead to a reduction in pipeline integrity. The repair is to compensate this reduction or regain as well as maintaining the pipeline strength. One can classify the repair methods based on the compensation alternatives into two main categories:

- The pipe piece replacement, where the line production should be stopped and the line is cut
- The installation of a strengthening/pressure containing clamp, thereafter the line can continue the production.

In both options, the solution should resist all the loads that the main line encounter (internal pressure, external pressure, thermal loads, axial loads, environmental loads). Further to that the clamp should facilitate sealing. In each following cases, there are some advantages and disadvantages. The challenges will be discussed in the next sections.

### 2.1 Pipe piece replacement

The damaged part of line (Figure 2-1) is replaced by a piece of the same (or even stronger) pipe. This piece -depending on the repair assessment and analysis results- can be either short or long spool. The main parameter to calculate the spool length is the damage affected zone that shall be removed, considering a safety margin.



Figure 2-1. Damage in the pipe, that shall be cut.

The spool can be jointed to the main line in different ways:

- **Welded**

The new pipe piece is aligned with the pipe end that has been cut and prepared according to welding specification procedures. Normally the new piece has the same size and thickness; hence the welding is of butt type (Figure 2-2). Welding can be performed on the surface or in a subsea dry habitat (diver assisted- or remotely operated-).

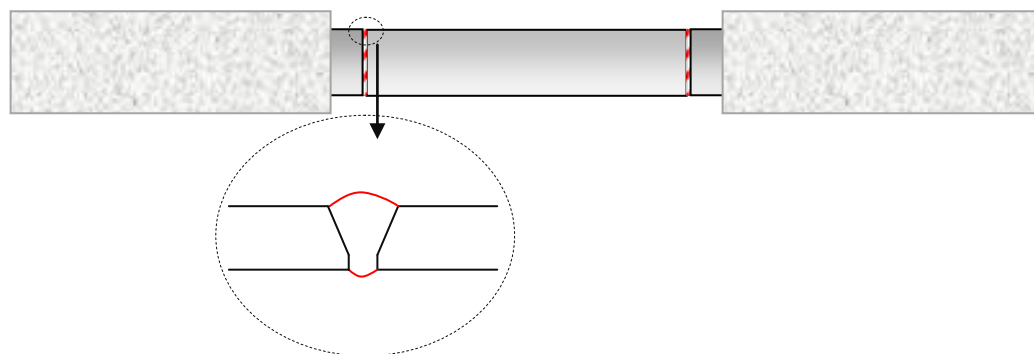


Figure 2-2. Welding the new piece of pipe to the main pipe line.

- **Flanged**

Either sides of the pipeline and the spool are welded to a flange and the flanges are being tightened together (either by bolts or special arrangement)(Figure 2-3).

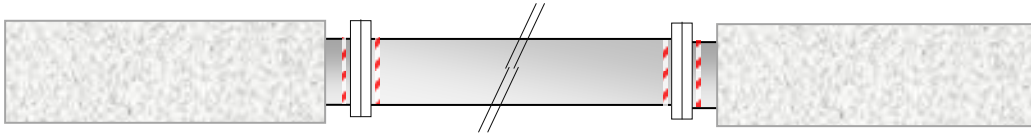


Figure 2-3. Flanged spool replaces the damaged and cut section of the pipe.

- **Mechanically coupled/clamped**

The new pipe can be connected to the mainline by either mechanical coupling or clamps.

- Coupling:

A pair of pipe sleeves connects the new piece of pipe to the main line as it is shown in Figure 2-4.



Figure 2-4. Mechanical couplings fix the pipe spool to the mainline and restore the integrity.

The locking mechanism can be one of the following types:

- Gripping wedge: the coupling internal profile provide the gripping force in friction shape (Figure 2-5). Reference can be made to the gripping mechanism in clamps of DW RUPE (section section 7) patented by Stress Subsea (Figures 7-3 & 7-4).

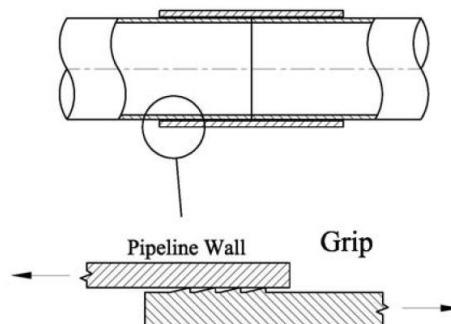


Figure 2-5. A sleeve with the surface profile providing the gripping forces.

- Forge: the internal profile of the coupling accommodates the forged external profile of the pipe (Figure 2-6). Reference is Eni/Saipem SiRCoS repair system.

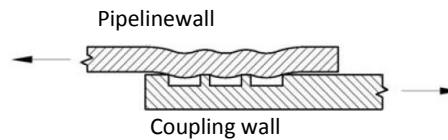


Figure 2-6. Forged surfaces provide the gripping mechanism.

- Ball gripping: a series of balls are released within the activation and exert the grip force over the pipeline wall (Figure 2-7). Reference is made to Morgrip coupling used in the Statoil PRS (Section 6).

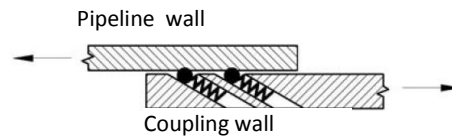


Figure 2-7. Ball gripping mechanism that is used in Morgrip technology.

- Welding: a sleeve coupling is welded to the main pipeline and the spool wall. The weld can prepare the anchorage force as well as the sealing (Figure 2-8).

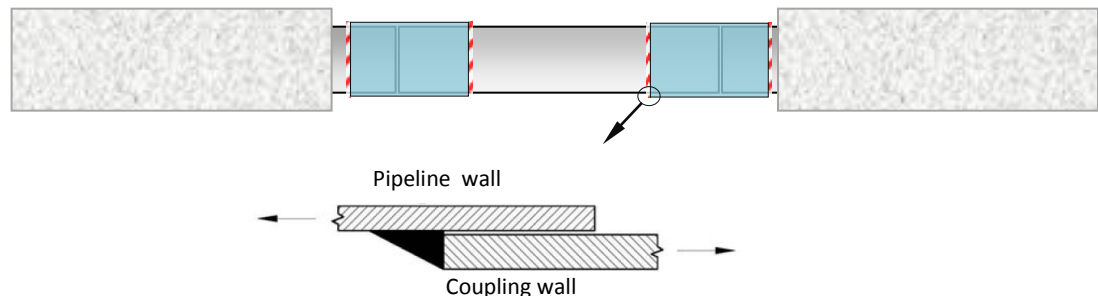


Figure 2-8. The repair spool is integrated to the main line by a pair of welded sleeves.

- Clamping  
Similar to the sleeve but in halved shapes such that the half pipes (clamps), are bolted together around the pipes (Figure 2-9). A locking mechanism and a sealing mechanism in the clamp secure the pipeline integrity.

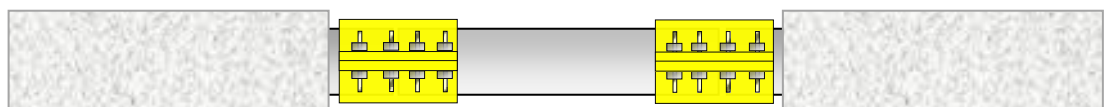
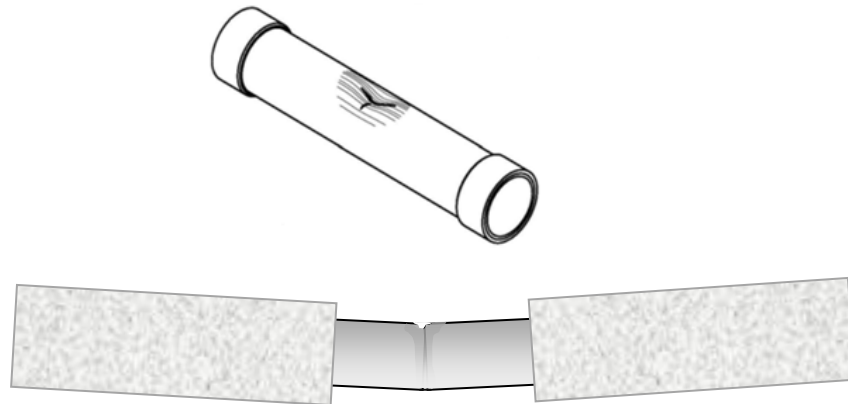


Figure 2-9. The repair spool is integrated in the main line by a pair clamps.

## 2.2 Clamping

In some cases, the damage is classified as tolerable (short affected length or non-progressive defect) through the pipeline defect assessment process and there is no need to cut the pipe (Figure 2-10). For those cases, clamps can compensate the weakened integrity. Depending on the defect type (leaking or dent/gouge), the clamp can be acting as a pressure vessel either as a structural support. The main duty of the clamp is to increase the structural strength of the line at the damage point and/or prepare facilities to seal any possible leakage in the future. The clamps can be designed as the temporary solutions as well as permanent ones.

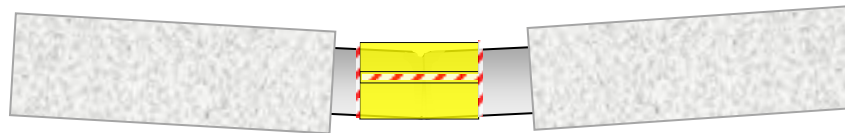
Generally, a halved-pipe joint is installed around the damaged/defected section of the line.



*Figure 2-10. Local minor damage in pipe that can be repairable temporarily or permanently. The defect can be dent, buckle or even a corrosion pinhole.*

This joint can be integrated into the main line in different ways:

- welded  
Halved shelves are welded together and to the spool- and pipeline- walls (Figure 2-11).



*Figure 2-11. The clamped half-shelves are welded together and to the pipe body around the damaged point.*

- bolted  
The bolting increases the hoop strength and also the normal reaction force is contributing to the friction force against the axial loads (Figure 2-12).

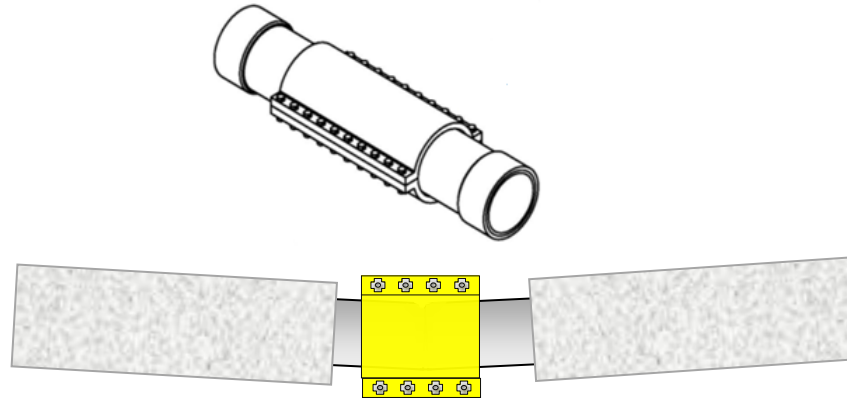


Figure 2-12. The clamp half-shelves are bolted together and squeezed around the pipe at the damaged location.

- grouted  
It is similar to the normal clamp, however instead of the complex sealing mechanism, grout cement (or any other filling material) is injected in the annulus between the clamp casing and the pipe body. It gives a rigid joint against the static loads.

The above discussion is summarized in below table

Repair class	Integration technique		Application and References	
<b>Pipe Replacement</b> • Damaged part of pipe is cut and new pipe is replaced	Welded	<i>Butt welding of new pipe to main pipes</i>		Dry Habitat Repair/Tie-in
	Flanged/Bolted	<i>Pipe ends flanged and bolted to a flanged piece of new pipe</i>		Above Water Repair/Tie-in
	Mechanically coupled/clamped	Coupling	Wedge Grip	DW RUPE/ Stress subsea Techn.
			Forge Grip	
			Ball Grip	PRS/ Morgrip Techn.
Welding Sleeve				
	Clamping		DW RUPE	
<b>In-situ Clamp</b> • no need to cut damaged part of pipe	Welded			
	Bolted		Repair Clamps	
	Grouted		Ref.: UK CATS Pipeline Repair	

### 3 Case Study I: The Kvitebjørn Pipeline Repair

#### Pipeline specifications:

An about 147 km long 30" pipeline transports the rich gas from Kvitebjørn and Visund platforms to the Kollsnes reception facilities. The operation pressure, the temperature at the gas entrance end and the wall thickness is 132 barg, 50 °C and 19.2 mm, respectively.

#### Pipeline damage:

During a routine external inspection by a ROV, a serious buckle was discovered. A 10-ton anchor of an unknown vessel hit and dragged the pipeline 53 meter out of its initial position at a depth of 210 meter (Figure 3-1). The anchor was found just nearby the damage point, with the anchor chain connected and underneath the pipe which means that before the chain broke, the line was pulled off the seabed about 30 meter (calculated by simulation, based on the pulling force and the found position). Such pulling force made a sharp dent in the pipe body (17 degree) and also dragged the nearest expansion curves out of position.

Since the diving depth in Norwegian rules is maximum 180 meter, the subsea activities were supposed to be done remotely by ROV.

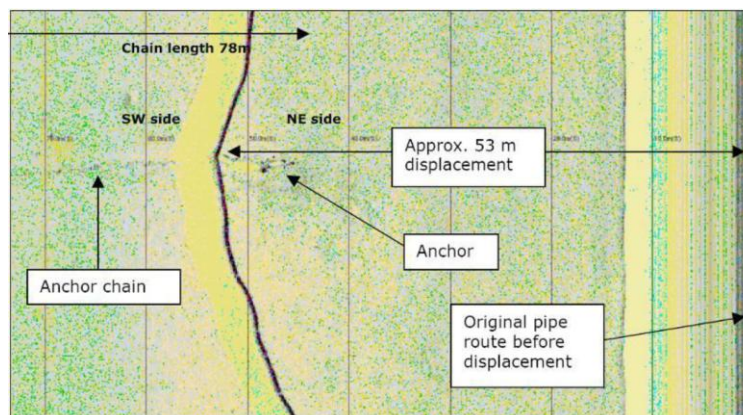


Figure 3-1. The pipe was found 53 meter out of its position, buckled.

#### Temporary Solution:

Based on the surveys and the investigations, calculations and analysis have been performed and it resulted in the possibility to operate the pipeline with the discovered defect, if the pipe be secured by rock dumping at the damaged location and the pipe internal pressure was maintained within a certain range.

The measured minimum wall thickness was found to be 16.3 mm in the damaged area. The minimum wall thickness required for the bursting is 18.1mm , which gives 14.6 mm after subtraction of 2.5 mm corrosion allowance and  $\pm 1.0$  mm fabrication tolerance [IKM doc. : D111-IK-P192-F-RE-001 Rev01 - Global Analysis of Anchor Damage pg 10 of 86 ].

The rock dump required for the pipeline protection and fixture against lateral movements at the damage point was calculated to be 2 meter high on top of the pipe.

**Permanent Repair:**

The pipeline was shut down following the report of a leakage at the buckled point. The pipeline production was stopped and the repair contingency operation started by determining the cut out length within the damaged point in the line. A 7m-section of pipe was cut out and the pipeline free ends were shifted toward the original route where the repair could be done (30 meter was the maximum shifting). The relocation was performed by utilizing air bags lift force and a vessel’s lift and drag forces through crane wires connected the pipe end.

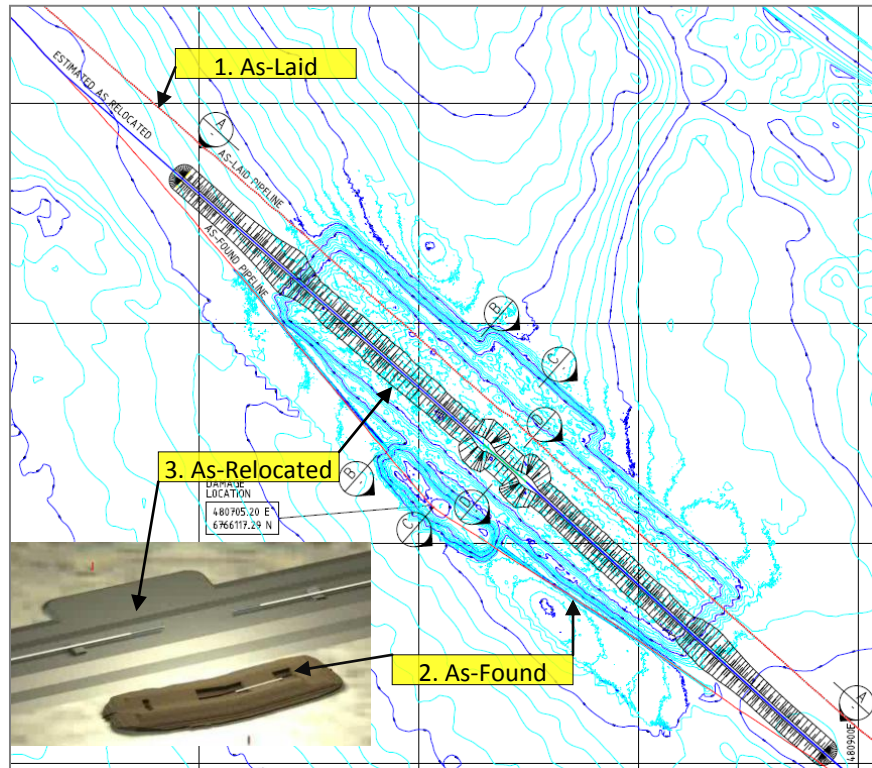


Figure 3-2. Kvitebjørn pipeline repair area. As-laid, As-found and As-relocated arrangement and also post-repair rock dump. [Ref.: 1601921-IKM-Y-RE-0001 - D111-IK-P192-F-RE-010]

After positioning the lines, frames were deployed to lift the line ends off the seabed and the final cutting on both ends was performed. The concrete coating and the seam weld had to be removed. A 25-m long spool was fabricated and brought to site in order to replace the damaged section and connected the pipeline cut ends. The spool was connected to the main line by mechanical connectors. After the connection the integrated pipe was laid on the sea bottom (Figure 3-2). The line was tested prior to re-commissioning.

The system in place for the repair, that is called Statoil PRS (Pipeline Repair System), will be discussed later in the next sections.

The production from the Kvitebjørn was stopped for 8 months. It means a considerable loss of income and shows how significant the pipeline repair contingency is.



## 4 Case Study II: The CATS Pipeline Repair

### Pipeline specifications:

The 404 km long 36" Central Area Transmission System (CATS) pipeline transports the natural gas from the CATS riser platform in the North Sea to reception facilities in England. The minimum operation pressure is 105 barg. The Pipeline wall thickness is 28.4 mm.

### Pipeline damage:

The mooring anchor of a tanker dragged the pipe in June 2007. The incidents occurred in shallow water (32 m depth) close to landfall (6 km away from Tees estuary). No leakage had been observed. The concrete coating was damaged at the hit point and pipe was pulled through the backfill soil. Since the water depth was shallow, the detailed inspections had been conducted by divers following the pressure reduction.

The damage status was not as severe as expected. The different measurement and non-destructive test did not show any cracks or gouges.

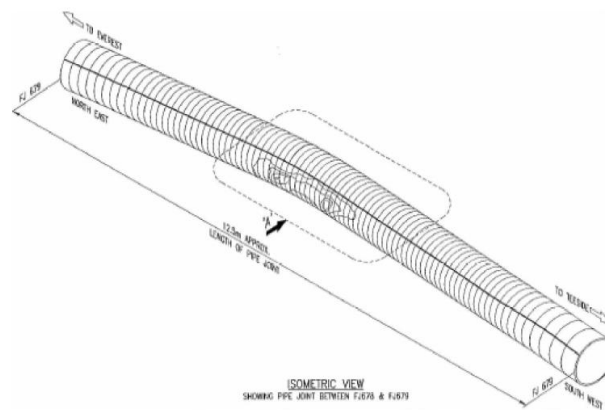


Figure 4-1. deformed shape of pipe after anchor hitting. The anchor flukes caused two dent either side of point with maximum curvature. [Source: IPC2008-64480]

Further detailed mapping, showed the existence of two dented points extending from 8 o'clock up to around 10 o'clock (looking along the line from Teesside end), with the maximum depth of 31mm. the dents covered the seam weld in its upper tail (Figures 4-1 & 4-2).

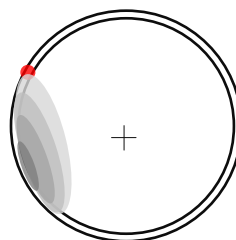


Figure 4-2. pipe cross section at the dented point. The dent tail covers the seam weld of pipe. The dented area extended to the seam weld where the combination of dent and crack is possible.



**Damage assessment:**

The dents should be assessed in order to check the static strength of the pipe after damaged as well as the fatigue strength and any possible reduction in the pipeline life that is subjected to pressure fluctuations.

For the static part of the assessment, in general PDAM is can offer methods to evaluate the strength of the dented pipe. For this case, by having the weld in the dented area, the methods in PDAM are not applicable, since the prediction is difficult for dented weld and the burst and fatigue strength can be significantly lower than that of a plain dent of the same depth due to the possibility of crack initiation during the denting [ref. PDAM, IPC2008-64480]. NDT (Non-Destructive Test) results showed no defect in welds made confidence that the weld had enough toughness. Hence, the dent could be considered as a plain dent and then the PDAM was reference for the assessment. According to PDAM, the plain dent with a depth less than 7% of the pipe diameter has no effect on the static strength. Dent was tolerable at MAOP (Maximum Allowable Operating Pressure) since the dent depth was measured 3.4% of the pipe diameter in CATS case.

For the fatigue strength evaluation, there is a method recommended by PDAM for the dented weld that is to take the dent as a plain dent with an additional factor for the presence of the weld in the dent. The assessment resulted in a need to have reinforcement around the pipe and to keep the dent away from the movement (particularly in radial direction).

**Pipeline repair:**

The decision was made to support the damaged section of the pipe structurally. For this purpose, a grouted steel clamp was designed (Figure 4-3). It provided high rigidity and prevents the radial movement over the dented pipe under the pressure cycling. The cement grouting filled the annulus between the pipe and the clamp half-shells.

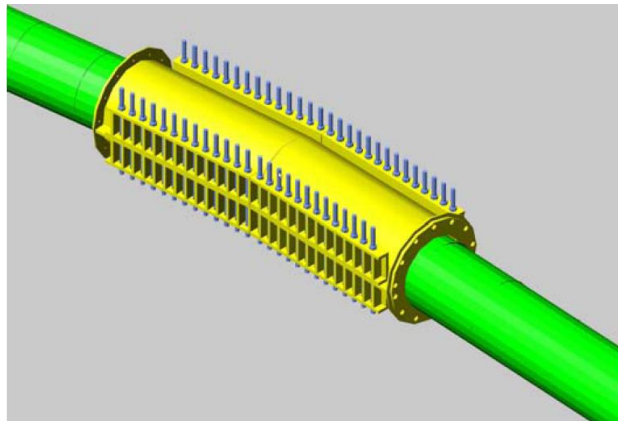


Figure 4-3. Grouted clamp [Source: IPC2008-64480].

The sleeve length was 4.2 m with a 6.5 degree mitered elbow in the middle. The clamp was installed by divers and the grouting was done following the bolt tightening.

## 5 Repair Technique: Above-Water Repair

For some cases, the easiest and the optimum way of fixing a pipe is to recover the pipe to the dry surface and utilize welding technologies in order to connect the pipe ends or the new piece of pipe in-between or connecting a flange to each ends. Applicability of this technique is a function of some parameters. For shallow waters and small size of pipes, technical parameters are in favor of this cost saving management, and above-water connection is more justified. Here is a list of those parameters:

- pipe size, weight per unite length and the SMTS (Specified Minimum Tensile Strength)
- water depth
- pipeline length (for dewatering possibilities)
- length of damaged section
- availability and cost of the proper construction vessel
- damage location (nearby third party or a fixed installations)

The vessel hiring costs and the pipe weight are the most governing parameters.

### General procedure:

Although for each case there can be special procedures, a general method can express at least the common basic activities.

Depending on the case, the damaged section can be lifted together with the pipe itself or be cut prior to the line lifting. The below figures (5-1 to 5-4) show the method corresponding to latter case.

Depending on the above parameters, lines can/shall be dewatered to reduce the lifting load subsequently depending on the vessel size and ultimately the cost. Sometimes the costs for dewatering operations are considerable and further evaluation is required.

A construction vessel with enough davit capacity comes in position over the pipe such that both free-ended lines can be handled by the davits (or any other lifting tool). Divers assist to connect rigging lines to the pipes (figure 5-1). Once the connections are done, the lines are lifted off the sea bottom up to the surface, where the construction deck is facilitated to do repair related tasks: detail inspection, cutting, pipe end preparation (beveling, machining), alignment, etc. (Figures 5-2 & 5-3).

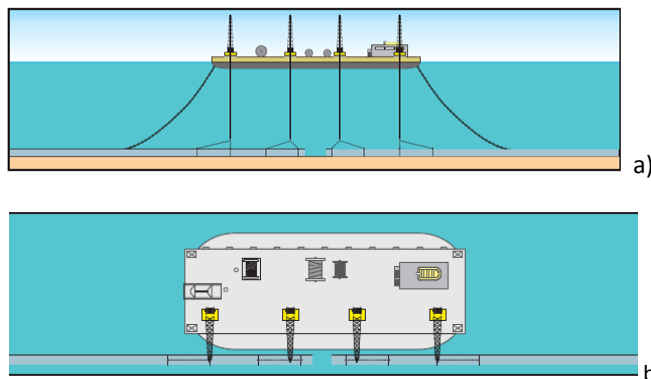


Figure 5-1. Upon cutting off the damaged section of pipe, the vessel with lifting capacity is in place and the riggings are connected to the pipe ends.

- a) Side view
- b) Top view

[Source for all the pictures in this section:  
INTECSEA Worley Parsons Group]

[[http://151.2.170.110/ecologia/Documenti/VIA/IGI\\_Posidon/doc/Parte1\\_Elaborati\\_di\\_Progetto/Metanodotto\\_Offshore/Allegati/AllegatoH/allegato\\_H.pdf](http://151.2.170.110/ecologia/Documenti/VIA/IGI_Posidon/doc/Parte1_Elaborati_di_Progetto/Metanodotto_Offshore/Allegati/AllegatoH/allegato_H.pdf) visited 07.02.2011]

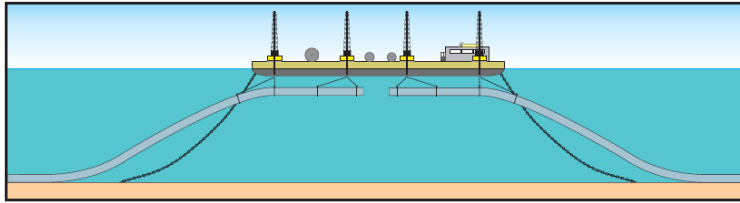
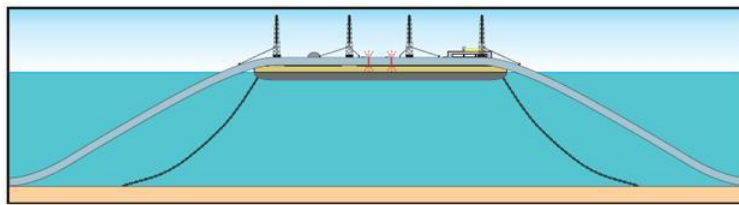
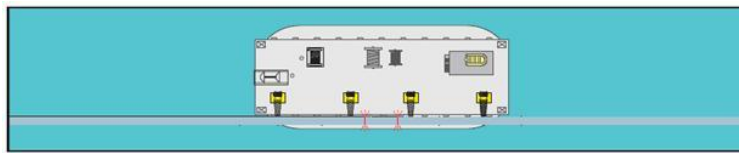


Figure 5-2. The pipe ends are lifted off the seabed, using the lifting davit or cranes. It can also be done one after the other when welding flange is the case.

A new piece of sound pipe (spool) is welded to the recovered ends on the construction deck. In some cases, when lifting both ends is not possible or the damaged section is long or because of any other reason, a flange is welded to the pipe end. It is done for both sides in two separate go, then a flanged spool will be fabricated and installed in between.



a)



b)

Figure 5-3. The pipe ends are on surface, aligned and the new piece of spool is welded in between.

- a) Side view
- b) Top view

Following the welding, the quality of weld is examined by NDT methods before laying back the repaired line on the seabed. The line configuration may be changed slightly due to accommodating an extra length of spool piece (figure 5-4). In case that the flange connection be the solution, the flanged lines are laid on sea bed and the “closing” spool will be deployed and installed in between by diver assistance. Upon the pipeline repair and securing in place, generally a hydrostatic test will be performed to check the integrity prior to decommissioning the line.

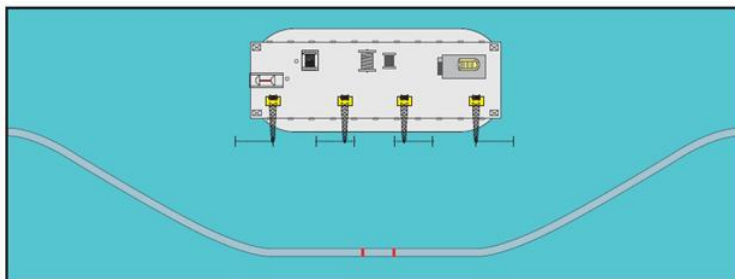


Figure 5-4. The repaired pipe is laid back on the seabed. Due to possible change in length the pipe might be off the original route.

**Advantages:**

- fast response method
- facilitating the application of the most efficient connection (welding)

- cost effective method in some cases

**Disadvantages:**

- weather sensitive
- limited application in terms of pipe size, length and water depth
- risk of new buckle during lifting and lowering
- vessel capability, availability and costs

Since the feasibility of such operation depends on a series of parameters, analyzes shall be performed for each case. Furthermore the cost might be the governing parameter that requires a cost analysis as well as to see how costly it is even though it is practicable.



For the depth more than 1000 meter, there is a program called Deep PRS under development by Statoil. Deep PRS can be an extension of the technologies used for the waters below 1000 meter (the Morgirp coupling or welding) or any new technology.

For the pipe sizes less than 10-inch, 'Small PRS' is in place that is based on utilizing mechanical couplings.

Generally, the matrix is divided into main parts: diving depth and beyond diving depth what for diving depth (the hatched area in Figure 6-2b) divers do the repair jobs or handle semi-automatic tools.

For the depths beyond the diving access where remote techniques shall be employed, there are two main options that is shown by two different colors in Figure 6-2b: the left side (blue area) is for the Morgrip coupling option and for the cases located at the right side (pink area) the intensions focus on the welding technologies. The area in between depends on the case where either of those techniques might be considered and there is no strict ruler for such cases. Deep PRS is on top of these two areas.

In the sections below (6-2 to 6-4), the PRS with the mechanical coupling and the operational procedure is reviewed as well as the coupling itself. The welding method of repair is discussed afterward in section 6-5. Remotely operated welding as the main core of Deep PRS is reviewed and the challenges will be discussed in an individual section.

I have had a visit from Statoil PRS yard at Killingøy. The visit photos are available at the appendix.

## **6.2 Statoil PRS (coupling)**

The repair system assumed the replacement of the pipe piece as the repair solution and the pipe ends are supposed to be ready (coating removed, face prepared) for mechanically coupling with the new spool just before the deployment.

The system was designed to install coupling for the range of 10 to 20 inches diameter size and seabed slope up to 28 degrees in water depths down to 600 meter (Norman, 1997). Based on demands, the PRS capability is being upgraded to handle up to 48" pipelines (Gjertveit, Berge, and Opheim, 2010)

### **6.2.1 System Elements**

The system consists of four main sub systems:

- Coupling Installation Frame (CIF)
- Coupling Carrier Module (CCM)
- Power and Control Module (PCM)
- H-Frames

### **6.2.2 Coupling Installation Frame (CIF)**

A passive frame with four legs and two claw mechanisms forward and afterward, enables the pipe ends and spool end with lifting and alignment. It is also a base for the Power & Control and the Coupling Carrier Modules. The fabrication weight of the frame is 65 Tonnes (Norman, 1997)

The main loads over the frame are; the pipe end weight, spool end weight, modules weight and also the weight of the coupling itself. The dynamic and environmental loads due to wave and current are also acting on the frame.

Figure 6-3 shows the CIF with CCM carrying a Morgrip coupling.

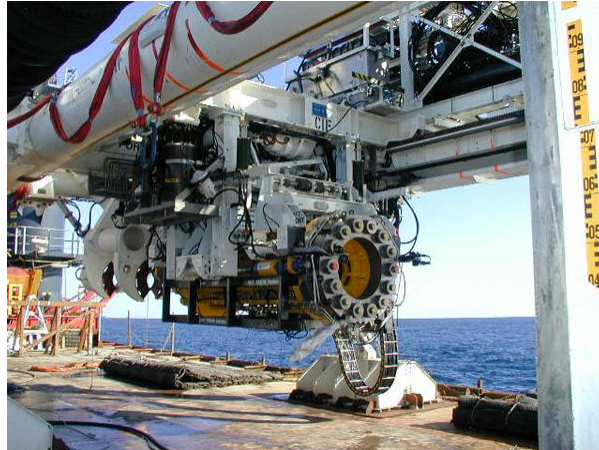


Figure 6-3. CIF with a Morgrip carried by CCM (source: Hydratight)

### 6.2.3 Coupling Carrier Module (CCM)

CCM is an integrated module with the CIF to carry and control the alignment of the Morgrip coupling. The CCM and CIF are designed such that the CCM with the coupling can travel along the pipeline axis. This traveling capacity is 4,56 meter (+/- 2.28 m). The vertical movement can be in range of +/- 1.5 mm and maximum transverse movement is of +/-1.5 mm (figure 6-4).

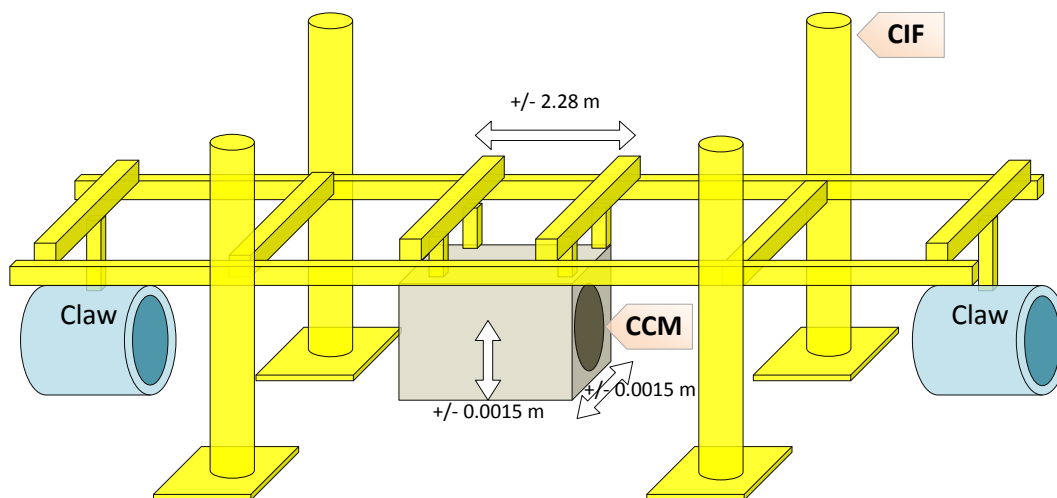


Figure 6-4. CIF and CCM 3D arrangement.



The CCM is designed such that the re-docking of the coupling is possible whenever it is needed. All equipment operates down to 600 meter deep (Norman, 1997). The hydraulic system is being integrated with an Emergency Disconnect and Release mechanism that can be activated by ROV or a diver.

CCM parts:

1. Carrier Frame
2. Suspension Frame
3. Coupling Frame
4. Carrier Railway System
5. Cable & Piping System

Figure 6-5 illustrates the parts schematically.

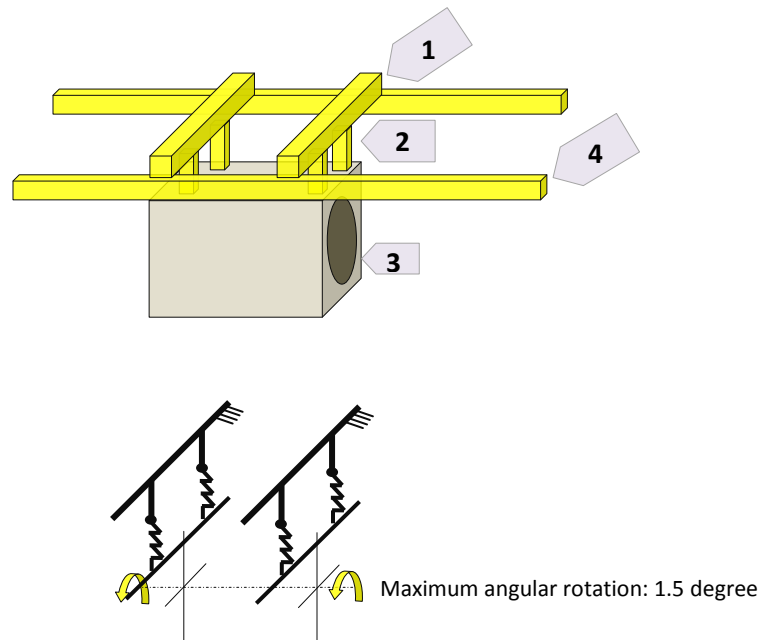


Figure 6-5. Coupling Carrier Module (CCM). The compliancy of the module structure provides the angular and transversal motions.

The coupling frame (#3) is suspended from the carrier frame (#1) via a suspension system (#2) that has a compliant mode to prepare coupling radial and angular flexibility (Norman, 1997)(Figure 6-5). The carrier frame itself can travel along the pipeline axis over a railway system (#4) and bogie flanged wheels. Two rack and pinion drives connected to two geared hydraulic motors supply the driving forces for the carrier system. There is a wire anchor on the carrier beam that enables operator to use ROV to pull the frame in an emergency case. The hydraulic and electric connections between the PCM (Power& Control Module) are through hoses and cables via a drag chain on one side of the CIF.

Figures 6-4 & 6-5 show the schematic view of the systems. The claws and the coupling frame jaws are parted-circles and encircle the pipe body by hydraulic pistons those are activated by ROV or remote control from the surface.



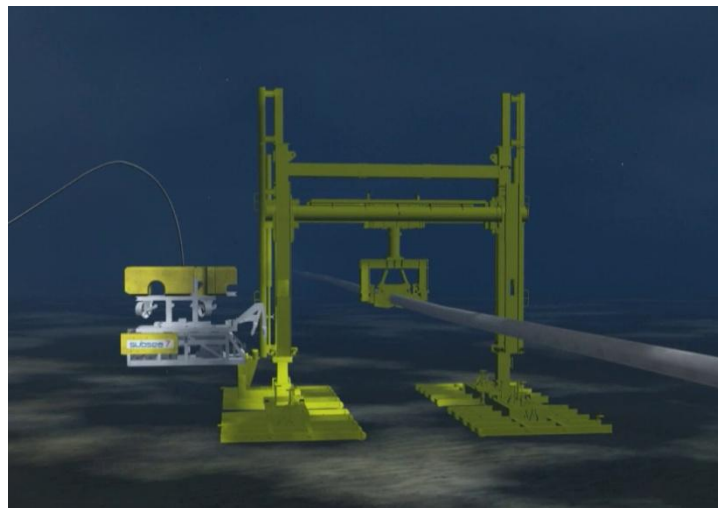
#### **6.2.4 Power and Control Module (PCM)**

The PCM is designed to service the CIF and CCM functions as well as the Morgirp operations. As the main items of the module, there are dozens of solenoid valves, panels, manifolds electrical cabling and ROV interface connector and override tooling. A multi-bore connector links the PCM to the CCM and the coupling itself.

For an emergency case or PCM failure, ROV will interfere via an override mechanism (which is included in PCM) and decouple the CIF from the coupling.

#### **6.2.5 H-Frames**

Two lifting frames ease the pipeline end handling during the repair operation. H-frames are located at a certain distance from pipe ends and lift the pipe off the seabed by hydraulic-jaw claw. The claw is connected to a frame that can move vertically once the ROV operates it. The force from the pipe weight transferred to the ground through the frame legs and the mud-mat plates (Figure 6-6).



*Figure 6-6. H-frame (source:Subsea7)*

Further to above subsystems, there are some ancillary units that support the repair operation. The main ancillary units are the Coating Removal Unit (CRU) (figure 6-7) and the Weld Seam Removal Unit (WSRU) (Gjertveit, Berge and Opheim, 2010). These units are carried by ROVs and normally there is no need to have a frame (Figure 6-8).

CRU works based on high pressure water jet cutting of the concrete coating over the pipe. Once the concrete coat is removed in large pieces, the concrete re-bars are cut by the ROV cutting tools and afterward the residual concrete over the pipe surface is removed.

The WSRU is supposed to remove the longitudinal weld cap over the pipe surface. A diamond disc is used to remove the cap. However the newly manufactured seam-weld pipes have seam line with very smooth caps.



Figure 6-7. Coating Removal unit (CRU) to remove concrete coating. (Sources: Statoil)

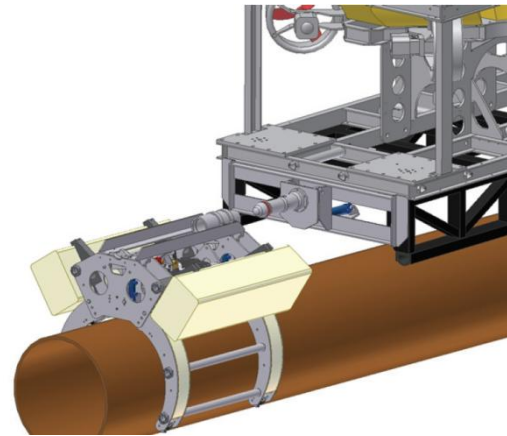


Figure 6-8. ROV carries the WSRU (Sources: OTC20814)

Both the CRU and WSRU are to get very smooth and sound surface at the pipe surface since the finished surface improves the sealing and gripping performance.

### 6.3 General Operational Procedure

For each pipeline damage with its own specification there might be a special solution for the repair. In general there can be presented a procedure to repair pipelines base on some assumptions which are highly probable. Basically the damaged part of the pipeline shall be removed and the PRS is supposed to replace a new piece of pipe. If we want to list the activities, there can be divided into activities prior to PRS deployment, PRS activities and Tilt and the tasks after the main repair jobs.

Following the damage assessment, and the decision to implement the repair, the repair spread team would be mobilized. The damaged section with the calculated length would be cut and recovered to the surface. Normally the subsea civil jobs are a part of the sequence. The pipeline are required to be back on the as-laid (or designated) route since in the most cases (anchor drag or hurricanes) the source of severe damages also pull the pipe out of route. Seabed preparation might be required just before bringing back the pipe into the original location. Once the pipe ends and the pipe spool are in the desired location, PRS tools will be deployed.

- The frames are in place and the initial alignment is done with the H-frames.
- The CIF is deployed over the pipe. The wires guide the frame over the pipe such that the center of the frame is located over the end.
- The coupling is shifted aside, and the H-frames assist to lift the pipe into the CIF claw.
- The pipe end and the Morgrip are aligned by using the coupling guide funnel and the CIF claw. The offset is being monitored by the cameras in the CCM.
- The coupling is slide onto the pipe with the CCM.
- The second H-frame over the spool pipe lifts the spool into the CIF claw.
- The pipe end and the spool end are aligned by the CIF claw (and H-frame), the gap between the ends is closed sufficient.
- The Morgrip coupling is pulled into its final position (on both pipe and spool sides).

- The coupling locking mechanism is activated.
- The CCM releases the coupling and the pipeline, the coupling and the spool piece that are all integrated on side are lowered to the seabed by using the CIF claws and the H-frames.
- The procedure is repeated for the other side of spool

Once the new piece of pipe is integrated into the main line, the integrity is tested hydro-statically and then any required civil task that shall be performed to secure and protect the newly repaired section of the pipe against unwanted loads. Below figures show the schematic view of the procedure for one end of the spool. Similarly the other end of the spool is integrated to the line.

Figure 6-9 illustrates the main steps of the procedure in more details, where the pipe ends are being mated and the mechanical coupling is engaged and locked and finally the pipe is lowered and laid on the seabed. In order to monitor the sensitive alignment operation, some cameras and laser technology are being employed. Figure 6-10 shows the close up view of the coupling installation steps using the CIF.



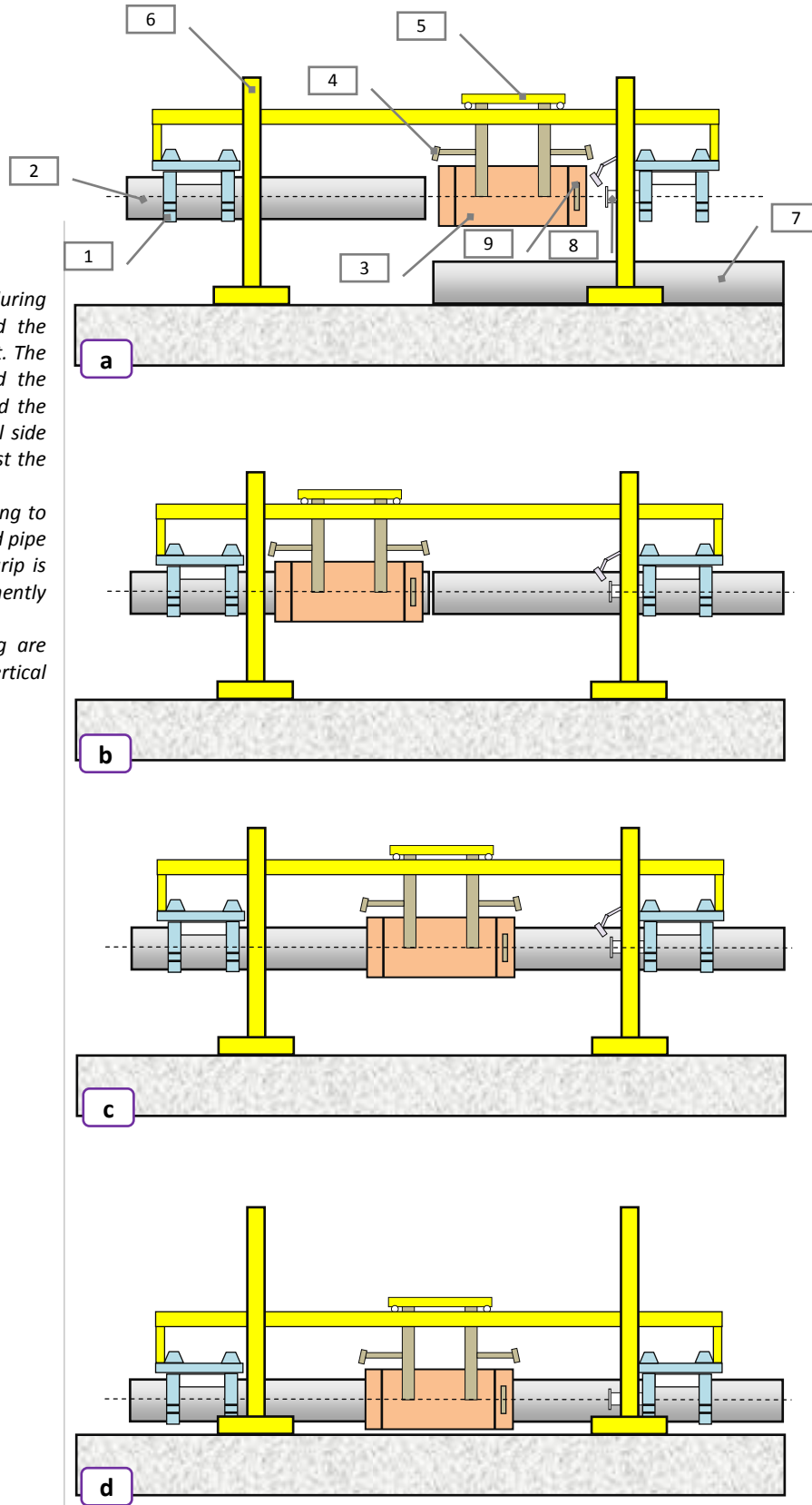


Figure 6-10. CIF actions during coupling installation. CCM and the coupling are shifted to the right. The line side pipe is lifted (a) and the CCM moves toward and around the lifted pipe to the left. The spool side pipe is lifted and aligned against the line side pipe end (b).

The CCM transverses the coupling to the right and around the aligned pipe of the spool side (c). The Morgrip is then activated and the permanently locked.

The unified pipes and coupling are lowered on the seabed (d) by vertical motion of the CIF frame.

- 1, CIF Claw
- 2, Pipe 1 (line)
- 3, Morgrip coupling
- 4, Camera
- 5, CCM
- 6, CIF
- 7, Pipe 2 (Spool)
- 8, Laser
- 9, Mirror

## 6.4 Morgrip Coupling

The Morgrip coupling is being the core of the PRS, since diver-assisted welding methods are facing the serious challenges for the deep waters. The Morgrip technology is owned by Hydratight and developed for the depths beyond diver access (Figure 6-11).

Hydratight's products are used for different sizes. Morgrip connectors are already proven for the sizes 4", 12" and 16" (Hydratight web site: <http://www.hydratight.com/en/products/morgrip/subsea-diverless>) (and also 30" for Kvitbjørn case). The diverless Morgrip connector is claimed to be available up to size 42". Increasing the pipe size leads to needs for huge couplings which raise the challenges related to weight and size.



Figure 6-11. Morgrip connector (source: Hydratight)

The coupling is initially activated hydraulically when it is installed, and for the operation life the mechanical locking system is in place.

The Morgrip has rows of spring-loaded spheres that will be forced into the pipeline and keep the spool and pipeline connected.

In the remote types of coupling, the main design objectives shall be:

- Pipeline gripping
- Pipeline Sealing
- Hydraulic activation
- Mechanical locking

(Norman, 1997)

Figure 6-12 shows the schematic view of a typical Morgrip coupling. The number of ball rows may change for each case, depend on design parameters.

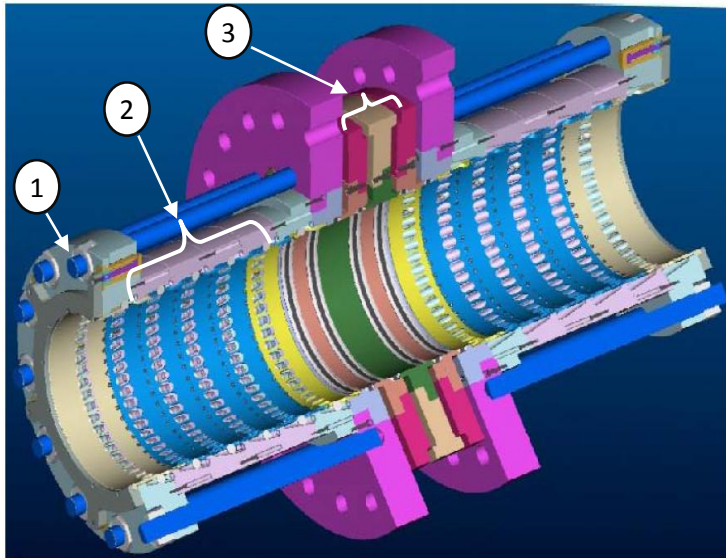


Figure 6-12. the Morgrip different parts:  
 1. mechanical locking  
 2. gripping rows  
 3. sealings

(Source: IKM Ocean Design in-house document)

### 6.4.1 Gripping system

The gripping is supplied by several rows of steel balls that are spring loaded and during activation the ball segments are pushed toward the pipe's external surface (Figure 6-13). The material of ball is of grade BS 535A99 that is bearing steel with high surface hardness. The balls are positioned in a tapered housing that is locked by pins in a passive state. Springs are released just prior to hydraulic activation by removing the locking pins. Once the balls contact the pipe surface, the hydraulic pushing force causes swaging effect and provides a grip that compensate the pipe strength regardless the gripping force from the sealing system.

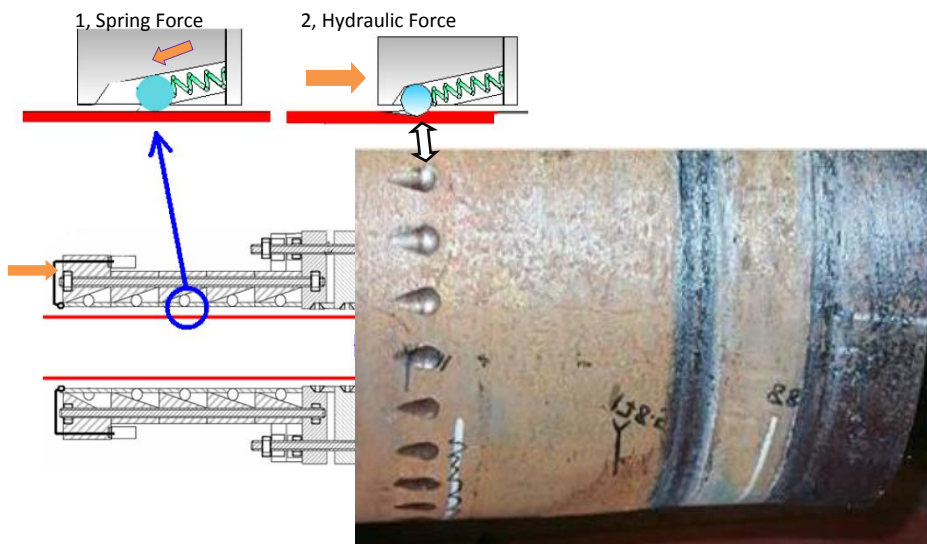


Figure 6-13. Gripping system in Morgrip coupling. The balls indent the pipe metal and are trapped in.

(Source: Statoil)



In case it is required to remove the coupling, the gripping mechanism is facilitated such that the ball bearings can be retraced into housings.

Ball rows are designed to be independent of each other and the springs can accommodate the pipe ovality and the standard variation (+/-1%) in pipe diameter.

### 6.4.2 Sealing system

A twin sealing system provides the sealing against the leakage from the damaged pipe. The seal is a Metal-Graphite-Metal sandwich that is compressed onto the pipe and resulting in the radial sealing. In the Morgrip design, the sealing is engaged at the same time as the balls swage into the pipe in one-run activation.

The figure below shows the sealing arrangement before and after activation, schematically.

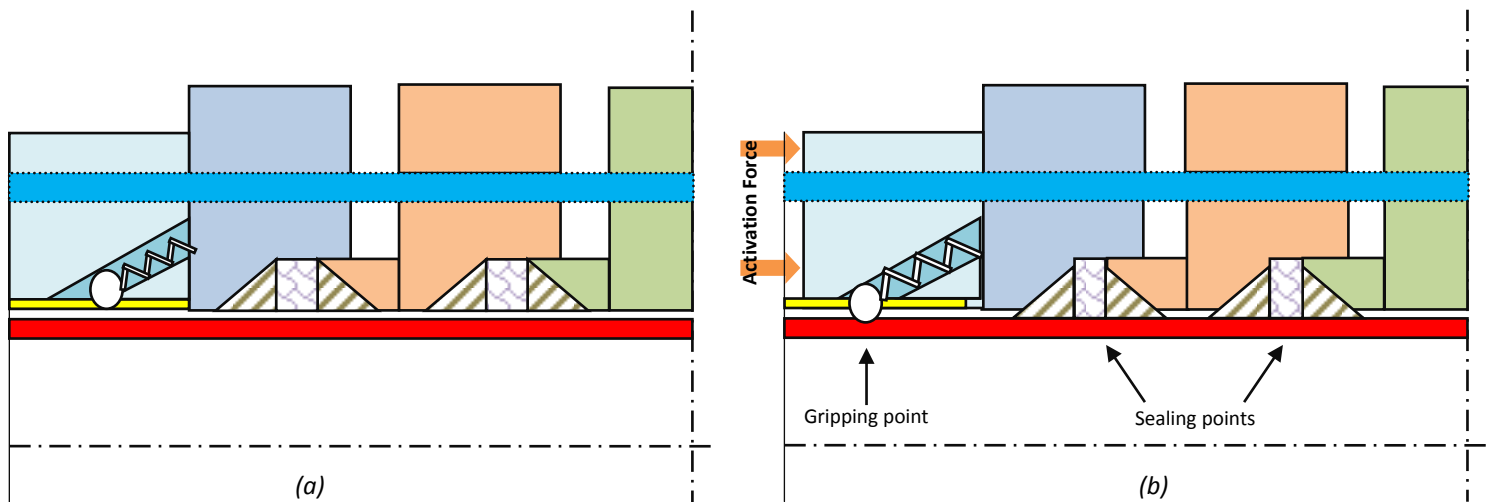


Figure 6-14. Morgrip activation mechanism. Gripping ball rows are locked by ball cages (yellow part) before activation (a). The hydraulic activation force and the spring restoring force activate both sealing and gripping mechanism (b).

The graphite filler energizes the metal rings and the metal rings provide the limiting support to avoid longitudinal extrusion of the graphite ring in order to have more radial packing. The double series of the sealing rings on each side of the coupling increases the reliability of the sealing system. The test is conducted by injecting seawater into the annulus space between two sealant rings.

### 6.4.3 Hydraulic activation

The Morgrip coupling is activated by the hydraulic force (or it can also be done by an ROV or for the shallow water by diver-exerted torque). PCM inject the required oil at high pressure to the main activation port on the coupling. The pressure starts to rise, and the cage for the balls retracing is released at lower pressure. When the pressure is increased, the balls are swaged into the pipe and at the same time the sealing system is activated i.e. the sealing ring is compressed onto the pipe's outer surface.



For the diverless methods, the hydraulic activation is the preferred solution. The ROV can also be used to manipulate the tensioning over the activation bolt. Hydraulic activation is a temporary system which will be removed when the permanent mechanical locking is engaged. The subsea bolt tensioning tools have been developed and upgraded and are being broadly utilized. Even for the diver assisted installations, hydraulic forces are more desirable since the bolt tensioning has a procedure seems hard to follow by divers.

#### **6.4.4 Mechanical locking**

Since having a permanent hydraulic pressure over the connector is expensive and un-reliable, upon the hydraulic activation, a mechanical locking which is normally a bolting mechanism is engaged for the design life of the connector. The tension prepared by the bolting maintains the gripping and locking systems.

### **6.5 Remotely Operated Welding**

Welding is the most efficient and reliable solution for the integrity compensation, particularly for the big size pipes. The sealing is perfect and the strength is identical to the rest of the pipeline. For diver-accessed depths, welding is performed with the intervention of divers to supervise and manipulate in case it is required. The welding in Statoil's PRS is divided into:

- Diver-assisted welding
- Remotely Operated Welding

For both applications, the pipes are to be aligned and a habitat shall surround the welding space and dewater and dry it.

For diver-assisted welding, the habitat is accessible for divers (Figure 6-15). Divers can re fill the welding consumable drums, check the welding operation and detect any stop in welding operation and fix it or report it to the surface. In fact the dry habitat provides a working room similar to normal working atmosphere on the surface except that the pressure is high in order to overcome the hydro-static pressure.



*Figure 6-15. Dry habitat with the diver access and assistance (courtesy of Statoil).*

Remotely operated welding is the main part of the DEEP PRS program in Statoil. A feasibility study to extend the remotely operated welding down to 4000 meter water depth is ongoing. The MIG (Metal Inert Gas) welding for depth of 2500 meter is experienced. The TIG (Tungsten Inert Gas) is proven to be efficient only for depths up to 1000 meter. The welding can be butt-welding where the new piece of pipe is beveled and aligned with the pipe (Figure 2-2) or fillet weld where a sleeve pipe is to connect the pipe spool to the main line (Figure 2-8). The butt-to-butt closure has limitation on the alignment that shall be very precise while the fillet weld does not need very accurate alignment of pipes. Weld examination is a challenge for fillet type of welding. The ongoing plan in Statoil PRS is based on the sleeved joint with fillet weld. The application of butt weld type of connection is under study as a R&D project in SINTEF. Figures 6-16 and 6-17 show the Remotely Operated Welding Tool (ROWT). A camera is mounted inside the tool over the welding torch. It provides the ability to monitor the welding operation from the surface.

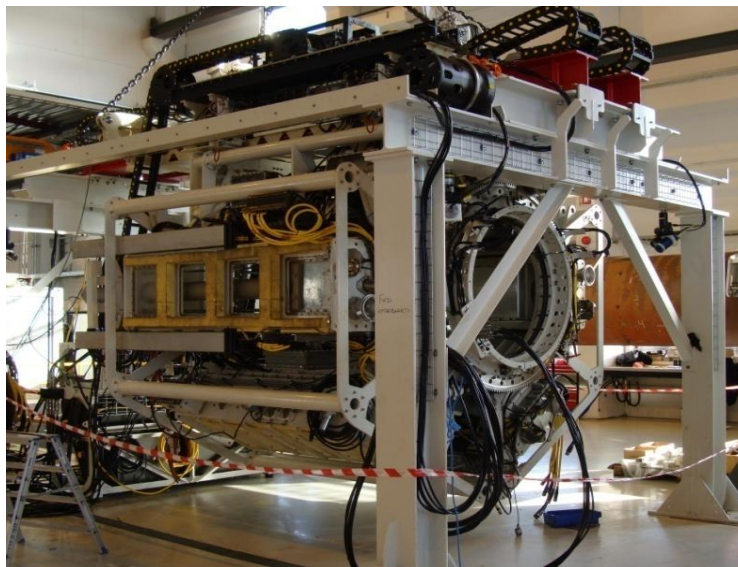


Figure 6-16. ROWT: Remotely Operated Welding Tool (courtesy of Statoil).

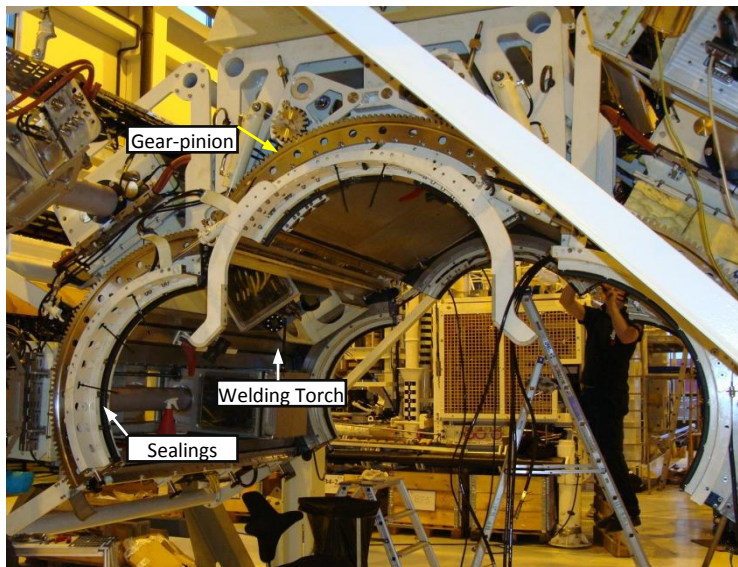
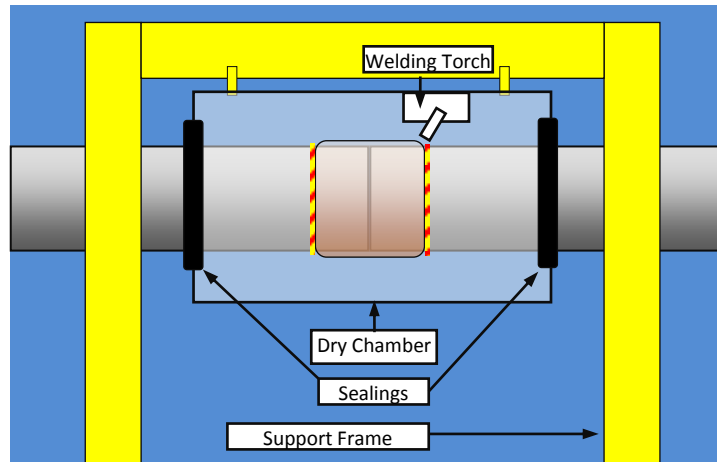


Figure 6-17. ROWT, three surrounding parts provide the room for dry welding (courtesy of Statoil).

A sealing mechanism should be in place all the time during welding to keep the welding space dry (Figure 6-18).



*Figure 6-18. ROWT, dewatered and dried space for welding is necessary before start welding. Purging is done by inert gases.*

For the sleeve type of connection: it contains two internal environmental seals each side to prevent water seeping back into the welding zone. In addition it is a blower nozzle to help blowing away any surface water in the gap. Since the humidity affects the weld quality, it shall be monitored all the time. The humidity level shall be controlled to be below 300 ppm which is the welding specification. For the butt-weld type of connection: a specific design of smart plug can be utilized for aligning and the back sealing.

A gear-pinion mechanism rotates the whole chamber while the welding travels (Figure 6-17).

## 7 Deep Water Response to Underwater Pipeline Emergencies-DW RUPE

As a result of a JIP (Joint Industry Project), an emergency repair contingency method has been developed to respond to the repair jobs in water depths from 300 meters to 3,000 meters in the US Gulf of Mexico. The program is split into two categories, the pipeline and the flow line repair. The main idea is to employ full structural clamps (as connectors) and a spool piece (Figure 7-1). Using the clamp and avoiding the “slip on” connectors reduces the risk of damage with the elastomer seals that might be due to rough cut end of pipes.

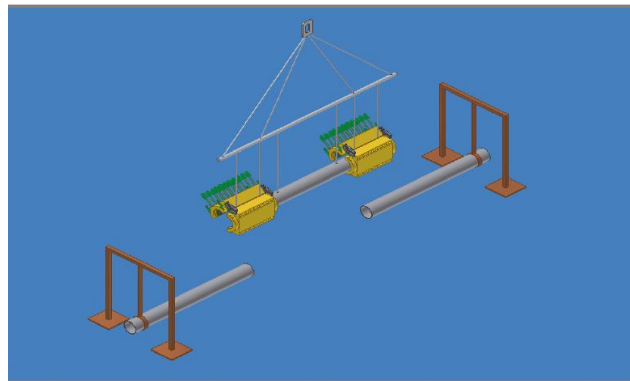


Figure 7-1. Clamped spool piece installation (source: OTC19207).

The studies showed that ‘crack in welds’ is the most probable reason of pinhole leaks in a pipelines, and for those kind of deficiency a full structural clamp is advised to seal the leak and stop the crack propagation.

As a benefit of this system, the need for pollution control units (such as tents or bags- which are used to collect spilled oil from the damaged pipe) is minimized. The lift frames placement is such that they create containment “humps” during pipe cutting. After cutting pump-able plugs can be used during the spool piece installation (Ayers et. al, 2008).

This JIP was originally divided in two categories: one for pipelines (larger diameters) (DW RUPE-PL) and one for the flow-lines (smaller diameter) (DW RUPE-FL). The main technical requirement for the flow-lines differing from the pipelines is related to removal of a thick, tough and hard layer of thermal insulation on the outer diameter of the flow-lines. If this challenge can be solved (by improving the removal tools), the in-line spool-piece solution based on subsea repair will be the better option for the flow-lines rather than lifting and recovering to the surface that is not feasible all the time due to adjacency to the manifolds or the weight of pipe. Hence, there would be one common plan for both flow-lines and pipelines at the end.

The initial plan was based on employing a set of split clamps and spool-piece. Figure 7-3 shows the arrangement for the clamps and spool pipe. The structural split clamps are fixed to the spool and are deployed using spreader bar while the clamps are opened with hinges (Figures 7-1 & 7-2).



Figure 7-2. Opened clamp (source: OTC19207).

The test of the split clamps showed that the clamp can accommodate the nominal pipe diameter plus 1.5% ovality in the pipe with the efficient sealing and gripping (Ayers et al, 2008). Tolerances are a matter of challenges for clamp designs. Tests may reveal mismatches if the tolerances are not considered during design.

The gripping system is acting almost as for the Morgrip: conical pieces of metals slip over each other's surface in a confined space and create the radial gripping along the outer diameter of the pipes.

Since the sealing system is engaged with the outer surface of the pipe (and not the pipe end edges) a rough pipe end has less effect on sealing mechanism and efficiency.

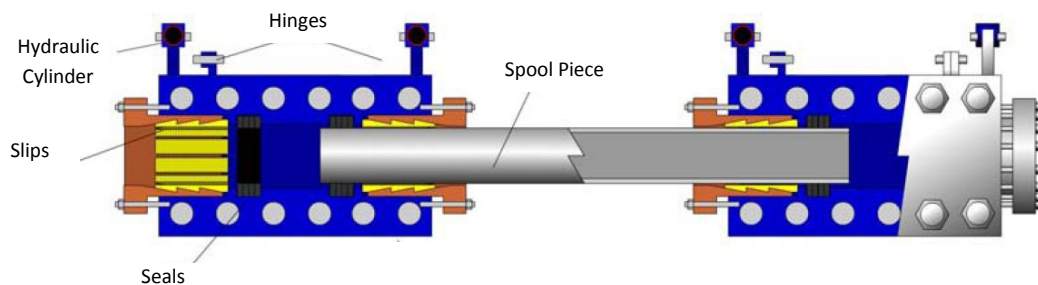


Figure 7-3. The clamped spool (source: Stress subsea, Inc).

The pipe ends are already cut and prepared for the final alignment and spool connection (Figure 7-4). Hydraulic cylinders are placed on the clamps. The clamp halves are closed and bolted once they are in final position. The cross sectioned part of the clamp shows the gripping system engaged the pipe outer diameter.



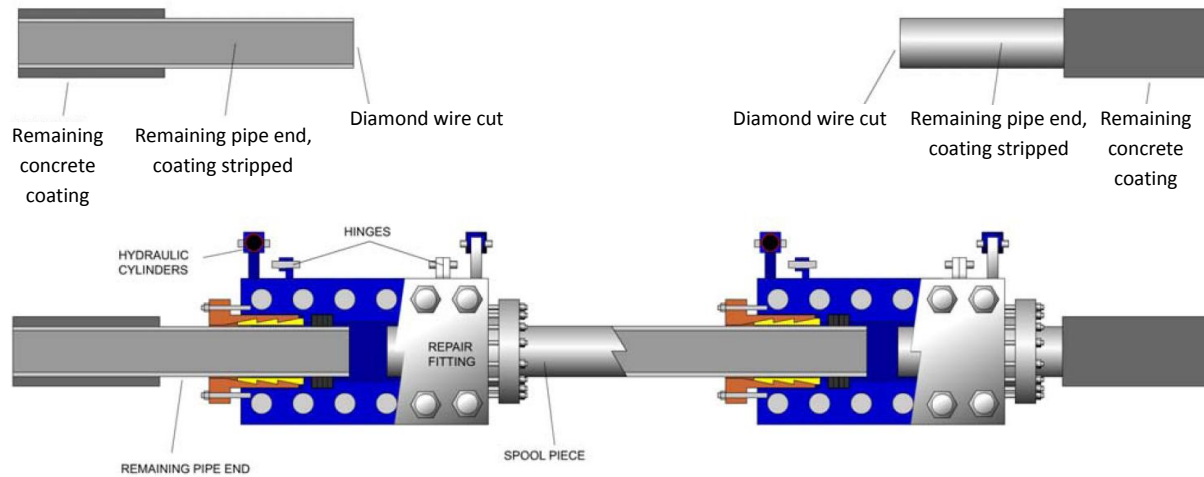


Figure 7-4. The clamped spool installed and the pipe ends are connected (source: Stress subsea, Inc).

The schematic of the typical repair sequence is illustrated in Figure 7-5.

The procedure is almost same as for the Statoil PRS. In DW RUPE, the location of the lifting frames is such that a hump will be created. And the frames are located at the same time either side of the damaged point in the pipe. The CIF-type of tool is not needed anymore as the spool and clamps are integrated and lowered together while the clamps are opened. A-frames (H-frames for Statoil PRS) are re-located after the pipe ends are blocked by pump-able plugs. The bolt tensioning will be done by ROV.

The challenges for the procedure might be listed as:

- Calculation of the distance between the frames to create hump effect.
- Frame-standing alignment of the pipe ends and spool is difficult to handle, it is especially harder for the long spool. Also the weight of the clamps for the larger sizes might be a problem.
- There is an extra pigging operation required at the end.

Generally speaking, the procedure steps are:

- to deploy A-frames at either sides of the damaged location, lift the pipe from two points,
- to cut the damaged suction off the pipe,
- (using the ROV) to insert the pump-able plugs into the cut-end of the pipes,
- to lower the clamped spool down to the pipe ends,
- to engage and activate the clamps with the pipe ends,
- to lay down the fixed pipe on the seabed,
- to recover the tools and frames to the surface,

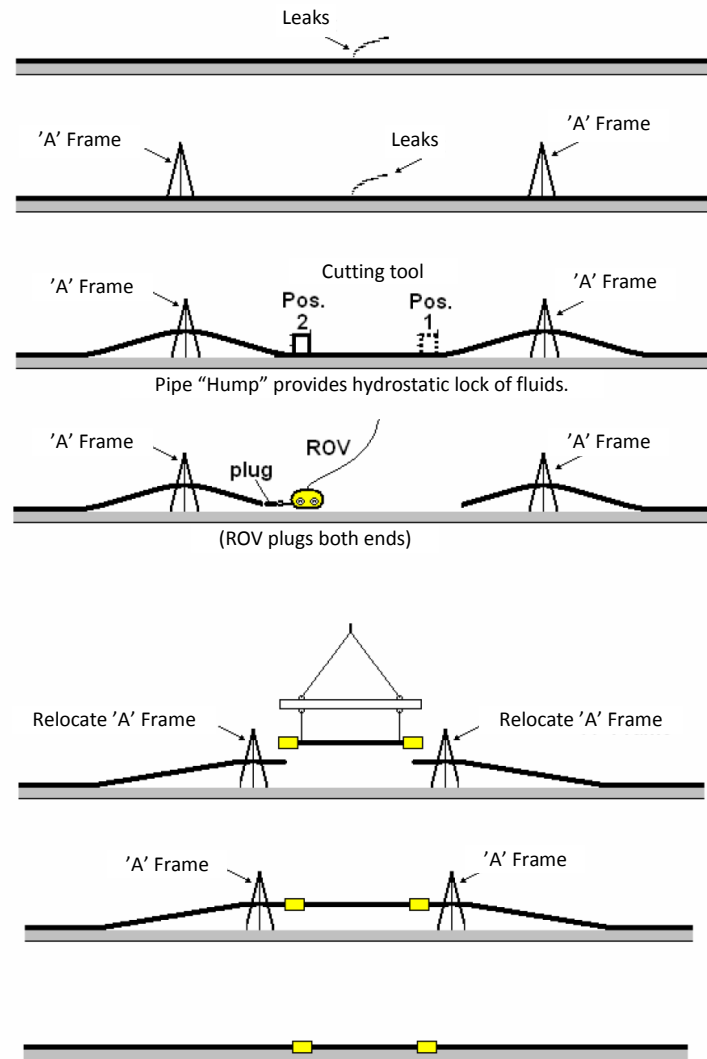


Figure 7-5. Installation sequence (Source: OTC17772).

Once the pipe is cut to remove the damaged section, the residual stresses (due to the damage-causing loads) are released. This can be raised as an advantage for the “replacing” type of repair.

For **flow-lines** where normally the size of the pipe is small, if recovering to the surface is the solution, the same steps are repeated for the cutting and removing the damages section. The plugging is done by a pulling head, and the head is then connected to the recovery wire. Each end of the pipe is recovered to the surface and depends on the length of the damaged pipe it is repaired on the surface or a PLET (Pipeline End Terminal)-type of joint is welded to the pipe end (Figure 7-6).

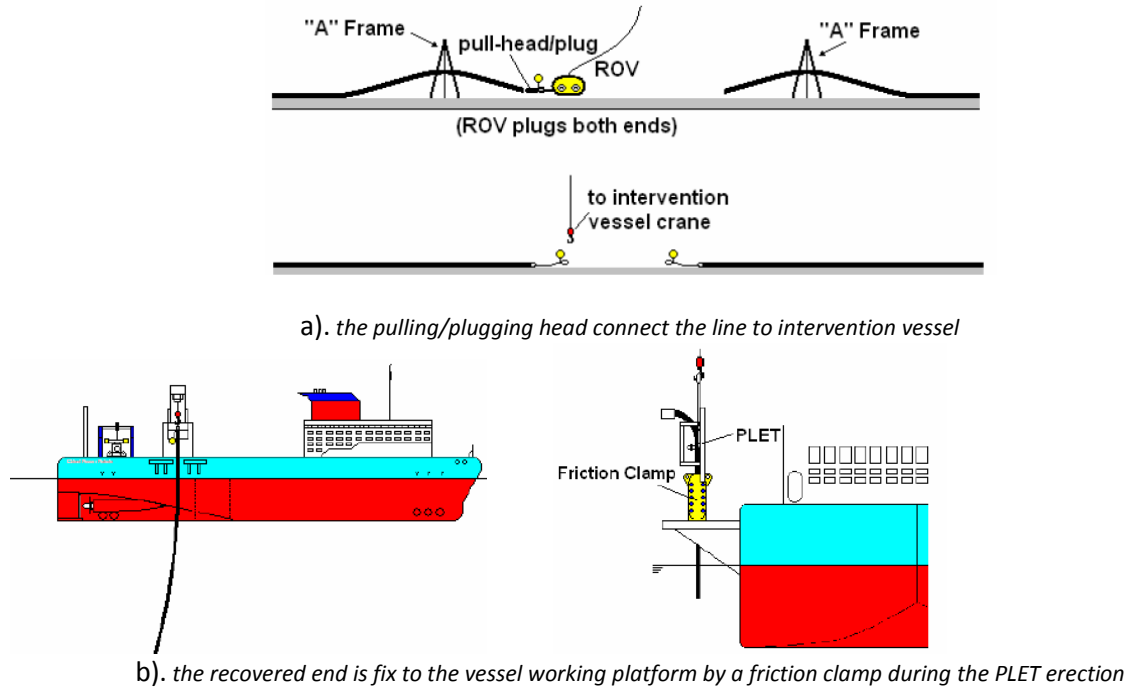


Figure 7-6. Recovery method for repair of Flow-lines (Source:OTC17772).

Once the same task is done for the other pipe end, and the pipes are laid back to the sea bottom, a pipe spool similar to the tie-in jumpers is deployed and complete the connection of line (Figure 7-7).

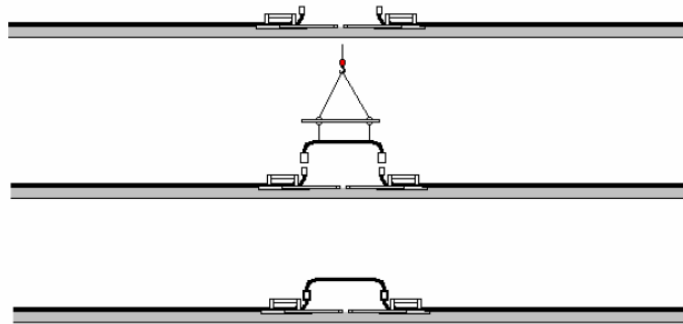


Figure 7-7. A jumper-type connector pipe completes the line (Source: OTC 19207).

### Upgraded DW RUPE

After Hurricane Katrina in August 2005, the repair methods and rectifications needed to be upgraded. Several alternatives and technologies were studied. New designs came out and were being tested. The main improvement was in the connector part of repair plan. Some of the designs are reviewed below:



Dual Grip and Seal Connector

The connector is made of two Grip and Seal connectors that are welded together. The design is proposed by Oil States Industries, Inc. (Ayers et. al, 2008). Shell is one of the main clients for this design. The system is shown below (Figure 7-8).

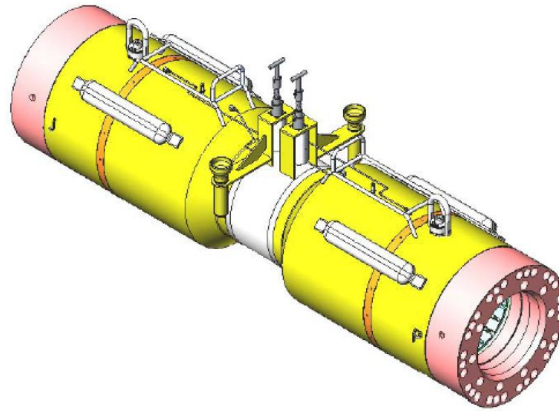


Figure 7-8. Dual Grip and Seal Connector (Source: OTC 19207).

The installation method differs from the clamp type alternative. The connector erection and skidding is based over an indexing base (Figure 7-9). The connectors are primarily mounted on the replacing spool and are deployed at the installation location on seabed, where the lifting frames and indexing bases lift the pipe ends and make them ready for spool installation. Once the stabbing guides on the indexing base bring the spool into the right position, the index guides slide the connectors toward the pipe ends and the connectors locking system will be activated (Figure 7-10).

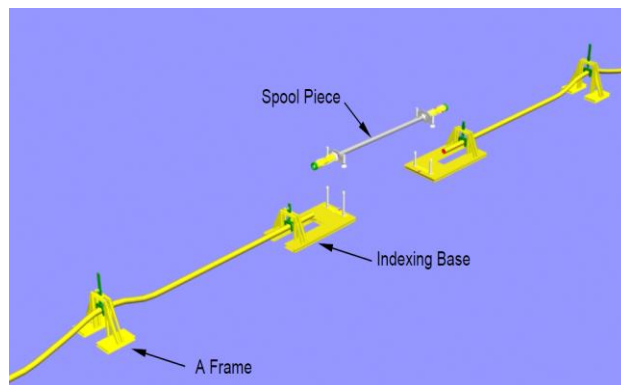


Figure 7-9. In-Line Connection System Profile (Source: OTC 19207).

A spreadsheet is established to analyze the pipe lifting that is an engineering tool to plan the pipe lifting and cutting operation. The lifting force and height, the distance between A-frames (creating the hump

effect) and the distance between indexing bases and A-Frames and similar parameters can be obtained from this spreadsheet.

First cut in the line can cause an effect called spring-back of line that is due to the residual horizontal tension in the pipe. Since the residual tension itself is a function of the pipelay angle, the spring-back in shallow water is generally larger than in deep water (more vertical angle e. i. less horizontal tension) (Ayers et. al, 2008).

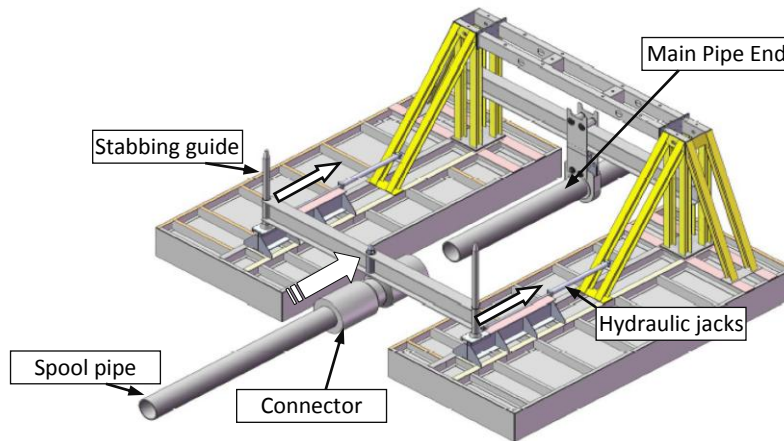
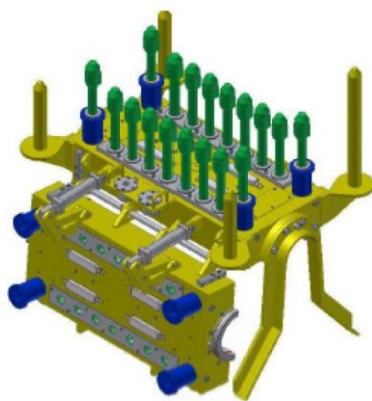


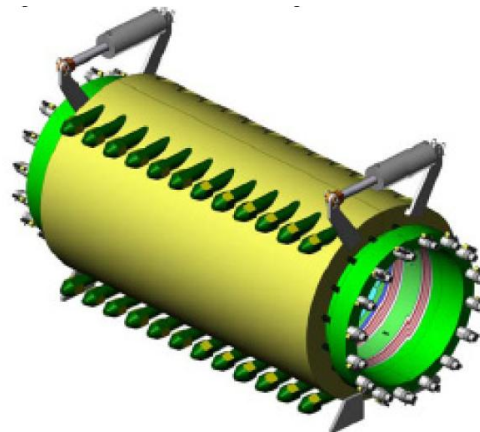
Figure 7-10. Indexing Base (Source: OTC 19207).

### Structural Leak Clamps

The other improved design developed in the JIP studies was for the structural leak clamps. The study was divided into main categories: one for the pipe sizes between 10 and 16 inch the other for the sizes from 18 to 24 inch. The design is based on diver-less installation considerations. Figure 7-11 shows two typical designs of the mentioned categories.



a). Clamp Size : 10-16 inch (Quality Connector System, Inc.)



b). Clamp Size : 18-24 inch (Oil states Industries, Inc.)

Figure 7-11. Structural Leak Clamps (Source: OTC 19207).

On the small size clamps (Quality Connector System, Inc. design, Figure 7-11 a) there is a guide for the time of installation to piggyback the clamp over the line where it leaks. The bolts are tightened by subsea hammers.

For the bigger size clamps (Oil States Industries design, Figure 7-11 b), the installation force is achieved by hydraulic jacks and for permanent locking, bolts will be tightened after the final installation.

## 8 Subsea7 PRS

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Following a damage in a 12" pipe operated by Total in Angola, Subsea7 was awarded a contract to develop a diver-less Pipeline Repair System (PRS). The Water depth is 1350 meter and the whole operation is ROV assisted.

The Subsea7 design for the case is based on replacement of a new spool (loop) and using a set of Grip& Seal type of connectors.

The method is almost as same as the Statoil PRS. The main difference is the tools for the connector installation which is done by the CIF in the Statoil system. Subsea7 designed a grillage skid that is put on top of two pieces of mud-mat (Figure 8-1).

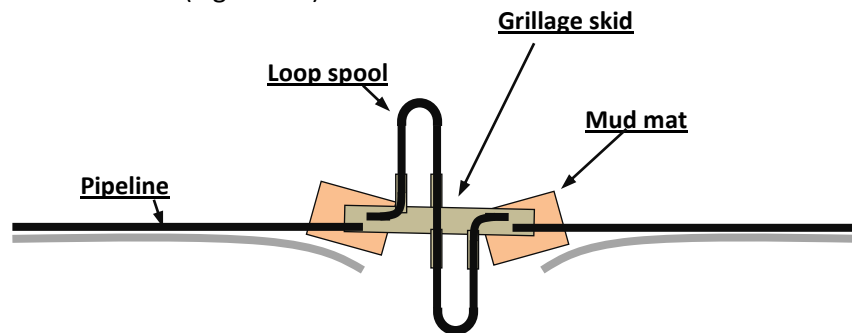


Figure 8-1. Subsea7 repair system (top view). The damage pipe is replaced by a loop.

The system elements are listed as:

- *Mud mat*  
To make a stable working base.
- *Grillage skid*  
To prepare the skidding platform for different activities over the pipe.
- *Loop spool and the mechanical connectors*  
To replace the damaged section of the pipe.
- *Connector installation tool*  
To act like the CIF in the Statoil system. It is also preparing a support for the extra length of the pipe that shall be cut.
- *Pipe handling frame*  
Similar to H-frames in the Statoil PRS.
- *Pipe alignment frame*

To align the pipe end with the spool end.

- *Coating removal tool*  
To remove the coating over the length that the connector will be installed over.
- *Pipe cutting tool*  
To cut the pipe.
- *Pipe end preparation (beveling) tool*  
To bevel the pipe end to fit the connector and/or mating pipe end.
- *Pipe alignment tool*  
To check the angular alignment of the pipe and spool.

The operation is shown in Figure 8-2.

The mud-mats and the skid will be left on location just underneath the repaired pipe. These act like a permanent support.

The loop is to accommodate any axial movement and load. It decreases the axial loads on the Morgrip connector.

## Repair methods for damaged pipeline beyond diving depth

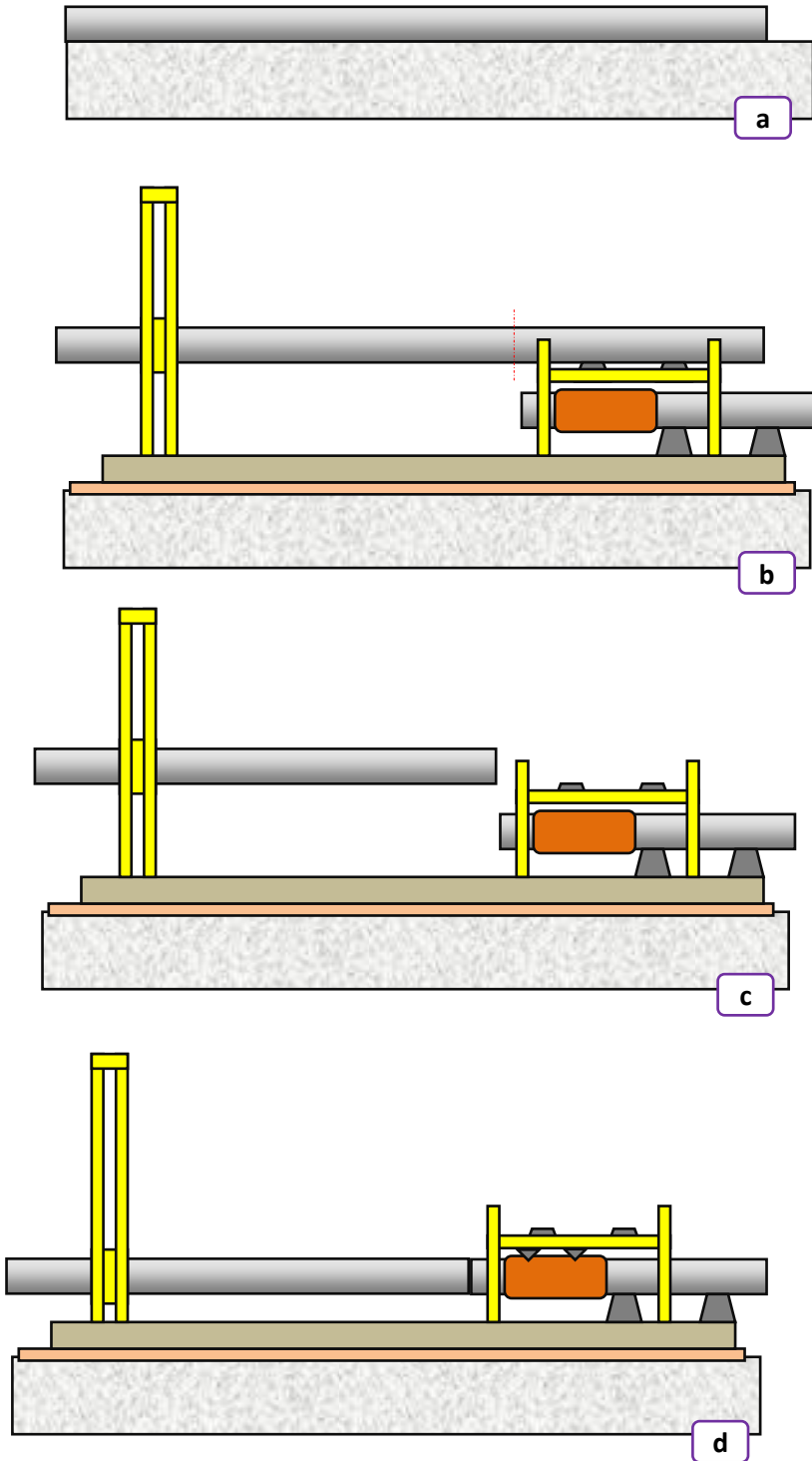
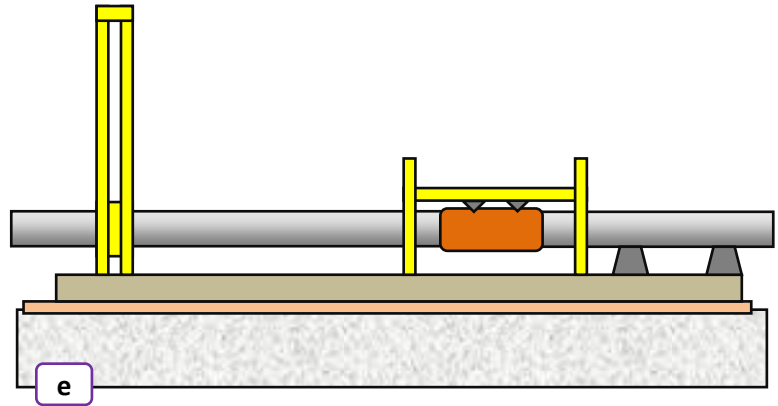


Figure 8-2. Subsea7 technology for TOTAL Girassol pipeline repair.

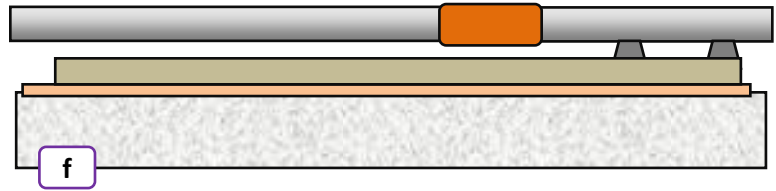
- a) The damaged pipe is already cut and the ready
- b) The grillage skid and the connector installation tool with the loop and connector itself are deployed on the seabed and the pipeline end is lifted and placed on top of the connector installation tool. After measuring the pipeline end is cut to precise length.
- c) The extra length is cut.
- d) The handling frame lower the pipeline end and using alignment frame, the two pipe faces are mated.

Figure 8-2 (cont.).

- e) The connector and the connector installation tool is moved to the installation place.
- f) The connector is activated and the installation tool and the handling frame are removed upon the pipeline is laid on seabed or support.



e



f

## 9 BP Mardi PRS System

BP has established and developed a deepwater repair system for the Mardi Gras Transportation System (MGTS) in Gulf of Mexico. The deepwater section of MGTS is located in depth of 4500 feet (1300 meter) to 7300 feet (2200 meter) where the export line is installed.

The damages on the pipe are categorized as:

- Minor damages such as pinhole leak,
- Major damage such as buckling,
- Catastrophic damage such as slope failure.

Definition of minor and major damage in Martin, Killeen and Chandler’s (2004) paper is that if the extended length of the damage is equal to or less than the pipe diameter it is minor damage and if the length is great than one pipe diameter it is defined as major damage.

Three main repair methods are studied and developed for different damage scenarios:

- Clamp Repair,
- Surface-Lift,
- On-bottom Repair,  
(Martin, Killeen and Chandler, 2004).

For the minor damages, generally the repair clamp is the solution and for the major damages-where the replacement of a pipe section is required- either surface-lift or on-bottom repair (or the combination of both) can be decided. The vertical Jumper Spool (VJS) is the core of the two latter solutions. Since the decision on the method depends on several parameters, the PRS is a modular system with enough flexibility. The below table summarizes the application of the different repair methods for different damage types in deep-waters.

Damage Type	Repair solution		Comments
Minor	Clamp Repair		
Major	Surface-Lift	Vertical Jumper Spool	“High Lift Capacity” Vessel/ Surface welding/ Similar to DW RUPE for flow-line repair
	On-Bottom		Subsea repair/mechanical coupling
Catastrophic	Lay new pipeline		A major damage when the slope is greater than 5 degree also needs to be re-laid.

Being in the vicinity of crossing points and Steel Catenary Risers (SCR) is also a limiting factor for the Surface-Lift method further to vessel lift capacity. Vertical jumper spool (VJS) accommodates the pipeline expansion.

Figure 9-1 shows the general arrangement of VJS and the other components involved in on-bottom repair system.



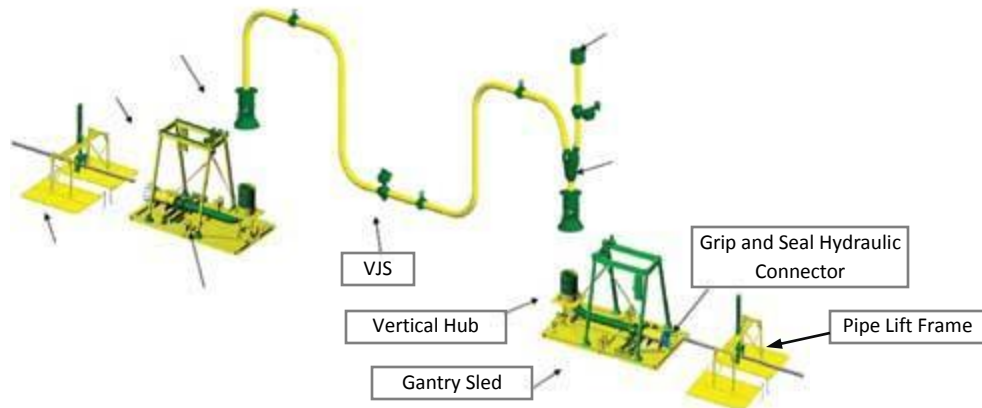


Figure 9-1. Vertical Jumper Spool (VJS) Installation (Source: Offshore Magazine).

## 9.1 System Elements

Apart from VJS, the main components in MGTS PRS are listed and described briefly as follows:

- **Grip and Seal Hydraulic Connector (GSHC)** (Figure 9-2)

It connects an elbow (with a hub at the other end) to the pipeline end and provides a structural connection joint. It is assembled into the gantry sled (Figure 9-3) and it will be installed remotely by ROV when the pipeline end is prepared. The gripping mechanism is using a wedge-shaped slip segments inside the body (Oil States website, 2011). The gripping shall support the tension (from internal pressure and externally exerted tension) and compression (from thermal longitudinal expansion) loads. The dual-grip design provides support for both tension and compression loads. The sealing consists of two stacks of elastomer packers with an annulus space in between which makes the pressure-test possible upon the connector setting and installation (Oil States website, 2011). This is provided in dual arrangement in order to verify the joint integrity (Martin, Killeen and Chandler, 2004). The axial compression strains packers radially against the pipe outer diameter.

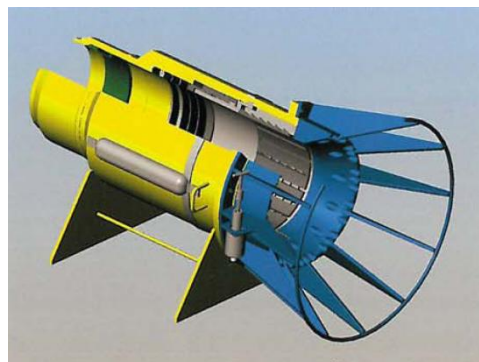


Figure 9-2. Grip and Seal Hydraulic Connector (GSHC) (Source: Oil States Website).

In some cases, the GSHC acts like a Pipeline Recovery Tool (PRT). For instance, if any damage happens during the installation and the cut pipe needs to be retrieved to the surface. In order to

protect the connector against corrosion anodes are attached to the body. The innovative design focuses on multiple-size GSHC. At the moment the multiple size design is available for 16 and 20 inch and also 24 and 28 inch.

Obviously, when the pipeline end is recovered to the surface in the Surface-Lift repair method, the GSHC is not utilized and an elbow is welded to the pipeline end directly.

- **Gantry Sled**

This is a supporting structure to install the elbow to the pipeline end (Figure 9-3). The GSHC is mounted on one end of the elbow (toward the pipe) and an upward-looking male hub is welded to the other end (toward the VJS). The Gantry Sled acts like a bridge crane and with conjunction of an alignment guide frame slides the GSHC-elbow-hub assembly over the pipe end. Hydraulic power is used for the movements. An ROV supplies the hydraulic power and controls the actions. Once the connector and pipe end are aligned, ROV actuates the GSHC to connect to pipeline.

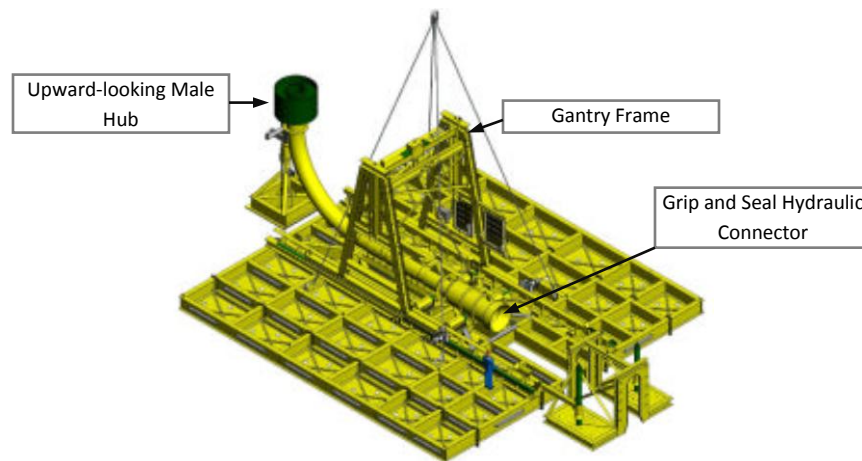


Figure 9-3. Gantry Sled (Source: OTC 16635).

Upon the connection, the vertical hub is a part of the pipeline and the VJS can complete the line through the hub. After connection, the alignment guide frame and gantry frame will be removed. And only the mud mat and the pipe assembly itself will remain on seabed.

- **Collet Connector**

The final connection between the VJS and upward-looking hub is prepared by Collet Connector. The collet connector (with the VJS) is installed remotely and easily by running tools. A metal seal is used in the collet connector design. It has at least the same bending strength as the pipe itself but is considerably weaker against the torsion loads.

Figure 9-4 shows the collet connector (the green segmented part). It provides a female fitting against the male hub from the elbow. Figure 9-5 shows the after-connection arrangement.

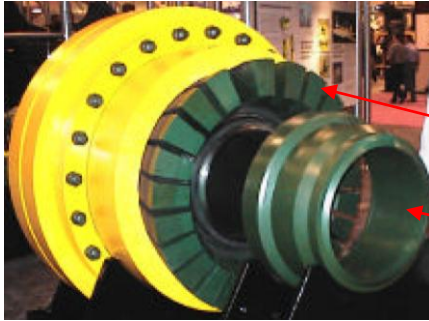


Figure 9-4. Collet connector (Source: OTC 16635)

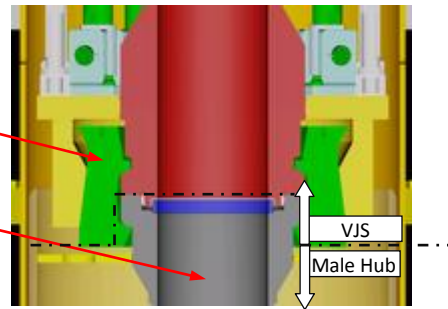


Figure 9-5. Collet connector after connection to upward-looking male hub (Source: Oil States)

▪ **Pipe Lift Frames (PLF)**

The PLF is to lift the pipe off the seabed and to provide access to the pipe end for the repair operations (Figure 9-1). It can lift the pipe in the vertical and lateral directions. It also allows the pipe rotation. The PLF functions are manipulated by the ROV hydraulically. Foldable mud mat eases the subsea lowering and retrieval (Figure 9-6).



Figure 9-6. Pipe Lifting Frame (OTC 16635).

## 9.2 Operational Procedure

Depending on the method of repair, the procedure can be planned as follows:

### 9.2.1 Clamp Repair

Steps:

1. Leak detection and isolation (or decreasing flow rate)
2. Pipeline lifting upon the PLFs deployment either side of damage location
3. Deployment and installation of the repair clamp over the leak
4. Lay back the pipe on sea bottom and retrieval of PLF

Steps one to three in Figure 9-7 show the above procedure.

### 9.2.2 On-Bottom Repair

Steps:

1. Leak detection, isolation or flood the line,
2. PLFs deployment on either sides of damaged section and lift the line,
3. Secure the damaged section with rigging,
4. Cut and recover the damaged section to the surface,
5. Deployment of guide frame over the pipeline end,
6. Deployment of Gantry Sled,
7. Connection of the GSHC-elbow-hub to the pipeline,
8. Locking the assembly to the basement and removal of gantry frame and PLF,
9. Repeating steps 5 to 8 for the other cut end,
10. Metering, fabrication and installation of VJS.

### 9.2.3 Surface-Lift Repair

Figure 9-7 illustrates the steps for both the clamp and on-bottom repair methods.

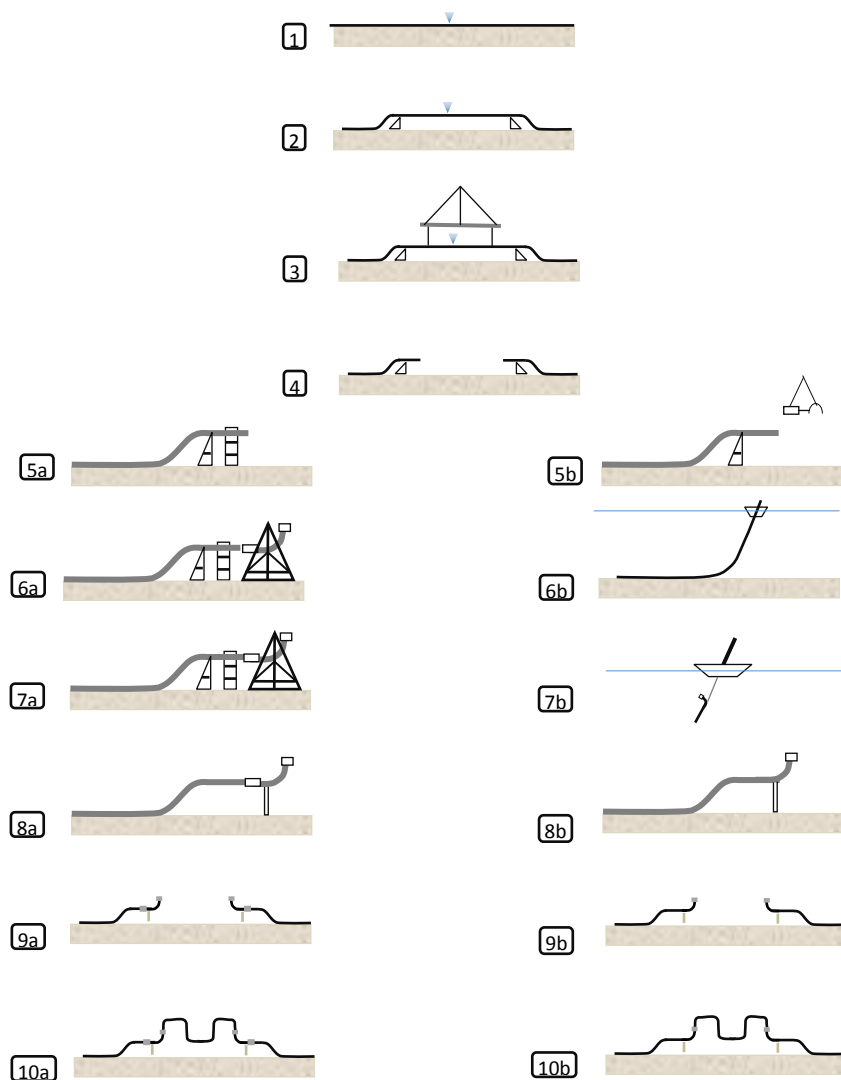


Figure 9-7. Operational steps for on-bottom and Surface-Lift repair methods (Step 1-10a and 1-10b respectively).

Steps one to four is similar to on-bottom repair method, the rests are:

5. Connecting the PRT (Pipeline Recovery Tool) to the cut end of pipe and dewater it (if necessary),
6. Lifting the pipeline end to the surface,
7. Welding the elbow-hub assembly to the recovered pipe end,
8. Lowering the sled-elbow-hub assembly to the sea bottom,
9. Repeating steps five to eight for the other end,
10. Similar to step 10 for the on-bottom repair method.

## 10 Eni/Sonsub/Saipem SiRCoS

SiRCoS stands for “Sistema Riparazione COndette Sottomarine” (Italian phrase) that means Subsea Pipeline Repair System in English (Spinelli, 2009). SiRCoS is a repair system established by Eni/Saipem (Saipem/SES developed it for Eni) to support subsea pipeline interventions in the area of the Mediterranean and Black Sea. The main requirements for the system are diverless repair intervention and fully piggability after the repair (Spinelli, 2009).

In this system the diverless depth is the depth in excess of 250 meter which is the practical limit for the saturation diving.

Similar to the most of repair systems SiRCoS considers two types of repair: the installation of a clamp on the local damage and replacement of damaged pipe with new spool.

The actual maximum water depth for the system operation is 2,200 meter. Maximum seabed slope angles are 10 degree and 15 degree transversal and longitudinal, respectively. The pipe size range is within 20 inch to 32 inch.

In the replacement type of repair, the focus is on a forged locking mechanism (metal to metal) (Figure 2-6). For this type of repair, there is a forging tool and a coupling device called the end connector. The first one is a tool to install the latter. The forging tool strains the pipe body onto the end connector wall permanently by using a hydraulic expansion force (Figure 10-1).

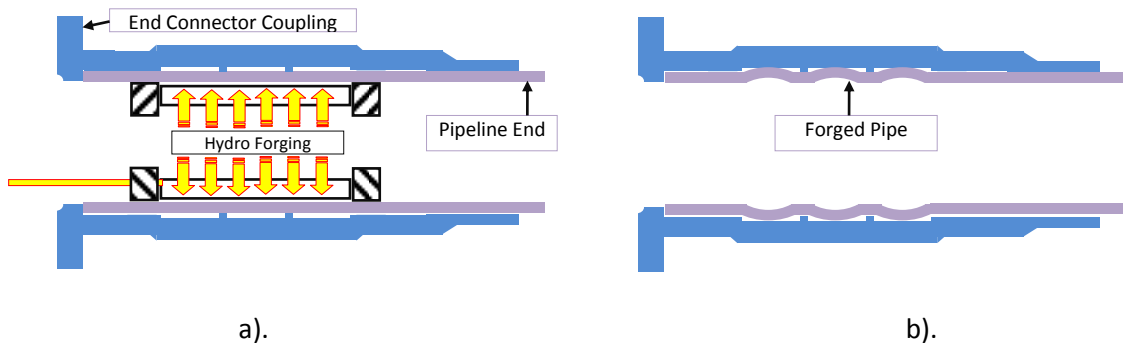


Figure 10-1. Forging the pipe wall on the end connector. The forging tool expands the pipe inside the pre-machined wall of end connector (a). The forged pipe and the coupling are integrated (b).

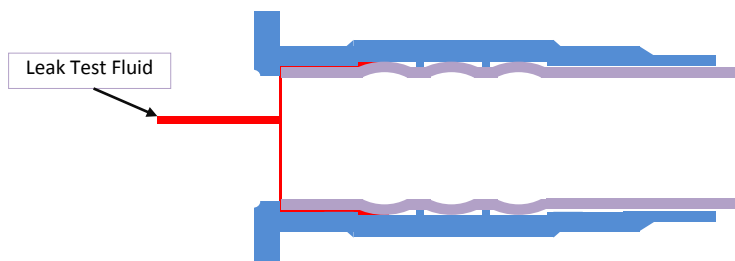


Figure 10-2. Leak test of the annulus space between the pipe and end connector.

The plastically deformed pipe (with a very high strain value) provides the sealing (Giuliano Malatesta, Brandi and Spinelli, 2008) as well as the gripping mechanism in conjunction with machined grooves on the internal side of end connector piece (high friction effect). Once the forging is completed, the annulus between the forged pipe and the end connector is leak-tested (Figure 10-2) (Eni Website, 2011).

Figure 10-3 shows an end connector that is ready for installation. The end connector design shall be such that it resists the same kind and size loading as the pipeline itself. The connector wall shall be in its elastic range and this prepares circumferential stress around the pipe and improves the sealing (Giuliano Malatesta, Brandi and Spinelli, 2008).

For each case and size, stress analysis and tests shall be conducted. The end connector is fixed in place and installed by a module that can be handled by ROV easily due to built-in buoyancy elements (Figure 10-4).

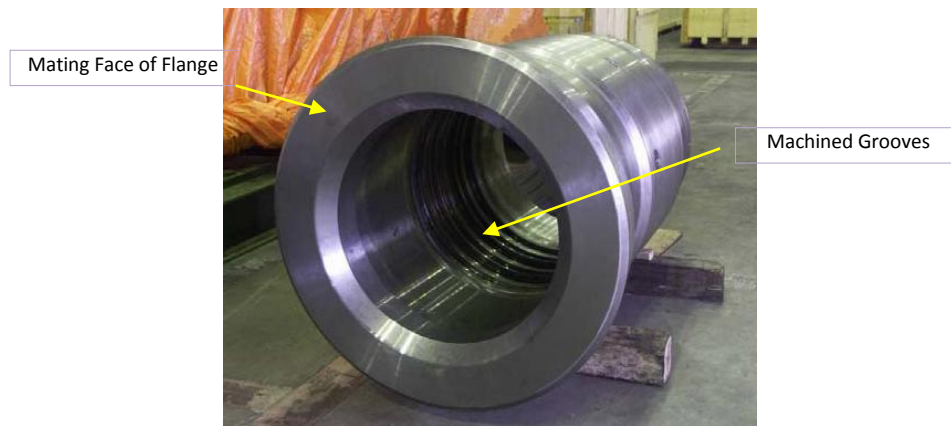


Figure 10-3. End Connector (Source: ISOPE 2009).

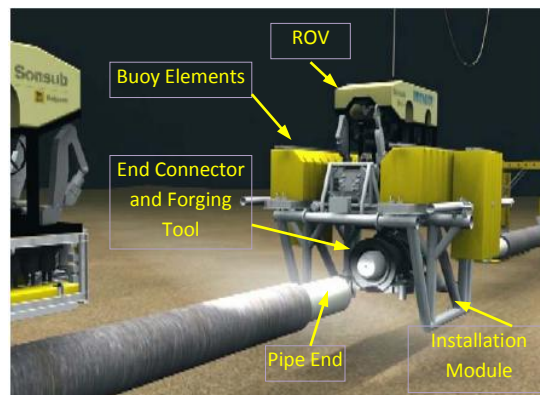


Figure 10-4. End Connector Installation (Source: ISOPE 2009).

Once the end connector is installed over each end of the pipe at the repair location, metering gives the configuration of the in-between pipe spool. Both sides of the spool are flanged (welded) with the specific design for the bolting. The mating flanges, one from end connector side and the other from the



spool side are pushed together in a clamp type surrounding jaw that is tightened hydraulically (Figure 10-5 a). Due to uncertainty in the precise distance between the two pipe ends (spool length), the spool will have an elongation in the mid point. Once in place and adjusted to the required length, the spool is locked by a cold forging system similar to that of the end connectors (Figure 10-5 b&c).

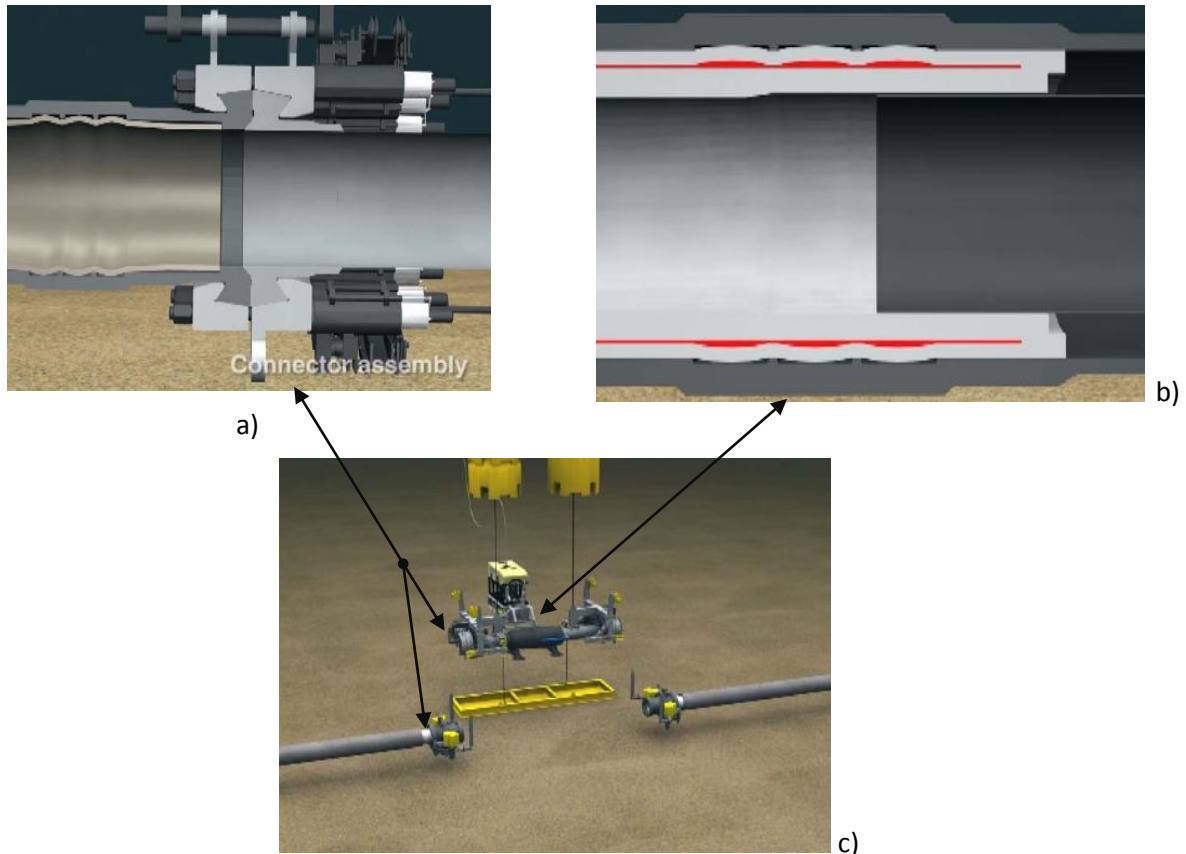


Figure 10-5. Spool Installation (Source: ISOPE 2009).

- a) The Flange connection between pipe end and spool
- b) Spool piece central forging (red color shows the pressurizing water into the forging chambers)
- c) Spool installation, utilizing the surface-bottom and local guides

The operational procedure is basically similar to the other systems. Following the damage detection and production considerations, the repair team is mobilized and following actions are taken:

- Lifting the pipe at the damage location through H-frames at either side of the damage,
- Securing the section that is planned to be cut and recovered to surface,
- Cutting and removing the damaged length,
- Removing the concrete layer (if any),
- Installing the end connector,
- Deploying the spool installation module, and completing the spool installation,



- Laying the pipe back on the seabed,
- Recovering the lifting and installation tools to the surface.

The overall view of the operation is illustrated in Figure 10-6 pictures. All photos are taken from the ISOPE paper by Spinelli and Sergio Fabbri (2009).

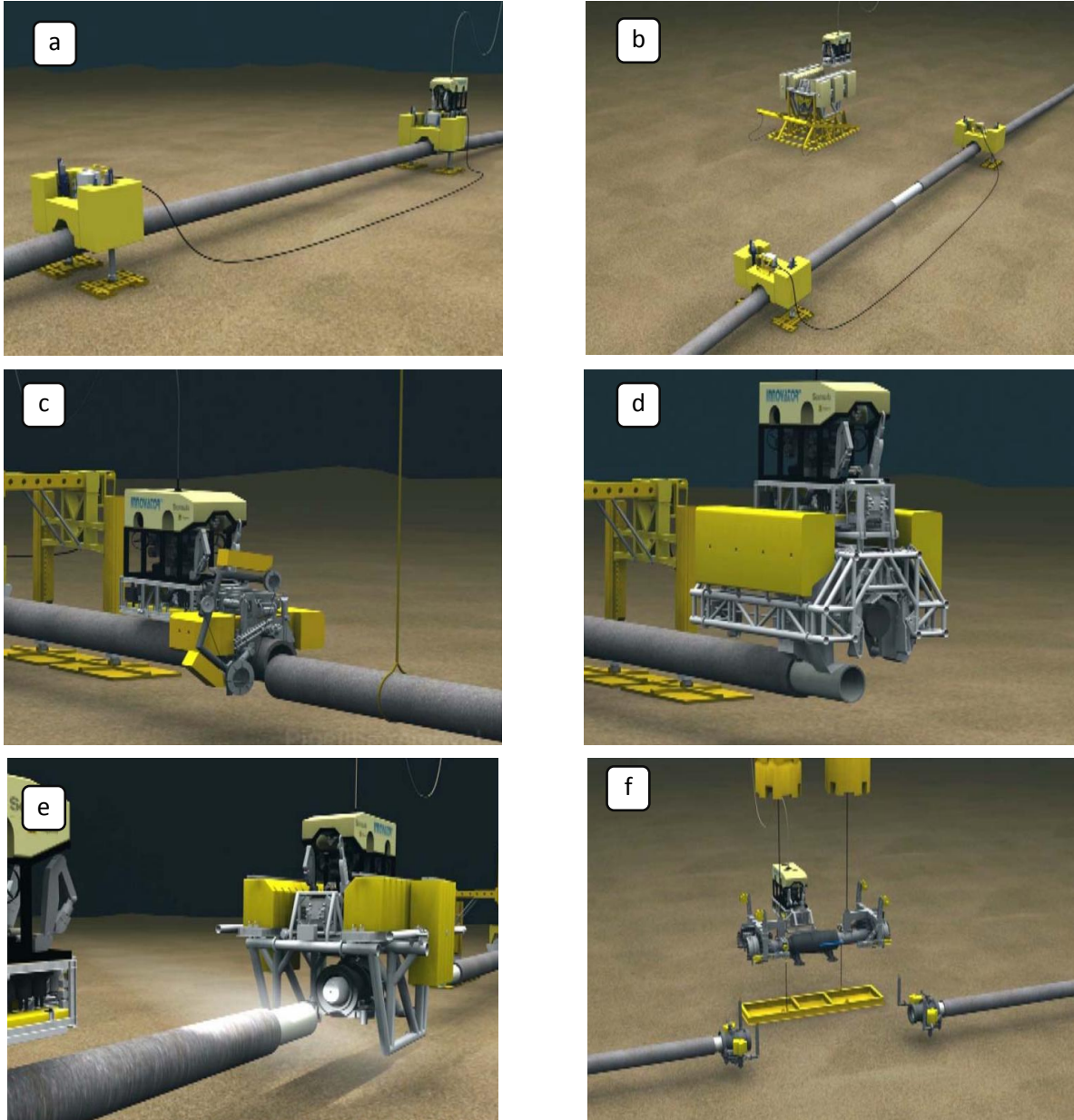


Figure 10-6. Eni/Saipem SiRCoS repair operation steps (Source: ISOPE Paper by Spinelli and Sergio Fabbri)

- a. Pipe Lifting*
- b. Concrete and Coating Removal*
- c. Pipe Cutting*
- d. Pipe End Coating Removal and preparation*
- e. End Connector Installation*
- f. Spool Installation*

## 11 Method Summary, Challenges and Ideas

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### 11.1 Method Summary

The deepwater pipeline repair systems described in previous sections are the best known systems fronting the challenging cases in different areas such as North Sea, Gulf of Mexico and Mediterranean Sea. They are almost similar in many aspects. The main differences refer to the integrity compensation. There might be however more systems for deep water repair.

In this subsection, the methods and alternatives for diver-less repair are reviewed briefly while challenges will be discussed later in the next subsection.

#### 11.1.1 Above-Water repair

The solution is fit for the cases where the length of pipe that should be cut and replaced is short, and recovering the pipe is feasible from a lifting capacity point of view as well as the pipe strength itself e.i. small pipes in shallow waters. The preferred option for the integrity compensation purpose is welding but if the spool is longer than the vessel handling capacity the recovered ends are flanged and the line is completed by a flanged spool that is installed subsea.

The factors involved when selecting this method are:

- Pipe properties: size, weight per unite length and the SMTS
- water depth
- pipeline length (for dewatering possibilities)
- length of damaged section
- availability and cost of the proper construction vessel
- damage location (nearby third party or the fixed installations)

#### 11.1.2 Statoil PRS

The Statoil PRS method supplies the contingency needs for North Sea area. It comprises diver-assisted welding, remotely-installed couplings and remotely-operated welding. The system covers the pipe range of 10 to 48 inch and the water depth down to 1000 meter. Deep PRS is under development for depths down to 4000 meter and tests for 2500 meter are verified. The Deep PRS development is mainly based on remotely-operated welding technique. Welding technique is the fillet weld type which integrates the spool and the line with a pipe sleeve. Butt-weld design is under investigation and study.

The Morgirp coupling with the steel ball gripping mechanism is the core of the PRS system for smaller pipe sizes. Lifting frames with hydraulic power and control support the preparation and repair operation. The coupling installation frame manipulates in the main task by aligning the pipe and spool ends, adjusting (moving back and forth) the coupling over aligned-ends and activating the locking and sealing system.

There are some limitations in Statoil PRS that can be listed as follows:

- Maximum seabed slope is 5 degrees along the pipe axis and 10 degree across the axis,
- The maximum pipe size is 48 inch,
- Maximum water depth is 1000 meter (2500 meter tested).

The challenges are discussed in following section (11.2) generally.

#### **11.1.3 DW RUPE**

DW RUPE is a response plan to the pipeline damage incidents in Gulf of Mexico. It covers the depth range of 300 to 3000 meter. The system consists of several alternatives such as clamped spool, jumper-type connection and spool with Dual Grip and Seal Connector. For the leak type damage structural leak clamps are considered.

Replacement of a damaged section with a spool that is connected to pipeline cut-ends via a Dual Grip and Seal Connector is the main alternative for deeper waters. The connector is installed and activated remotely by an indexing base. This system prepares the facilities to minimize the pollution effect of pipeline damage and repair.

The limitations of the system can be listed as:

- Limited length of replacing spool,
- Maximum leak clamp size is 24 inch.

#### **11.1.4 Subsea7**

The system was established by Subsea7 primarily for a repair project in West Africa, where the depth was 1350 meter and the pipe size was 12 inch. In fact, that was an 'ad hoc' design for that case that it can be considered as a general solution. The coupling used is of Dual Grip & Seal (DGS) type. A looped spool can be a common solution for high pressure high temperature (HPHT) pipelines; especially a when buckling caused the damage. In this case the axial loads on the connector can be partially shifted to the loop.

The main challenge with this method is the volume of subsea jobs that imposes cost and hard marine operations.

#### **11.1.5 BP Mardi**

BP Mardi Gras pipeline deepwater repair system was developed for intervention support to Mardi Gras Transportation System (MGTS). Three main types of damage are defined: Minor, Major and Catastrophic. For the minor and catastrophic damages use of a repair clamp and relaying the line are the solutions, respectively. For the major damage case, where the damaged section needs to be replaced by a vertical jumper spool, the repair operations can be either the surface-lift or the on-bottom. On-bottom repair operation is a fully remote operation while in surface-lift the end vertical hubs are connected at the surface and the vertical jumper will connect the pipe ends.

The pipe ends are connected to a bend spool via a GSHC (Grip and Seal hydraulic Connector). The bend spool itself is welded to a male hub that will be a connecting point for the vertical jumper (collet

connector). The GSHC is available in the size range of 3 to 48 inch and for different classes (up to rating 600).

The challenge with this method is related to the post-installation loads due to change in pipeline configuration by having vertical spool.

#### **11.1.6 Eni/Saipem SiRCoS**

The SiRCoS is a pipeline intervention method established by Eni/Saipem to support the Mediterranean deepwater area with diver-less considerations. The method is based on replacement of a damaged section of pipe with new spool. The connection is achieved via end connectors mating spool flanged-ends. The flanged end connector grips the pipe OD at a cut end after a cold forging process that is a hydraulic expansion of inner pipe into pre-machined house of end connector's body. In fact the inner diameter of the pipe is deformed plastically. The elasticity of the pipe shall be supplied from the end connector body and the connector shall withstand the loads from the internal pressure and temperature (hoop) fluctuations further to axial loads.

The difficulty index is defined in Spinelli and Fabberias (2009) as the square of the outer diameter multiplied by the water depth ( $D^2 \times WD$ ) that means the water depth contributes to the difficulties of pipeline installation and operation and this role is getting more significant by going into deepwaters from one side. Improving the fabrication technologies to have larger diameters lay-able in deeper waters increases the repair difficulty from the other side.

### **11.2 Repair Operation**

Although for each damage scenario and case specification, there might be an 'ad hoc repair' solution, the repair operation steps are similar.

These steps are listed below. The repair method is selected in second step.

1. Initial detection and general assessment of the damage
2. Detailed inspection and evaluation to define need, extent and **type of repair** necessary;
3. Sourcing of spare materials and potential construction vessel(s) for performing the repair;
4. Negotiation with suppliers and contractors for supply of materials and repair services;
5. Manufacture of materials were not available from stock;
6. Development/qualification of procedures required to perform repair operations;
7. Isolation/conditioning of the pipeline to enable safe completion of repair operations;
8. Mobilization of construction vessel(s) to site;
9. Completion of preparation of the pipe repairs (e.g. coating removal/seabed excavation) and removal of the damaged section;
10. Reconnection of the two pipelines ends using the selected method for the repair;
11. Acceptance testing/inspection of the repair; and,
12. Re-commissioning of the pipeline for resumption of normal operation.

### ***Repair Operation Planning and Costs***

In order to be able to plan the repair operation, it is required to have estimated values for each sub activity and step. Probabilistic tools (e.g. Monte Carlo technique) are used to include the uncertainties within the analysis. The expected duration of repair operation is depending on a series of different factors, as follows:

- Type of repair: minor, major or re-laying,
- Contingency availability: if there are any contingency response plan in place,
- Operation area: how accessible the operation location is,
- Start date of repair.

For instance, the typical repair duration for a major damage case with no contingency plan is 370 days, while for the case that a repair contingency is provided, this value is 150 days.

Pipeline might be assessed as fit to operate on a temporary basis until repairs completion. A proper pre-planning of repair can minimize downtime of the pipeline. The typical duration of pipeline downtime (from steps 7 to 12) is in range of 50 to 80 days.

Cost for repair operation is also depending on many parameters (like those for planning). The typical cost for 'replacement' type of repair (major damage) is in range of 500-700 million NOK (Norwegian Kroner). For instance, a 24" pipe in Nigeria with replacement method cost 100 million USD (~600 million NOK) in 2009 (Offshore Magazine, 2009).

### ***Damage Detection***

The damage can be detected through regular inspections such as inline inspection by intelligent (MFL: Magnetic Flux Leakage) pigging, external visual or sonar surveys (ROV and side scan sonar) or it can be reported by third parties. In some cases, damage is detected late when it is extended and immediate action is required once it is reported. Damage detection at the right time, mitigates the consequences, gives enough time for repair planning and makes the operation simpler, faster and cheaper. When there is a defect such as crack (from field joint weld or corrosion) and the cyclic loads are existed, the RIGHT time of detection is very significant.

MFL inspection is still the best tool to detect the internal defects such as crack, metal loss, pitting and corrosion. However intelligent pigging is an expensive activity and the result interpretation needs very experienced specialists.

External damages, as it is mentioned above, are detected by ROV inspection or sonar surveys. There are still challenges to inspect non-exposed parts of line (e.g. buried parts, crossings and Pipe-In-Pipe or bundled pipes).

### ***Repair qualification***

Elements (such as fitting, coupling, etc.,) that are used for pipeline repair shall possess the similar qualification as for pipe itself. There are some tests, to be performed on repair elements prior to installation that can be categorized as Factory Acceptance Test (FAT) or basic test (DNV-RP-F113, 2007):

- Materials,
- Combined effects,
- Galling tests
- Polymer decompression limits,
- Activation test,
- Pressure test,
- Seal test
- Deactivation test
- Appearance/tolerances examinations

The installation shall be simulated and verified (with combination of FAT) in factory.

After coupling installation in repair operation, installation verification test shall be conducted. Final tests check if the completed installation meets the requirement and complies with the criteria. Mostly, the final testing refers only to a leak tightness test. In some cases, the verification comprises also monitoring and recording the important parameters by use of TV or sensors. This is for assurance of the prescribed criteria. The normal parameters shall be monitored during installation are:

- Pipe surface and end-cut conditions,
- Pipe alignment,
- Gap between pipe end and couplings,
- Contamination,
- Displacement and movement of coupling onto pipe ends,
- Activation displacement/force  
(DNV-RP-F113).



### 11.3 Challenges

Further to the challenges and limitations discussed above in the summary of the systems, there are a series of general challenges with the present methods and technologies that are as follows. The suppliers and operators are improving their services and capabilities to overcome the challenges.

#### ▪ Sloped Seabed

The systems and methods are for flat seabed or a very limited inclination (e.g. Statoil PRS standard specification tolerates 5 degree inclination and up to 30 degree in some very limited pipeline sections). This is very challenging for a repair operation and currently the main methodology is to replace the entire section and do the tie-ins in locations where the seabed is easier to operate at. Uneven seabed is common for deep water pipelines and in some areas it is very steep, reference is made to Ormen Lange pipeline route where it passes across steep hills (30 degree) (Eklund, Høgmoen and Paulsen, 2007). Figure 11-1 illustrates Ormen Lange seabed profile that is challenging for repair as well as for installation.

#### Recommendation:

The slope can be controlled during route selection engineering or a risk analysis shall be conducted for the most probable-damage-exposed part of line to show the pipe is in range of repair capabilities regarding the slope.

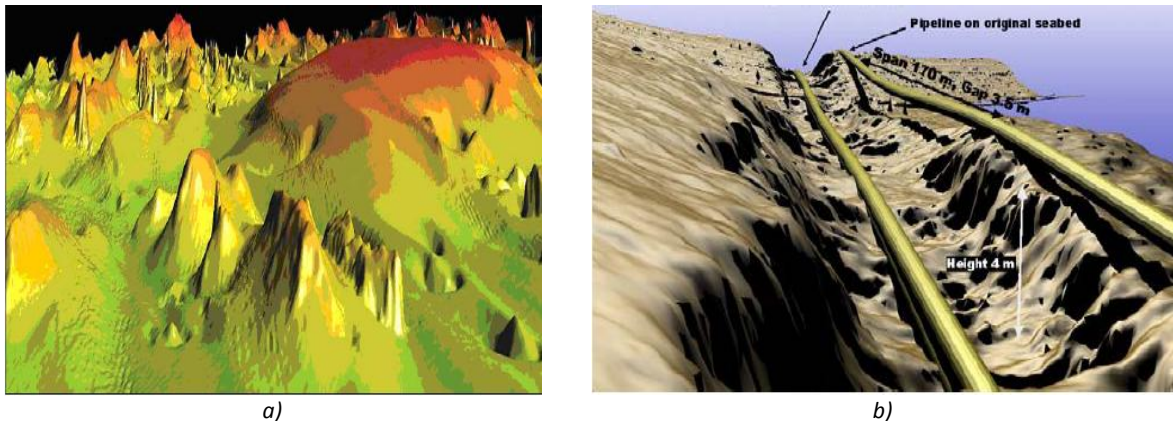


Figure 11-1. Ormen Lange seabed profile. Very uneven seabed (a) urges steep pipeline route (b) even after seabed preparation (Source: OTC-18967).

#### ▪ Sealing

Except for welding type of repair, sealing is a challenging issue for almost all other repair solutions. Although a coupling passes the test before being installed, there can always be a possibility to have leakage from the coupling.

The sealing performance is a function of several factors:

- Pipe geometry
- Sealing material
- Working temperature
- Working pressure

Pipe geometry is important particularly for metal-to-metal sealing designs. Pipe geometry refers to diameter and out-of-roundness parameters of the pipe and the pipe tolerances. Table 7-17 of DNV-OS-F101 (Offshore Standard: Submarine Pipeline Systems, October 2010) (Figure 11-2) describes the tolerances for different ranges of pipe diameters and different types of pipes regarding the pipe manufacturing process.

<i>D</i> [mm]	Frequency of inspection	Diameter				Out-of-roundness	
		Pipe body <sup>1)</sup>		Pipe end <sup>2, 3)</sup>		Pipe body <sup>2)</sup>	Pipe end <sup>3)</sup>
		SMLS	Welded	SMLS	Welded		
< 60.3	Once per test unit <sup>4)</sup>	± 0.5 mm or ± 0.0075 <i>D</i> , whichever is greater	± 0.5 mm or ± 0.0075 <i>D</i> , whichever is greater, but max. ± 3.2 mm	± 0.5 mm or ± 0.005 <i>D</i> , whichever is greater, but max. ± 1.6 mm		Included in the diameter tolerance	
≥ 60.3 ≤ 610						0.015 <i>D</i>	0.01 <i>D</i>
> 610 ≤ 1422		± 0.01 <i>D</i>	± 0.005 <i>D</i> , but max. ± 4.0 mm	± 2.0 mm	± 1.6 mm	0.01 <i>D</i> but max. 10 mm for $D/t_2 \leq 75$ By agreement for $D/t_2 > 75$	0.0075 <i>D</i> but max. 8 mm for $D/t_2 \leq 75$ By agreement for $D/t_2 > 75$
> 1422		as agreed					

where  
*D* = Specified outside diameter  
*t* = specified nominal wall thickness.  
 Notes

- 1) Dimensions of pipe body to be measured approximately in the middle of the pipe length.
- 2) For SMLS pipe, the tolerances apply for  $t \leq 25.0$  mm, and the tolerances for heavier wall pipe shall be as agreed.
- 3) The pipe end includes a length of 100 mm at each of the pipe extremities.
- 4) Once per test unit of not more than 20 lengths of pipe. For  $D \leq 168.3$  mm; once per test unit of not more than 100 lengths of pipe, but minimum one (1) and maximum 6 pipes per 8-hour shift. MR

Figure 11-2. DNV's table of pipe tolerances.

For example for two pipe sizes of 12" and 28" the tolerances is shown in table 11-1.

	Diameter				Out-of-roundness	
	Pipe Body		Pipe End		Pipe Body	Pipe End
	Seamless	Welded	Seamless	Welded		
12"	2,4	2,4	1,6	1,6	4,9	3,2
28"	7,1	3,6	2,0	1,6	7,1	5,3

Table 11-1. the pipe geometry tolerances for 12" and 28" pipes, according to DNV-OS-F101. The tolerances are +/- and in mm.

**Recommendation:**

From the table extracted from the DNV standard and calculated for our case sizes, there is a considerable difference between pipe body and pipe end and the pipe ends are supposed to have tighter tolerances. Based on this, it is recommended to cut the line at field joints ( as it is mentioned in notes (#3) below the DNV table, the tighter tolerance is for length of 100 mm from each end). Generally tighter tolerance means less probability of diameter mismatch for the pipe and coupling/clamps.

The sealing material shall withstand different kind of loads and be sufficiently flexible. The loads come from pressure and temperature or external loads and their variations. The material shall satisfy the requirements for whole design life without any needs to replace and shall resist against



different production states. The high-temperature-high-pressure pipelines need more design considerations.

For the high temperature working case, the graphite type of sealing materials can be used. The graphite sealing do not have memory and the load variation may affect the sealing performance. For low temperature cases with high pressure variations, elastomer (rubber) sealings show better performance. The concern with rubber sealing is the extrusion of the sealing due to loads. Normally steel anti-extrusion supports are used with rubber sealing. As an advantage for rubber sealing, they are hydrocarbon-friendly materials.

Metal-to-metal sealing (forged pipe and end the connector of Eni/saipem system), gives high sealing performance but since the forged pipe is in the plastic zone, there should be a risk of fatigue and crack growth due to fluctuating loads.

Recommendation:

Since welding gives the best sealing performance, for severe cases the welding method is recommended. A new idea in this regard is presented in the next section under “seal weld” solution.

▪ **Piggability**

Similar to the pipeline design phase, piggability shall be addressed during repair planning. The connectors and fittings (including the spool, flanges, bends,...) that are used for integrity compensation shall be such that the line is still piggable after repair and intervention. It shall support every kind of required pigging operations such as, commissioning pigging and inspection pigging. This shall be checked specially when there is a change in pipe internal diameter or curvature of pipe after repair. Generally the pipe shall not have curvature less than five times diameter (5D).

▪ **Anti-corrosion Coating**

In order to have access to the pipe body and to perform the repair jobs, it is required to remove all sort of coating over the pipe, including the anti-corrosion coating that is a very essential barrier against the external corrosion. Any change in coating shall be compensated by applying same coat or any other option.

Recommendation:

The bare pipe ends are covered by the inner part of sleeves (welding repair) or couplings/clamps. The rest of the cut-back of the bare pipe shall be coated or a sacrificial anode shall be attached (the anode can be integrated in coupling or sleeve). Some kind of composites that are water-activated (pre-impregnated wrap) is claimed to be applicable subsea (Green, 2010). However, the technologies are under development regarding subsea coating systems. The application tools and method is also a matter of concern and needs improvement.

A corrosion inhibitor solvent can be injected into the internal casing of the coupling/clamp (including the ball or wedge cage) and/or the annulus between coupling/clamp and pipe outer diameter. This also removes the trapped water.

- **Welding Quality**

The quality of the weld is a challenge for a remote welding operation since the welding quality is a function of welding atmosphere. The deeper water means higher welding pressure. The welding is not stable when the pressure is high (Richardson, Woodward and Billingham, 2002). In Statoil PRS, the TIG welding is stable only for depths under 1000 meter and can't be employed for deeper water (higher pressure). It has been observed that hydraulically-operated welding tools face difficulties in deep waters.

- **Control and Instrumentation**

In subsea and diver-less interventions, utilizing remote control and instrumentation is unavoidable. Hydraulic action and actuation basically represents the main platform for controlling of the repair operation. Although the hydraulic pressure is compensated by hydrostatic pressure, there is still some challenges. For the junction boxes for the instrumentation and electrical connections, the high pressure imposes special dry or seal design (that is normally supplied by oil). The complexity of the operation brings a huge amount of surface-to-seabed connections via a bunch of hoses and wires.

*Recommendation:* the developed technologies that have been employed in subsea control modules can be customized for repair purposes. Reference is made to Aker Solution technologies for diverless subsea connectors (DYP magasinet, 2010).

- **Angled Pipe**

For the minor damages in the case where the pipe is deformed and angled the repair clamp that seems the most fit-for-purpose solution, faces challenges since the sealing efficiency of a clamp is being directly affected by out-of-tolerance geometries. The clamp repair is less costly and quick response to a minor damage and maintains the productivity of pipeline temporarily or even permanently. Therefore it is the preferred method rather than using replacement methods.

*Recommendation:*

New ideas are presented in this regard in next sections (Angled Clamp).

- **Pipe-In-Pipe (PIP)**

PIP is a common and complex design to satisfy the flow assurance requirement of a deep water flowlines by preparing housing for high performance and thick insulations (O'Grady, Bakkenes, Lang and Connaire, 2008). Figure 11-3 shows two major types of PIP assembly: sliding assembly and bonded assembly.

## Repair methods for damaged pipeline beyond diving depth

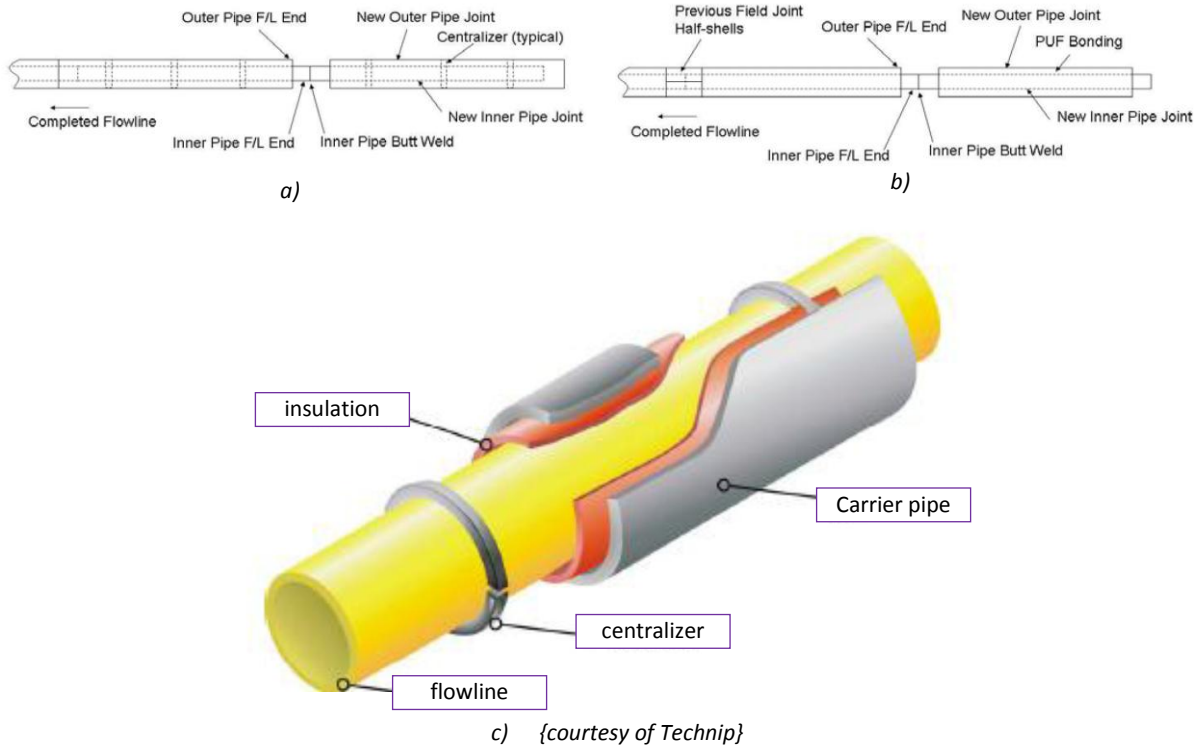


Figure 11-3. Pipe-In-Pipe assemblies: Sliding PIP (a) and Bonded PIP (b). (Source: OTC-18063)

This type of line is exposed to different failure risks. Further to normal risks that can happen for any line, axial buckling risk is also present, particularly when the water depth is increased and the operating temperature is higher and there is no pre-tensioning in the line (related to bonded assembly type) (Harrison and McCarron, 2006). Figure 11-4 shows how the stress is higher for pipeline with higher temperature in deeper water.

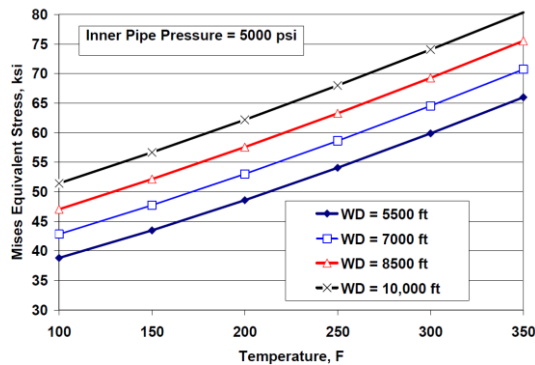


Figure 11-4. Effect of water depth combined with operating temperature on inner pipe stress at a certain inner pressure (Source: OTC-18063).

Damage in PIP lines can be challenging with respect to design complexity, specially for the flowlines with high temperature in deep and ultra-deep waters.

Recommendation:

Recommendations for such cases are given in the recommendation section (11.3) (PIP repair).

▪ **Bundled Pipe**

Similar to PIP, the complex design of a ‘bundled pipe’ is getting more common and popular in the offshore industry. The case is more challenging than for the PIP since there are different pipe size with different operating parameters (service, pressure, temperature,...) and even the control and hydraulic and electrical lines that are integrated together.

Damage consequences and repair strategies are of the main leading issues in bundle technology (Zabaras and Zhang, 1997).

Complexity with intervention and repair jobs, has urged the conservative considerations toward the need for repair and application higher safety factors (that averts the damage risk) during design engineering. Since a bundled-pipe design is generally used for short distance (in-field flowlines) the present method seems to be replacement of the whole pipe. However, bundle technology improves the thermal performance of flow-lines and results in lower risk of hydrate plugging (Zabaras and Zhang, 1997).

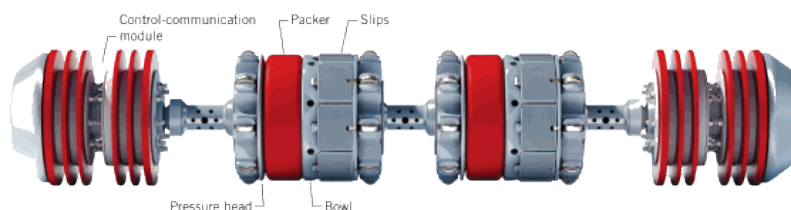
▪ **Pipeline Isolation**

In many cases in pipeline engineering it is required to isolate a section of a pipe from the rest of the pipe. In pipeline repair operations, it can be necessary to isolate the repair section. There might be several reasons to have isolation:

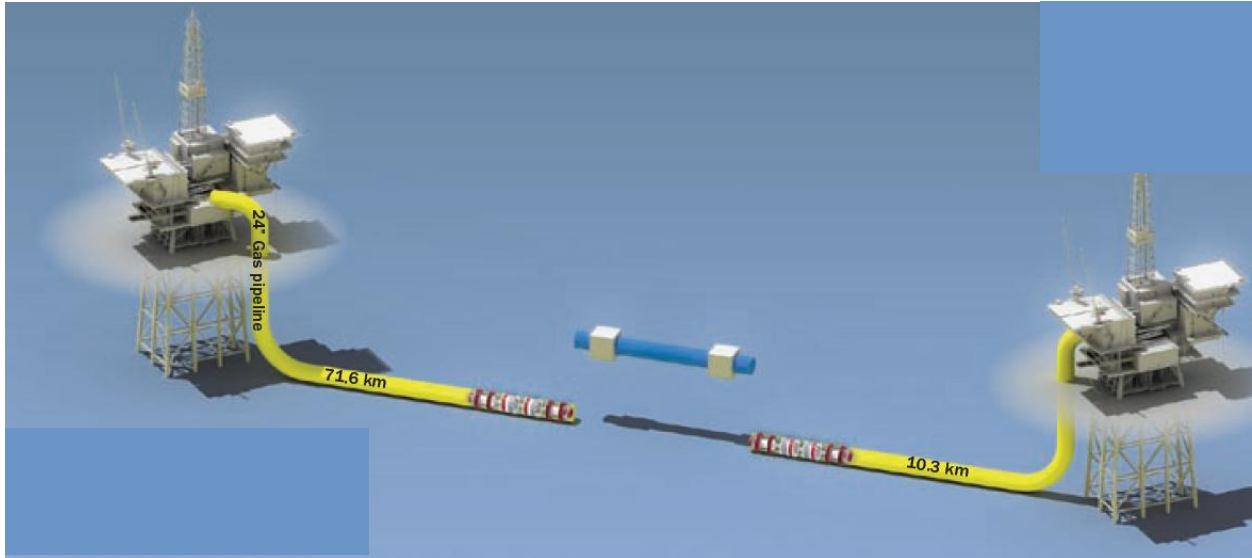
- to keep the line temperature, pressure or media in the major part of the line at the operation (production) requirement,
- to keep part of the line empty (and light) in order to have a feasible lift-to-surface after dewatering the flooded line,
- to avoid any hydrocarbon spill,

Isolation can be achieved by blocking discs like what normally is done for hot tapping. It can be done by lifting tools (heads) when the dewatering and lifting is the case.

There is a possibility to send a remotely operated isolation plug into a pipeline and plug the line at any arbitrary point. TD Williamson present a technology solution called SmartPlug® that is claimed to provide “tetherless, through-wall remote-controlled pipeline pressure isolation services” (TDW website, 2011) (Figure 11-5).



a).



b).

Figure 11-5. Pipeline Isolation. Smart Plug (a), schematic representation of midline replacement on pipeline at operating pressure (b) (Source: PSI).

- **Arctic Area**

Stepping into arctic areas is with a variety of challenges. Further to challenges for design, construction and installation of pipeline, there might be some arising challenges in those areas for pipeline repairs. These challenges can be mostly related to marine operations, application tools and low temperature.

- **Blocked Pipe**

Hydrate plugging can be a case that needs an intervention. The immediate actions are focusing on production and internal operational parameters. Warming up the hydrated fluid by internally-applied hot fluid or externally-induced heating seem to be the general solutions. In the worse cases, it might be required to cut the line and remove the plug.

- **Flexible Pipe**

Flexible pipes are widely being used in offshore industries. The most common application of flexible pipe is for subsea riser lines where there is a variety of dynamic loads.

The flexible pipe structure is made of several different layers. These layers can move over each others and it provides the flexibility against bending moments and axial load to some extends.

In case of a major and sever structural damage on flexible pipe, normally the whole pipe is recovered to surface and repaired. This is due to flexibility of such pipes.

Gas build up in outer sheath of pipe is one of the main issues in flexible pipe systems. There are some tools that can vent trapped gas by drilling a hole on sheath surface and put a clamp around the pipe with a relief valve at drilled point (Perry Slingsby System, 2011).

## 11.4 New Ideas, presented by the author of this report

### ▪ Seal Weld

Due to sealing challenges in mechanical connector systems welding can be employed in conjunction with the mechanical connectors, for primary sealing purposes. It makes the mechanical connection simple in terms of manufacturing the sealing parts and subsea actuation reduces the costs. It might be a proper solution for the cases where the product compositions or the operation temperatures impose limited application of material for sealing in mechanical connectors. The sealing weld is not supposed to take the loads and the gripping will accommodate the loads.

There might be the possibility to use wet welding (solid phase welding) as sealing barrier with combination of mechanical connectors. The solid phase welding is defined as the method in which the weld is achieved by using heat and pressure without fusion. It is also called “friction stir” weld. It is based on friction heat that is obtainable by using a hard rotating tool on the welding surface (Figure 11-6). Since the weld quality is sensitive to the water depth and the wet operation is limited to depth in order of few tens of meters (Richardson, Woodward and Billingham , 2002), solid phase (wet) welding can be used in shallow (diver-assisted) operations.

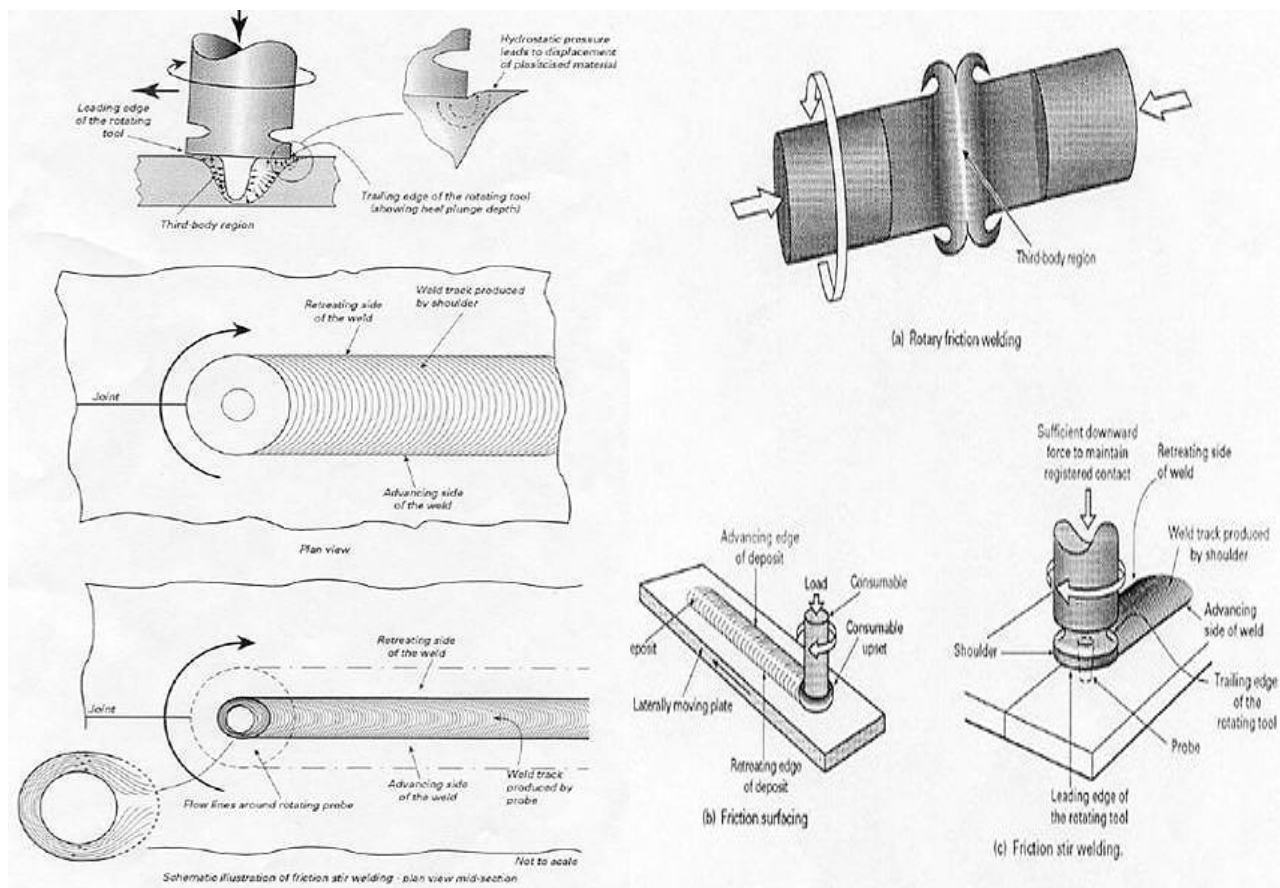


Figure 11-6. Solid phase weld (Source: Key to Metals website)

Figure 11-7 shows schematically, the possibility to employ wet welding as a solution for sealing uncertainties in mechanical connectors.

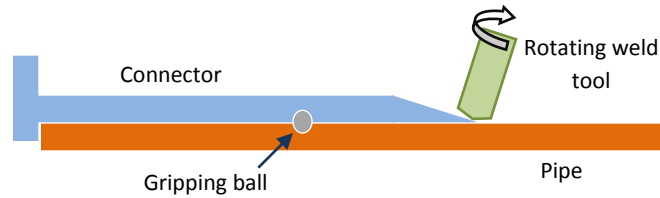


Figure 11-7. Solid phase welding, schematic for repair application.

▪ **Pipe-In-Pipe Repair**

If a PIP gets damaged and it is required to replace it, the common methods can be implemented for the main (inner) pipe. The main difference refers to the outer pipe and the annulus insulation compensation. If replacing the damage part is the case, the whole system will be replaced, including the inner and outer pipes plus the annulus material. The outer materials will be cut-back at the cutting points in order to have enough space for the spool connections (Figure 11-8a). Once the spooled PIP is connected to the main line, insulation and the outer shield shall be compensated at the connection points and nearby areas. At the bare sections, structural clamps can be deployed and installed (Figure 11-8b).

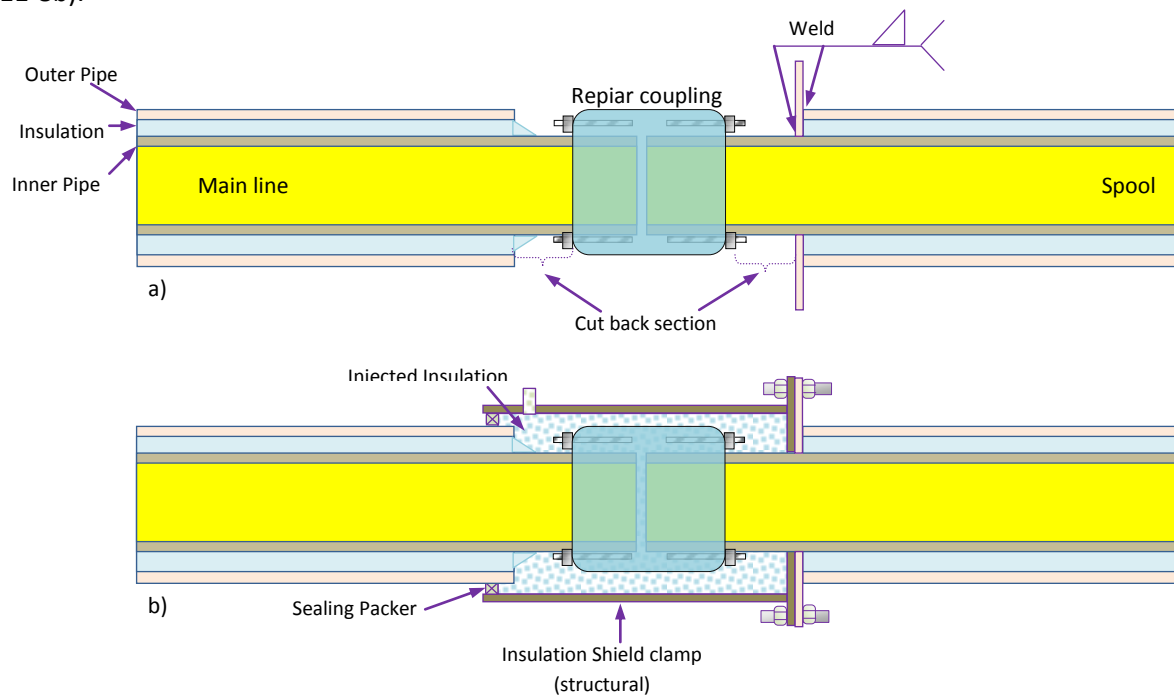


Figure 11-8. Pipe-In-Pipe (PIP) repair proposal. The insulation shield clamp is placed on the pipe after fixing the repair coupling and prior to insulation injection.

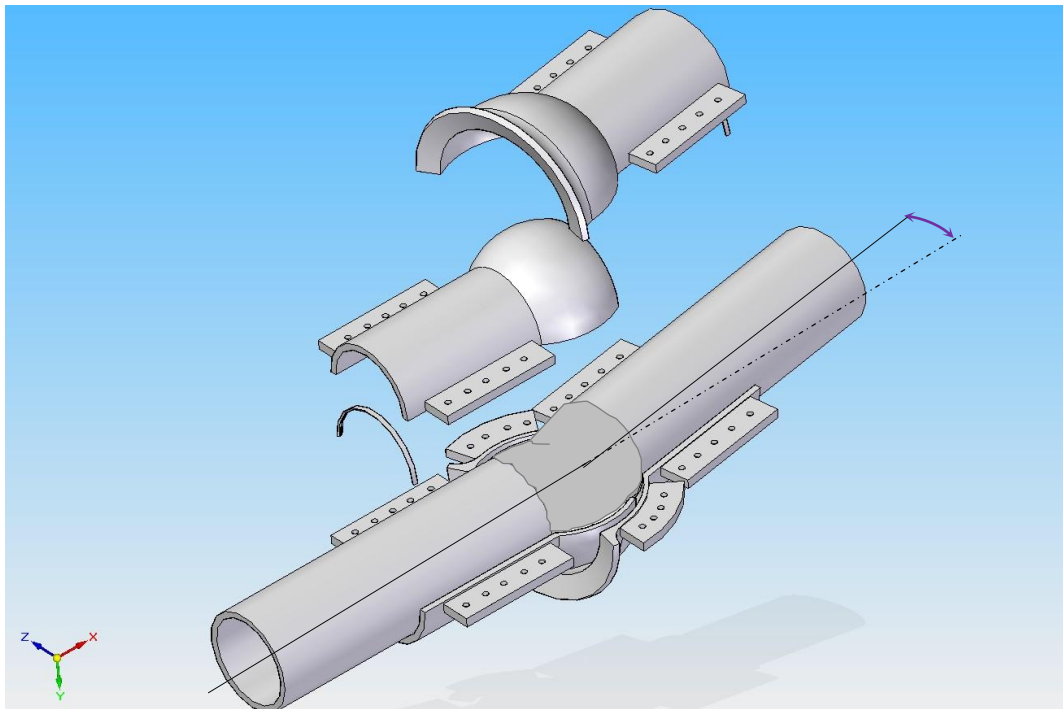


Insulation packing can be done by injecting water-based insulation into the installed clamp. The clamp will seal the insulation and be integrated to the main outer pipe from one side and connected to the shield that is used for connector insulation purpose from the other end.

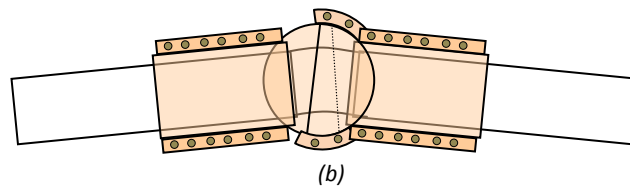
- **Angled Clamp**

Referring back to challenges related to a pipe that is angled with a minor damage that can be repaired by clamp sleeves temporarily or permanently, a new idea to respond to this case is presented below.

This clamp can be designed for pressure containment (leak repair) and/or structural purposes. The present clamp designs are fit for straight pipes with as-designed dimensions and geometry of the pipe. In real cases, specially when the damaged is due to external forces, the pipe is deformed radially and a straight clamp can not surround the pipe's outer geometry.



(a)(modeled by Solid Edge program-UiS License)



(b)

Figure 11-9. Angled-Clamp. Four main half-pipes (a), the installed arrangement around an angled pipe (b).



The angled-clamp comprises four main parts (half-pipes) (Figure 11-9). In fact it is a combination of two straight clamps that are connected via a ball joint arrangement. The radial and longitudinal sealing is similar to typical clamps for the straight parts. For the ball joint section, once all parts are assembled together around the pipe, an activation mechanism (similar to the Morgrip one) energizes the sealing and packs the annulus between two shelves of ball joint (Figure 11-10).

A ball or wedge gripping mechanism can also be utilized to accommodate the longitudinal loads and displacement. The sealing and gripping mechanism can be in multiplied rows, depending on the geometry and space.

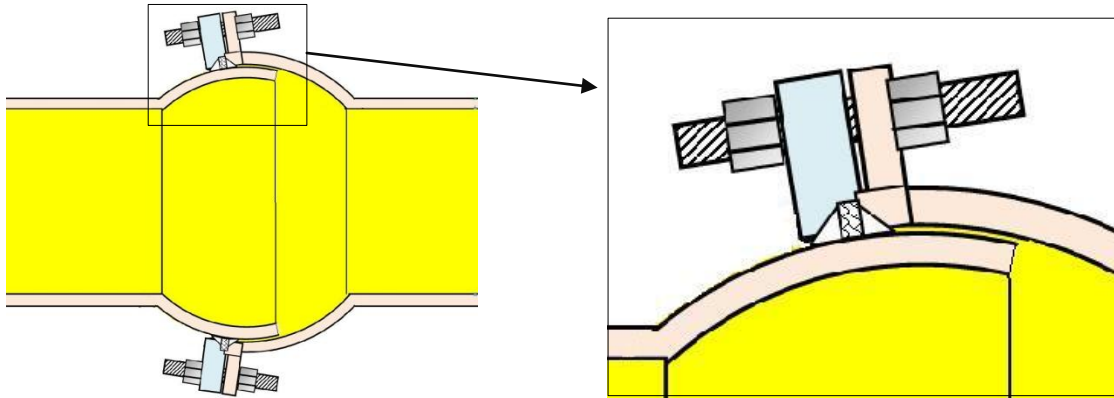


Figure 11-10. Angled-Clamp sealing mechanism. It can be doubled and with gripping ball rows (not shown here).

A structural fixture with calculated stiffness and damping shall be designed in order to limit the angular movement of the clamp sections after installation (Figure 11-13).

The hoop tightening is done through the clamp bolting for straight sections and the outer shelves of the ball joint. For the inner part of the ball joint, two wedge-shape buckles provide the internal clamping at either side of the joint (Figure 11-11 b).

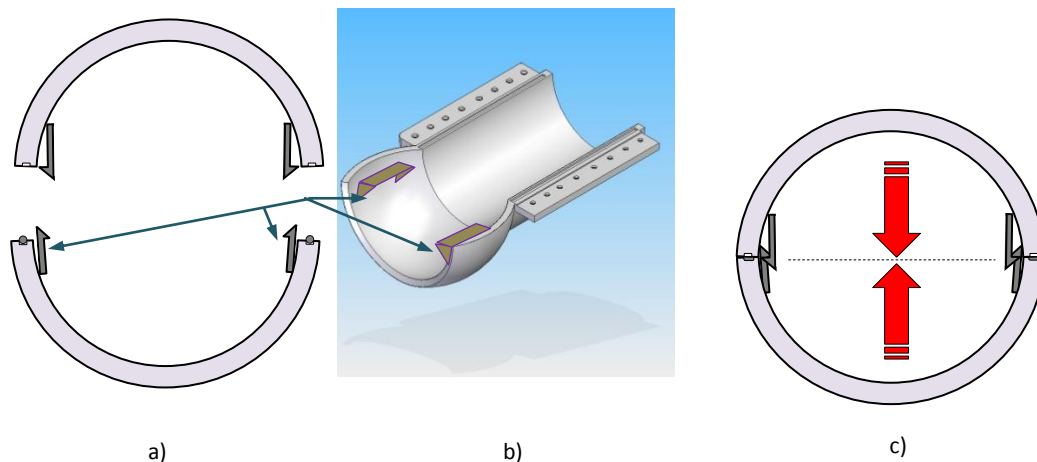


Figure 11-11. Clamp installation at ball joint cross section-inner parts.

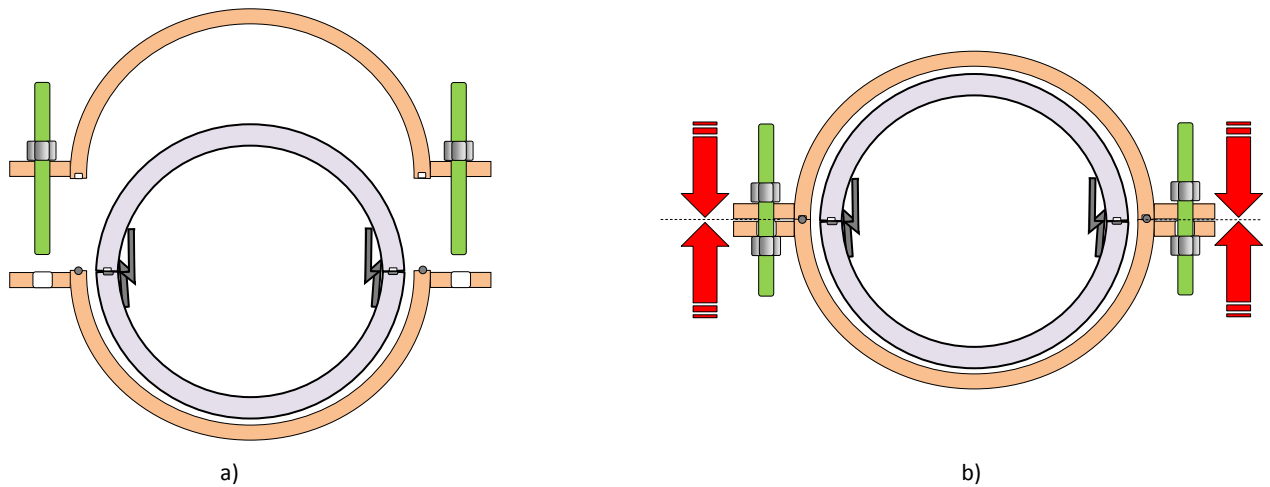


Figure 11-12. Clamp installation at ball joint cross section-outer parts.

For the installation, the inner parts are first clamped together around the pipe. The outer parts -that surround the pipe at the straight section and the inner parts at the ball section- complete the clamping and assembling (Figure 11-12). The longitudinal and radial sealing is engaged while clamping and tightening.

Upon the clamping, the sealing (and gripping) over the ball joint is activated when the final angular position of the clamp is already fixed. Tests will be performed to check the sealing performance.

This is a typical and general design and method of installation that can be customized for each particular case.

### Modular application

The angled clamp can be modular and for a certain pipe dimension, there can be several sizes of joint balls in order to cover different geometries of deformation. The modular design enables the operator to have the flexibility versus different damage scenarios. Figure 11-13 illustrates a modular application of the angled clamp.

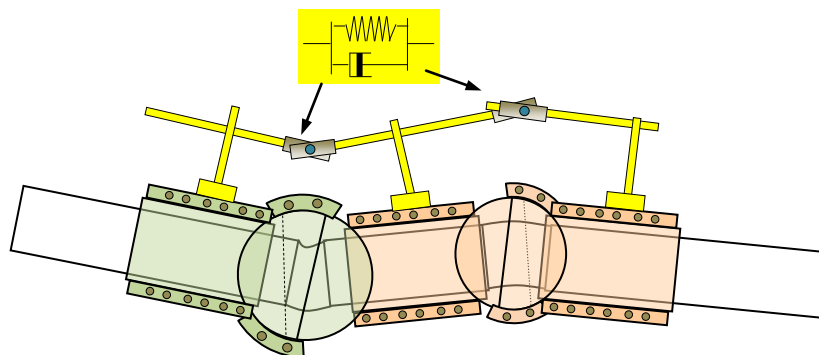
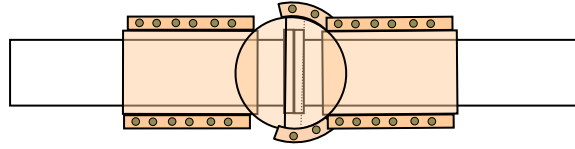


Figure 11-13. Combination of angled-Clamps with different ball joint sizes.

### Fitting repair application

The angled clamp can be applied for repair of minor damages (e.g. leakages) on (from) subsea pipeline fittings. Fittings such as flanges, valves or bends and elbows can be temporarily clamped (Figure 11-14).



*Figure 11-14. The ball joint clamp around a leaking flange.*

More detailed description is enclosed to thesis report in Appendix B.

## 12 Method Selection / Cases / Conclusion

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In this section, the repair method selection criteria will be discussed. Some realistic cases are defined and the proper repair methods are suggested for each case. Finally there is a conclusion subsection where the ideas and results of the thesis are reflected.

### 12.1 Method Selection

Different repair techniques and methods are presented in the previous sections. Basically every damage event is a specific case with its own specification that repair the repair method can be determined based on these specification (“ad hoc” solution). However, with some assumptions, generalized cases can be defined and the general solution(s) can be recommended.

The main factors in process of method selection are listed and discussed below:

- **Water depth;**  
The water depth is the most important parameter in order to choose the proper repair method. Based on the water depth, the solution can be one of completely different class of repair: the diver-assisted (for depths <180 meter) and diverless (for depths > 180 meter) repair. Broadly speaking, depending on some other parameters (e.g. pipe size and vessel capability), for shallow waters, the “surface-lift” method can be considered as another main class of repair.
- **Damage size;**  
Damage size and severity, divides the repair into three main categories: clamping (no need to cut and replace), spooling (to cut and replace new piece of pipe) and re-laying (to re-build a new pipe totally). The pipe defect or damage might be found tolerable or non-tolerable based on size and severity. The repair can be temporary or permanent, accordingly.
- **Pipe size;**  
The size of pipe deals with the type of connection tools. For the small size pipes, there is an intention to deploy mechanical connectors while for the larger size of pipe, welding is preferred since the mechanical connectors are very large for larger pipe sizes and even diver-assisted deployment would be expected to be problematic.
- **Pipe length (or repair location);**  
Different lengths of pipe may lead to different ways of repair. Adjacent installations may impose on the repair scenario. The isolation and re-commissioning of the pipe before and after the repair operation can be influenced by the pipe length.

Some other factors which are involving into the decision process can be listed as follows:

- **The geographical location of repair;**  
The availability and accessibility of/to the contingency response plan equipment can contribute to the decision process. It is reflected through the mobilization/demobilization costs. Third

parties' facilities may also have positive (supportive) or negative (interfaces and interference) effects.

- **Seabed profile;**  
Rough seabed means more challenges when there is a need for subsea (on-bottom) repair. In many cases, the seabed is not flat and preparation of civil activities is required prior to the repair operation. A slopping sea bottom makes the operation so hard or even in some cases impossible and the operator has to replace an entire section and perform the tie-in operation where the slope is right for subsea operation. The repair operator should also consider the free spanning issues.
- **Seabed material;**  
The seabed material is different for different areas. It might be soft or hard, muddy or rocky. The installation preparation and tools may differ for each seabed condition.
- **Length of damaged section;**  
The techniques for replacing different lengths of pipe are different. For example, if the pipe that shall be cut and replaced is long, re-laying might be the best solution and less costly, while for a short damage, a clamp can solve the problem.
- **Pipe flow (service);**  
The service of the pipe and the operation strategies may affect the repair solution. For example if pressure and/or temperature fluctuations are expected, the connector shall be tough enough to withstand the cyclic loads and fatigue issues shall be considered. The chemical composition of the service shall also be noticed when the material is chosen for the connector (or clamp) component to be sufficiently resistant (e.g. sealing material).
- **Sea state (wave and current);**  
The sea state and environmental situation is important when we select the repair method in two aspects: the repair-time for the marine operation and the loads on the newly repaired arrangement of pipe. For example, if the current is high in the repair area, the methods with vertical spool jumpers are not suggested or they shall be designed to resist the loads safely.
- **Pipeline age:**  
The age of pipeline can limit the connector type of repair since the wall thickness of the pipe might be less than the newly-built pipe and therefore the strength of pipe is less.

To select the proper method, the above technical parameters are involved beside the financial measures as well as environmental challenges. Figure 12-1 illustrates the schematics of the method selection process.

In order to see how the parameters contribute the repair method selection and since there are a series of involved factors, some specific cases are defined and discussed in the next subsection.

Statoil PRS matrix (Figure 6-2) can be a practical hint for method selection task. The matrix covers the water depth (vertical axis) and the pipe diameter (horizontal axis). It assumes the ‘replacement’ repair category and does not take the ‘clamping’ category into account. Development of such matrices and taking the other repair categories into account, may cover and provide flexibility with the other involved factors.

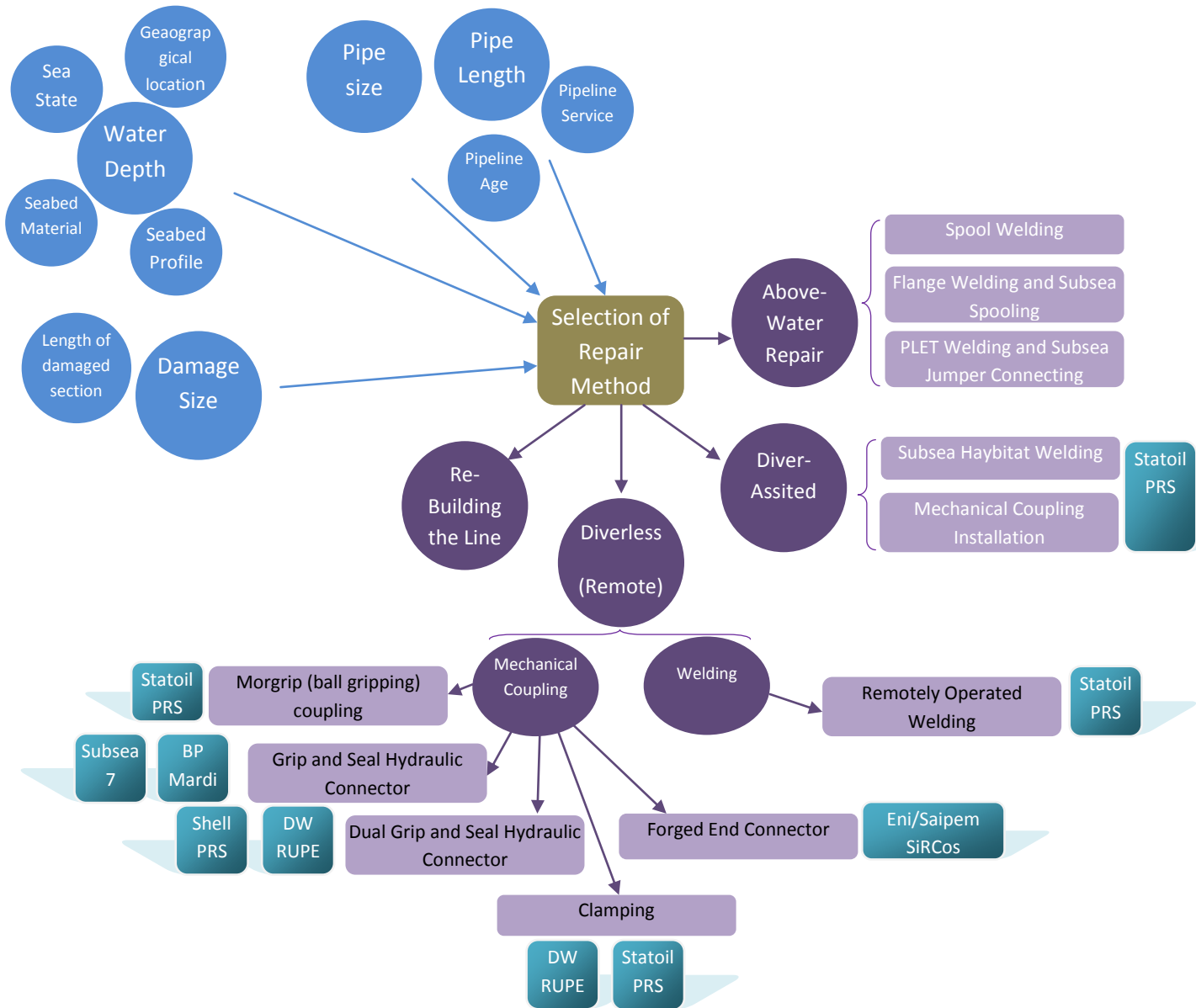


Figure 12-1. Schematic frame of ‘selection of Repair Method’.

## 12.2 Study Cases

The project focuses on some cases for different water depths, pipe sizes and pipe lengths. Twelve cases are defined here, based on pipe sizes and lengths as well as the water depth:

Water depths: 150, 350 and 1350 meters.

Pipe sizes: 12 and 28 inches.

Pipe lengths: 5 and 500 kilometers.

- **Case 1:**  
For the water depth of **150** meter, pipe size of **12** inch and length of **5** km. This can represent a flow-line in shallow waters.
- **Case 2:**  
For the water depth of **150** meter, pipe size of **12** inch and length of **500** km. This can represent a shallow section of a flow-line (from well to shore).
- **Case 3:**  
For the water depth of **150** meter, pipe size of **28** inch and length of **5** km. This can represent an export and/or an in-field line in shallow waters.
- **Case 4:**  
For the water depth of **150** meter, pipe size of **28** inch and length of **500** km. This can represent an export line in shallow waters.
  
- **Case 5:**  
For the water depth of **350** meter, pipe size of **12** inch and length of **5** km. This can represent a flow-line or in-field line in a depth beyond diver depth.
- **Case 6:**  
For the water depth of **350** meter, pipe size of **12** inch and length of **500** km. This can represent a section of a flow-line (e.g. subsea to shore) in a depth beyond diver depth.
- **Case 7:**  
For the water depth of **350** meter, pipe size of **28** inch and length of **5** km. This can represent an export and/or an in-field line in a depth beyond diver depth.
- **Case 8:**  
For the water depth of **350** meter, pipe size of **28** inch and length of **500** km. This can represent an export line in a depth beyond diver depth.
  
- **Case 9:**  
For the water depth of **1350** meter, pipe size of **12** inch and length of **5** km. This can represent a flow-line or in-field line in deep waters. Total's Girassol field in Angola is an example.
- **Case 10:**  
For the water depth of **1350** meter, pipe size of **12** inch and length of **500** km. This can represent a deep section of a flow-line (e.g. subsea to shore) or small gas export line e.g. Golfinho Field in Brazil's Espirito Santo Basin.
- **Case 11:**

For the water depth of **1350** meter, pipe size of **28** inch and length of **5** km. This can represent a flow-line or in-field line in deep waters.

- **Case 12:**

For the water depth of **1350** meter, pipe size of **28** inch and length of **500** km. This can represent a deep section of an export line.

A depth 1350 meter is mostly related to some newly developed field or areas under development; such as West Africa (Akpo Field, Nigeria), Brazil (Golfinho) and Australia (Greater Gorgon).

The length of the pipe is not a direct parameter by itself, it relates to the service type of line and severity of damage and the probable consequence. The location of damage is also determining the repair method. The vicinity to the line ends or other installation and interventions (crossing, trench, etc.,) can be expressed in terms of pipe length.

Figure 12-2 shows the schematics of the cases defined above.

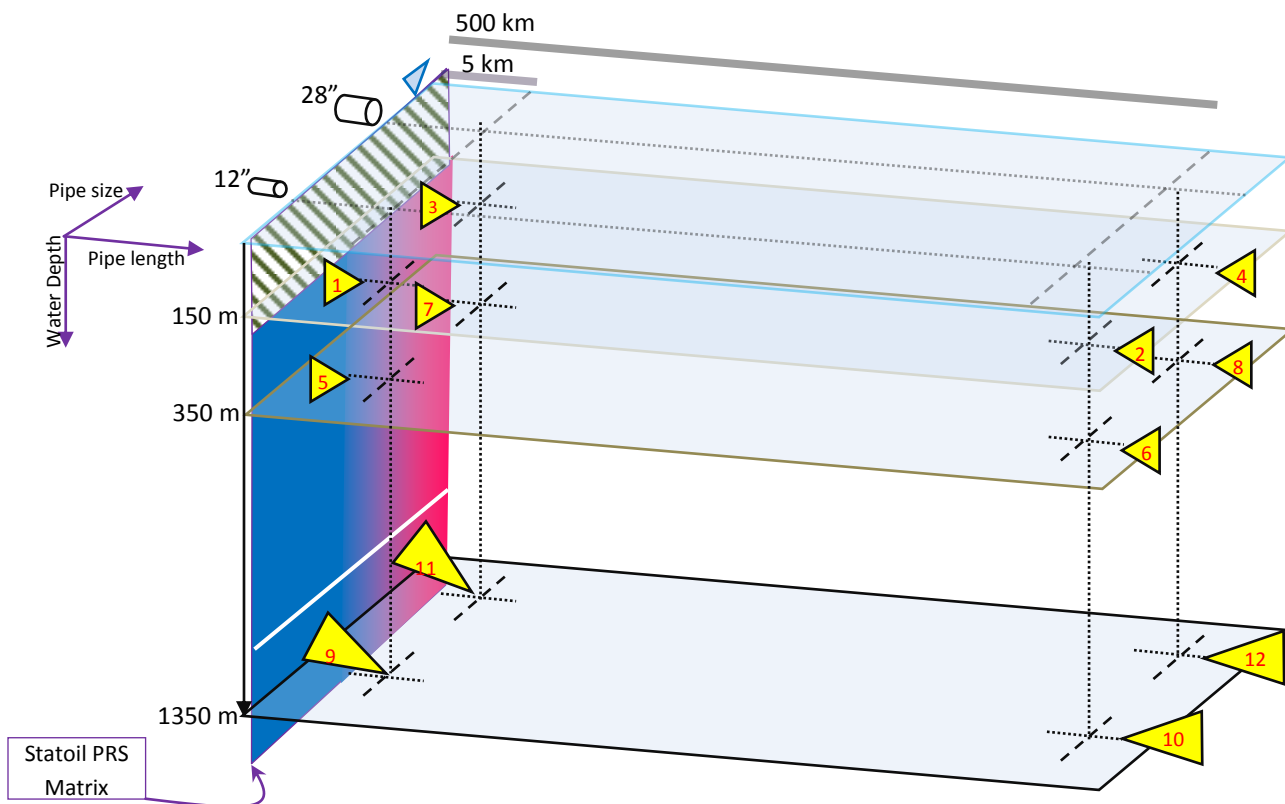


Figure 12-2 different cases for different water depth, pipe sizes and pipe lengths.

### Recommended methods

In order to make the case studies more specific and to recommend a solution for each case, we set some assumptions as follows:



- All the systems are available and mobilization/demobilization costs are same. Although these costs, in many cases, are ruling factor for management to decide on option.
- The pre- and post-activities are not including.
- The repair method is for “replacement” type of repair, unless it is mentioned specifically.

- **Case 1:**

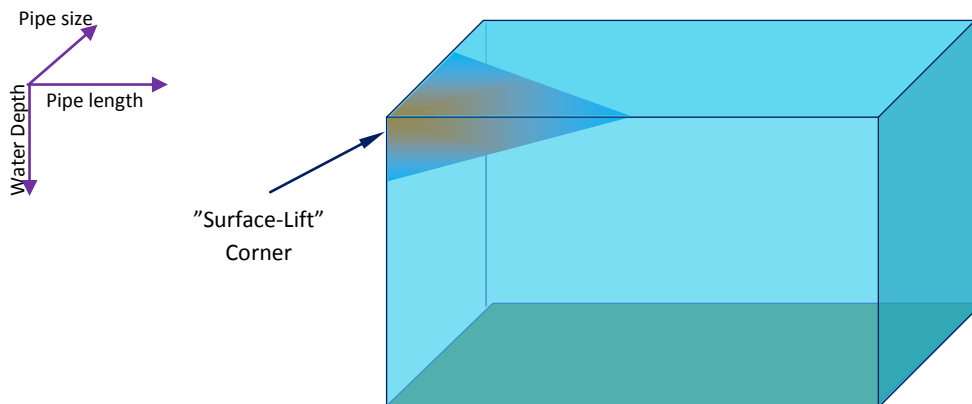
Since the pipe size is relatively small and the water depth is low, the above-water repair can be a solution, depending on the vessel availability. With respect to the short length of the pipe, dewatering of the pipe for surface lifting seems practical and efficient.

Diver-assisted method, including either the hyperbaric welding or mechanical coupling can be considered as the fittest solution for this case.

*Note:* Generally the small size pipe in shallow water can be lifted to the surface. A shorter length of pipe makes the operation more practical. It is shown in Figure 12-3 as “surface-lift” corner.

- **Case 2:**

Similar to case 1, the diver-assisted method can be the best solution. The above-water repair depends on vessel availability.



*Figure 12-3 General illustration of cases where the above-water repair or surface lift can be the solution. The feature of the matrix is corresponding to matrix in Figure 12-2.*

- **Case 3:**

The water depth for this case is still in range of diving operation. Habitat welding (reference: Statoil PRS) is the best solution, since welding is preferred. Mechanical couplings might be the option, even the size and weight looks a bit high to be handled by divers.

The surface-lift method needs engineering analysis.

- **Case 4:**

Similar to case 3, the habitat dry welding is recommended for this case.

- **Case 5:**

The water depth for this case is beyond diver access. Therefore, the remote operations are the options for study. Although the remotely operated welding method (Statoil PRS) seems to be the best solution, the remote welding is still a complex and sensitive operation and the mechanical coupling installation is more common for this case. The size of coupling is relatively small and can be manipulated by remote controlled tools.

Subsea7's Girassol PRS DW RUPE and Statoil's Small PRS are quite responsive. The BP Mardi system looks like a proper solution too, considering the size and the depth and also the thermal expansion challenges for flow-lines. The interaction of the vertical spool and the current (it is not deep enough yet to neglect the current) and also future risk of snagging shall be studied.

The Surface lift can also be considered after engineering check and vessel availability. The vessel for such case must be facilitated with enough tension machines, and the line may have to be dewatered.

- **Case 6:**

Similar to case 5, except for the Girassol PRS and BP Mardi system application that seems less justified as long as the case is for export lines with less (or even no) thermal issue(s).

- **Case 7:**

The water depth for this case is beyond diver access. Remote operations are the only options. Pipe size needs a large coupling, if the mechanical connection is the solution. Remote welding (Statoil PRS) is the recommended option for this case.

Other systems like BP's Mardi and Eni/Saipem SiRCoS can also be recommended. In such a case, the pipe is large and heavy (thicker pipe for flow-lines) and alignment of pipe parts is a hard subsea job.

- **Case 8:**

The recommended options for case 7, can also be the solution for this case. For the export lines normally the wall thickness is lower and the pipe is lighter than for the flow-line case (#7).

- **Case 9:**

In deep water, the small size pipe can be repaired by remotely-installed couplings. Statoil Small PRS, Subsea7's Girassol PRS, DW RUPE and BP's Mardi represent the solutions for this case. Higher pressure in deeper water makes the remote welding operation more complicated and sensitive. Eni/Saipem SiRCoS is not recommended since the internal space for the forging tool is not sufficient and the wall thickness for flow-lines are high and forging requires higher hydraulic pressure that brings some sorts of challenges itself.

- **Case 10:**

The recommendation is same as for case 9.

- **Case 11:**

For larger pipe size in deeper water the solution is purely remotely. Almost all systems which are mentioned in this project, offer the solution for this case. Statoil Deep PRS-that is under continuous development-, DW RUPE, BP Mardi, and Eni/Saipem SiRCoS provide the facilities for deep water subsea operations. Statoil Deep PRS offers two alternatives for this case: Morgrip coupling and welded sleeve.

The above-surface techniques might be restricted due to length that is required from bottom to surface during lifting, and also the possibility of nearby installations or tie-ins.

- **Case 12:**

For deep water export lines, the recommendation is the same as for deep water flow-lines, except that recovering to surface could be the solution. In this case dewatering will impose difficulties in terms of the gas volume required for dewatering plus the higher pressure for dewater pumping.

### **12.3 Conclusion**

Diverless repair and intervention in deep waters is a matter of challenge in pipeline integrity management. Pipeline damage is rare but the consequences can be huge, meaning that the risk is high. The tools and technologies required for repair operation need to be properly maintained and continuously upgraded. This leads to costly pipeline operations for a single operator. Establishing a regional 'repair club', sharing the experiences and results will lead to the expense reduction.

The deeper and more remote developments bring more and more challenges into the repair operation. The diverless repair can be improved in three aspects:

- The integrity compensator
- Application tools
- Marine operation

The main areas for 'integrity compensator' that is required to be improved, refer to sealing material and mechanism. It is worthy to mention that the present technologies for use of connectors are relatively new and there are just few occasions where these technologies have been used. It takes time, to see how these connectors can satisfy the requirements.

The largest challenges with the present methods refer to 'Application tools' involved in the repair operation. The remotely-controlled tools in deeper waters on a very remote seabed (where the alignment tolerances are, for instance, in range of a few millimeters) require upgrading. The hydraulic systems in deeper waters (i.e. under higher pressure) have shown their own difficulties.

The marine operation challenges can be summarized in ROV designs and operation. Improving ROVs' capabilities leads to an overall improvement of the system.

Although each case has its own specification that may change the repair solution, the general preference of alternatives can be listed as follows:

1. Above-surface welding and tie-in,
2. Above-surface welding (flanging) and subsea spooling,
3. Diver-assisted subsea welding,
4. Diver-assisted coupling installation,
5. Remotely operated welding,
6. Remotely operated coupling installation, and
7. Re-laying the line or the damage section with tie-in

#### **Recommendations:**

- Repair considerations can be implemented during pipeline design steps. A 'repair-oriented' pipeline design can be performed for the deepwater sections of a pipeline where the present

technologies are not proven. It can also be conducted for lines where repair seems impossible, like tunneled or bundle pipes.

The design improvement can be through a higher safety factor for deeper waters. The values for the safety factor can be achieved by conducting a probabilistic analysis for the different types of damages in deepwater pipelines.

The other measure that can be studied is the pipeline system configuration such that if there is any possible damage, the repair can be performed in a feasible way.

DNV-OS-F101 raises the repair concerns during design in section 5 clauses H103 & H109.

- Since the technologies required for repair operations are almost same as for tie-in and hot-tap operations, the methods can be upgraded with technologies and techniques that have been newly utilized and proven during the construction phase of deep water projects.
- Since the most frequent damage for deep water pipelines is supposed to be corrosion damage, development of high pressure repair clamp with more flexible deployment tools is recommended. The study results can be employed to upgrade mechanical coupling/connector designs as far as there are common areas of challenge such as sealing, gripping, tolerances, etc..
- The idea of an angled-clamp that is presented by the author of this report can be developed for some practical cases, when the pipe is deformed (angled) and it is required to support the pipe at the damage location structurally and/or operationally (Further work).
- The challenges with arctic pipeline repair can be studied separately. It may result in some contingency plan/solution for arctic fields which are considered or under development. Having a pipeline for an arctic field with reliable contingency repair plan may improve the conceptual design of such fields (Further work).
- Butt-welding and internal alignment tools can be studied and developed further. This would improve the time, cost and quality of repairs (Further work).

## 13 References

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- American Bureau of Shipping, 2006. *ABS Guide for Building and Classing Subsea Pipeline Systems*. Houston, USA: ABS Plaza.
- Amirushah, M. Zakaria, B. , n.d., *Deepwater Pipeline Design Rigid & Flexible*. [online] . Available at : <[http://www.ccop.or.th/download/PETRAD/PETRAD58\\_2011-01/Paper04\\_MAmirushahZakaria-PETRONAS-PMU.pdf](http://www.ccop.or.th/download/PETRAD/PETRAD58_2011-01/Paper04_MAmirushahZakaria-PETRONAS-PMU.pdf) > [Accessed 09 June 2011].
- Ayers, R. Hoysan, S. Robello, A. Gage, E. Stark, M., 2008. OTC 19207: DW RUPE: A New Deepwater Pipeline Repair Capability for the Gulf of Mexico and Other Deepwater Regions. In: Stress engineering Services and Enterprise Product Partners, *2008 Offshore Technology Conference*. Houston, USA, 5-8 May 2008. Texas, USA: OTC.
- Braestrup, M. W. Andersen, J. B. Andersen, L. W. Bryndum, M. B. Christsen, C.J. Rishøj, N., 2005. *Design and Installation of Marine Pipelines*. NJ,USA: Blackwell Science and ASME.
- Callanan, J., 2010. *Asia Subsea Market Overview- into the deep*. [online] Kuala Lumpur: Infield Systems. Available at: < [http://www.subseauk.org/documents/asia%20subsea%20outlook\\_infield.pdf](http://www.subseauk.org/documents/asia%20subsea%20outlook_infield.pdf)> [Accessed 22 March 2011].
- Det Norsk Veritas, 2010. *DNV-OS-F101: Submarine Pipeline Systems*. Høvik, Norway: DNV.
- Det Norsk Veritas, 2009. *DNV-RP-F116: Integrity management of submarine pipeline system*. Høvik, Norway: DNV.
- Det Norsk Veritas, 2007. *DNV-RP-F113: Pipeline subsea repair*. Høvik, Norway: DNV.
- Det Norsk Veritas, 2007. *Report No. 448 14183: Pipeline Damage Assessment from Hurricanes Katrina and Rita in the Gulf of Mexico*. Houston, USA: DNV.
- Eklund, T. Høgmoen, K. Paulsen, G. , 2007. OTC 18967: Ormen Lange Pipelines Installation and Seabed Preparation. In: Hydro and Reinertsen Engineering, *2007 Offshore Technology Conference*. Houston, USA, 30 April-3 May 2007. Texas, USA: OTC.
- Eni, 2010, *SiRCoS*. [online] Available at:< [http://www.eni.com/en\\_IT/innovation-technology/eni-projects/sircos/sircos-project.shtml](http://www.eni.com/en_IT/innovation-technology/eni-projects/sircos/sircos-project.shtml)> [Accessed on 13 May 2011].
- Espiner, R. Kaye, D. Goodfellow, G. and Hopkins, P., 2008. IPC2008-64480: Inspection & assessment of damaged subsea pipelines: a case study. In: BP Exploration and Penspen Integrity, *7<sup>th</sup> International Pipeline Conference*. Calgary, Canada, 29 September-3October 2008. Calgary, Canada: IPC.
- Giuliano Malatesta, G. M. Brandi, R. Spinelli, C. M., 2008. Evaluation of material response subjected to high plastic deformation when forged into Saipem submarine repairing system. In: Centro Sveiluppo Materiali S.p.A. Saipem-Sonsub and Eni Gas & Power, *18<sup>th</sup> (2008) International Offshore and Polar Engineering Conference*. Vancouver, Canada, 6-11 July 2008. Vancouver, Canada: ISOPE.

Gjertveit, E. Berge, J.O. Opheim, B.S., 2010. OTC 20814: The Kvitebjørn Pipeline Repair. In: Statoil ASA, *2010 Offshore Technology Conference*. Houston, USA, 3-6 May 2010. Texas, USA: OTC.

Green, M., 2010. Composite offer effective offshore pipe repair alternative. *Offshore Magazine*, 70(10), pp.84-85.

Harrison, G. McCarron, B., 2006. OTC 18063: Potential Failure Scenario for High- Temperature, Deepwater Pipe-in-Pipe. In: BP and ASGM Engineering, *2006 Offshore Technology Conference*. Houston, USA, 1-4 May 2006. Texas, USA: OTC.

Markland, A., 2010. Staying connected. *DYP: Magasinet fra foreningen fjernstyrt undervannsteknologi*, 2010(3), pp.29-30.

Martin, R. Killeen, J. Chandler, B., 2004. OTC 16635: Mardi Gras Deepwater Pipeline Repair System. In: INTEC Engineering and BP America, Inc., *2010 Offshore Technology Conference*. Houston, USA, 3-6 May 2010. Texas, USA: OTC.

Norman, D., 1997. UTI-97-075: The Statoil Deepwater Pipeline Repair System. In: Subsea Offshore Ltd., *1997 Underwater Technology International: Remote Intervention*. Aberdeen, UK, 8-10 April 1997. Aberdeen: The Society for Underwater Technology.

NORSOK Standard, 2008. NORSOK U-100 Manned underwater operations. Lysaker, Norway: Standards NORWAY.

Offshore Magazine, 2009. *Global wins offshore Nigeria pipeline repair contract*. [online] Available at:< <http://www.offshore-mag.com/index/article-display/350798/articles/offshore/pipeline-transportation/africa/global-wins-offshore-nigeria-pipeline-repair-contract.htm>> [Accessed 10 June 2011].

Oil States Industries, 2011, *Grip & Seal Hydraulic Coupling*. [online] Available at:< <http://www.oilstates.com/fw/main/Grip-and-Seal-Hydraulic-Coupling-451.html>> [Accessed on 09 May 2011].

Oil States Industries, 2011, *Collet Connector Systems*. [online] Available at:< <http://www.oilstates.com/fw/main/Collet-Connector-Systems-631.html> > [Accessed on 09 May 2011].

O'Grady, R. Bakkenes, H. Lang, D. Connaire, A. , 2008. OTC 19400: Advancement in Response Prediction Methods for Deep Water Pipe-In-Pipe Flowline Installation. In: MCS and Heerema Marine Contractors, *2008 Offshore Technology Conference*. Houston, USA, 5-8 May 2008. Texas: OTC.

PARLOC, 2003. *PARLOC 2001: The Update of Loss of Containment Data for Offshore Pipelines*. Croydon, UK: Mott MacDonald.

Parrott, R. Tveit, R., 2005. The Use of Intelligent Plugs to Isolate Operating Pipeline for Construction and Maintenance Activity, *Business Briefing: Exploration & Production: The Oil & Gas Review 2005*, [online] Available at:< [http://www.touchbriefings.com/pdf/1195/Plugging\\_tech.pdf](http://www.touchbriefings.com/pdf/1195/Plugging_tech.pdf)> [Accessed 27 May 2011].

Perry Slingsby system, 2011. Riser Sheath Clamp Repair System. [online] available at:[http://www.perryslingsbysystems.com/assets/pdf/brochures/Special\\_Projects.pdf](http://www.perryslingsbysystems.com/assets/pdf/brochures/Special_Projects.pdf) [ accessed on 14 June 2011].

Povloski, B., 2008. Mars field diverless spool piece repair a world first. *Offshore Magazine*, [online] Available at:< <http://www.offshore-mag.com/index/article-display/332247/articles/offshore/volume-68/issue-6/transportation-and-pipeline/mars-field-diverless-spool-piece-repair-a-world-first.html>> [Accessed on 09 May 2011].

Richardson, I. M. Woodward, N. J. Billingham, J., 2002. Deepwater Welding for Installation and Repair-A Viable Technology? . In: Delft University of Technology, Isotek Electronics Ltd. and Cranfield University, 12<sup>th</sup> (2002) *International Offshore and Polar Engineering Conference*. Kitakyushu, Japan, 26-31 May 2002. Kitakyushu, Japan: ISOPE.

Robello, A. Ayers, R., 2006. OTC 17772: DW RUPE: A Low-Capex Deepwater Pipeline Repair System for Gulf of Mexico. In: Stress Subsea, 2006 *Offshore Technology Conference*. Houston, USA, 1-4 May 2006. Texas, USA: OTC.

Spinelli, C. M. Sergio Fabbari, G. B., 2009. Saipem/Eni Offshore Pipeline System (SiRCoS). In: Eni Gas & Power and Saipem Energy Service SpA, 19<sup>th</sup> (2009) *International Offshore and Polar Engineering Conference*. Osaka, Japan, 21-26 June 2009. Osaka, Japan: ISOPE.

TDWilliamson Offshore Services, 2011, SmartPlug™ System. [online] Available at:<<http://www.tdwilliamson.com/en/Services/HotTapping/smartplugonshore/Documents/TDW+SmartPlug+brochure.pdf>> [Accessed 10 June 2011].

Thomas, W.M. Threadgill, P.L. Nickolas, E.D., n.d. . *Fricstion Stir Welding of Steel:Part One*. [online] Key to Metals. Available at:< <http://www.keytometals.com/page.aspx?ID=CheckArticle&site=kts&NM=21>> [Accessed 08 June 2011].

Zabaras, G.J. Zhang, J.J., 1997. SPE 38772: Bundle Flowline Thermal Analysis. In: E&P Technology Co., 1997 *SPE Annual Technical Conference and Exhibition*. Texas, USA, 5-6 October 1997. Texasm, Japan: SPE.



## Appendices:

## Appendix A-Visit: Photos

The Statoil PRS yard at Killingøy, 21<sup>st</sup> March 2011.



*Figure A-1. PRS Lifting (H-) Frame*



*Figure A-2. PRS Lifting Claw*

The main photos are used in report text .

## Appendix B- Angled Clamp Idea

The idea of Angled Clamp that has been discussed in section 11 is described in this appendix in format of invention claim that is recorded as author's idea in the Notary Public at Jæren (Figure A-3).

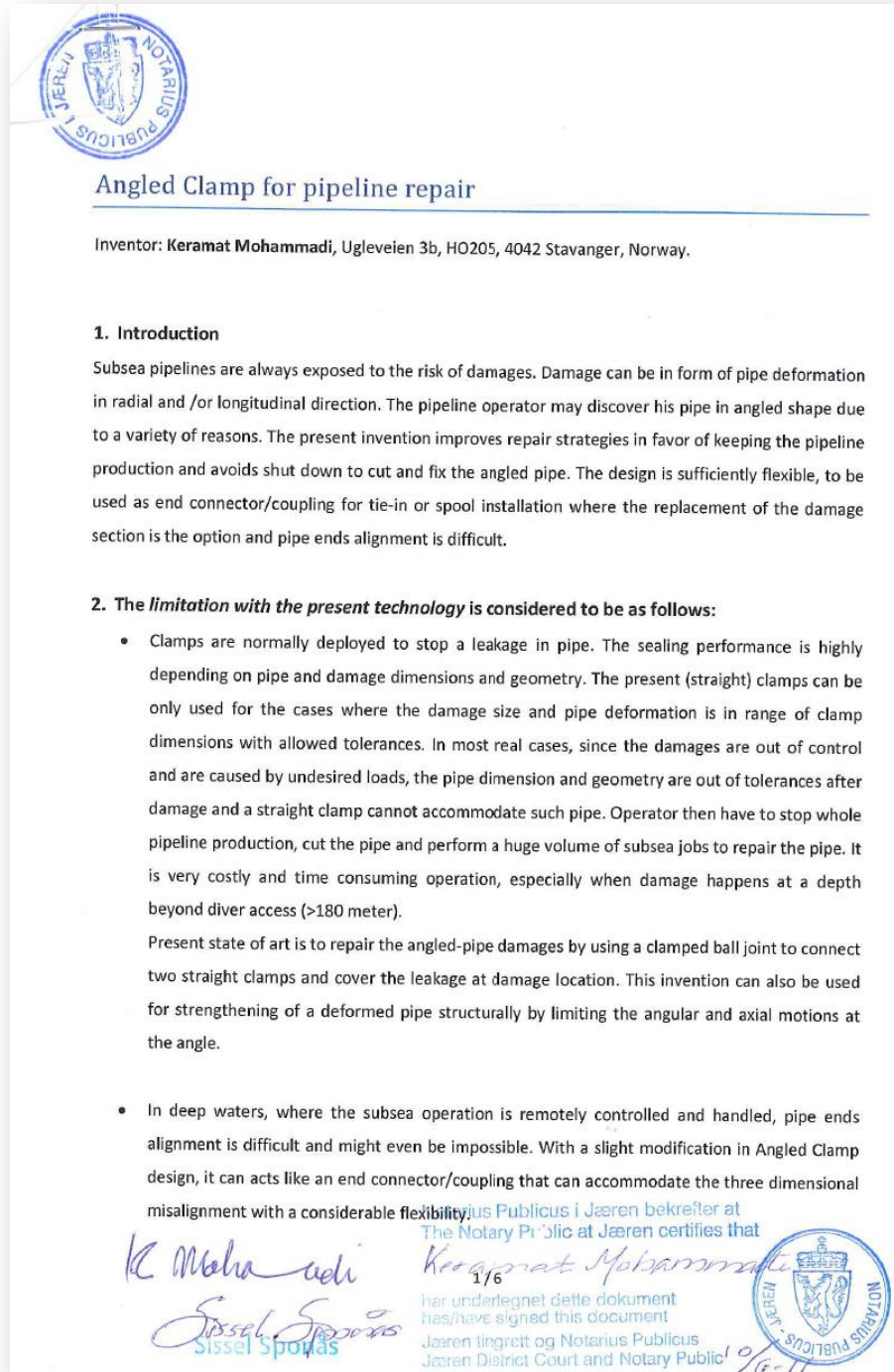


Figure A-3. Stamped Copy of Angled Clamp as author's innovative idea.

## Angled Clamp for pipeline repair

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### 1. Introduction

Subsea pipelines are always exposed to the risk of damages. Damage can be in form of pipe deformation in radial and /or longitudinal direction. The pipeline operator may discover his pipe in angled shape due to a variety of reasons. The present invention improves repair strategies in favor of keeping the pipeline production and avoids shut down to cut and fix the angled pipe. The design is sufficiently flexible, to be used as end connector/coupling for tie-in or spool installation where the replacement of the damage section is the option and pipe ends alignment is difficult.

### 2. *The limitation with the present technology is considered to be as follows:*

- Clamps are normally deployed to stop a leakage in pipe. The sealing performance is highly depending on pipe and damage dimensions and geometry. The present (straight) clamps can be only used for the cases where the damage size and pipe deformation is in range of clamp dimensions with allowed tolerances. In most real cases, since the damages are out of control and are caused by undesired loads, the pipe dimension and geometry are out of tolerances after damage and a straight clamp cannot accommodate such pipe. Operator then have to stop whole pipeline production, cut the pipe and perform a huge volume of subsea jobs to repair the pipe. It is very costly and time consuming operation, especially when damage happens at a depth beyond diver access (>180 meter).

Present state of art is to repair the angled-pipe damages by using a clamped ball joint to connect two straight clamps and cover the leakage at damage location. This invention can also be used for strengthening of a deformed pipe structurally by limiting the angular and axial motions at the angle.

- In deep waters, where the subsea operation is remotely controlled and handled, pipe ends alignment is difficult and might even be impossible. With a slight modification in Angled Clamp design, it can acts like an end connector/coupling that can accommodate the three dimensional misalignment with a considerable flexibility.

- In some subsea pipeline systems, pipe fittings are used. The most common fittings are flanges. Due to some reasons, there can be leakages from the flange. Fixing the flange leakages may lead to production stop and performing subsea repair operation.

The Present invention can be employed to solve the fitting deficiency, temporarily or even permanently, by encapsulating the flanges into a middle ball joint. Depending on the size of subsea valves, angled clamp can also be utilized to control leakage from valves.

### **3. Description of an Angled Clamp that can fix some sorts of pipeline damage**

In the following is given a description of an Angled Clamp that can solve the damage problem within the angled pipe. With reference to Figure 1, the clamp comprises four main parts (1,2,3 and 4). Each part itself comprises a half-pipe and a partial hemisphere that are welded together.

Sealing is provided through elastic material (elastomer) for radial and hoop directions in each part (items 1 to 4). The hoop tightening (clamping) is achieved by bolting mechanism for the outer clamp (items 3 and 4). For the inner clamp (items 1 and 2) the hoop tightening is done by bolting mechanism in the straight section and two wedge-shape buckles (male-female elastic wedges- items 10 and 11) (or a collet connector) provide the internal clamping at either side of the joint (Figure 4 ).

Steel ball or wedge gripping mechanism can also be utilized to accommodate the longitudinal loads and displacement (reference: Morgrip and Oil States designs) at both cylindrical and ball joints. The sealing and gripping mechanism can be in multiplied rows.

A structural fixture with calculated stiffness and damping shall be designed in order to limit the angular movement of the clamp.

For the installation, the inner parts (items 1 and 2) are first clamped together around the pipe. The outer parts (items 3 and 4) -that surround the pipe at the straight section and the inner parts at the ball section- complete the clamping and assembling (Figure 4). For diverless application, stabbing guides and funnels shall be designed for remote installation by ROV.

Upon the clamping, the sealing (and gripping) over the ball joint is activated when the final angular position of the clamp is already fixed. Tests will have to be performed to check the sealing performance. This is a typical and general design and method of installation that can be customized for each particular case. Other designs can also be considered for tightening the clamp rather than use of bolting.

For spool-type repair applications- where the alignment is not easily practical- the inner parts can be integrated in one piece and can be flanged or welded to spool ends, while the outer parts are still

clamped shape, and will be installed subsea around the pipeline end and the inner part (at the spool end). The rotational capability of the ball joint section accommodates angular misalignments.

The ball joint section of angled clamp can encircle a leaking flange, when flange repair is not possible or difficult for time being.

#### **4. Potential Patent Claims**

In view of the above description, the following claims may be set forward to which we obtain patent protection:

Claim one. Means for maintaining the integrity of a subsea pipeline that is deformed in an angled configuration by use of clamps connected to a ball joint characterized by using an angled clamp to repair an angled damaged pipe.

Claim two. Means for connecting subsea pipeline ends and repair spools by use of clamps connected to a ball joint characterized by using a ball joint end connector to connect misaligned pipes.

Claim three. Means for maintaining the integrity of a subsea pipeline at a leaking fitting by use of clamps connected to a ball joint as described in claim one, characterized by using an angled clamp to repair a leaking pipeline fitting.

#### **5. Figures**

Figure 1. Angled Clamp composition.

Figure 2. Angled-Clamp sealing mechanism. It can be doubled and a gripping ball rows (not shown here) can also be considered.

Figure 3. Structural support of clamp.

Figure 4. Cross sectional view of clamp installation at the ball joint section.

Figure 5. Angled Clamp for fitting repair.

#### **6. Date**

Written on 09<sup>th</sup> June 2011



Figures:

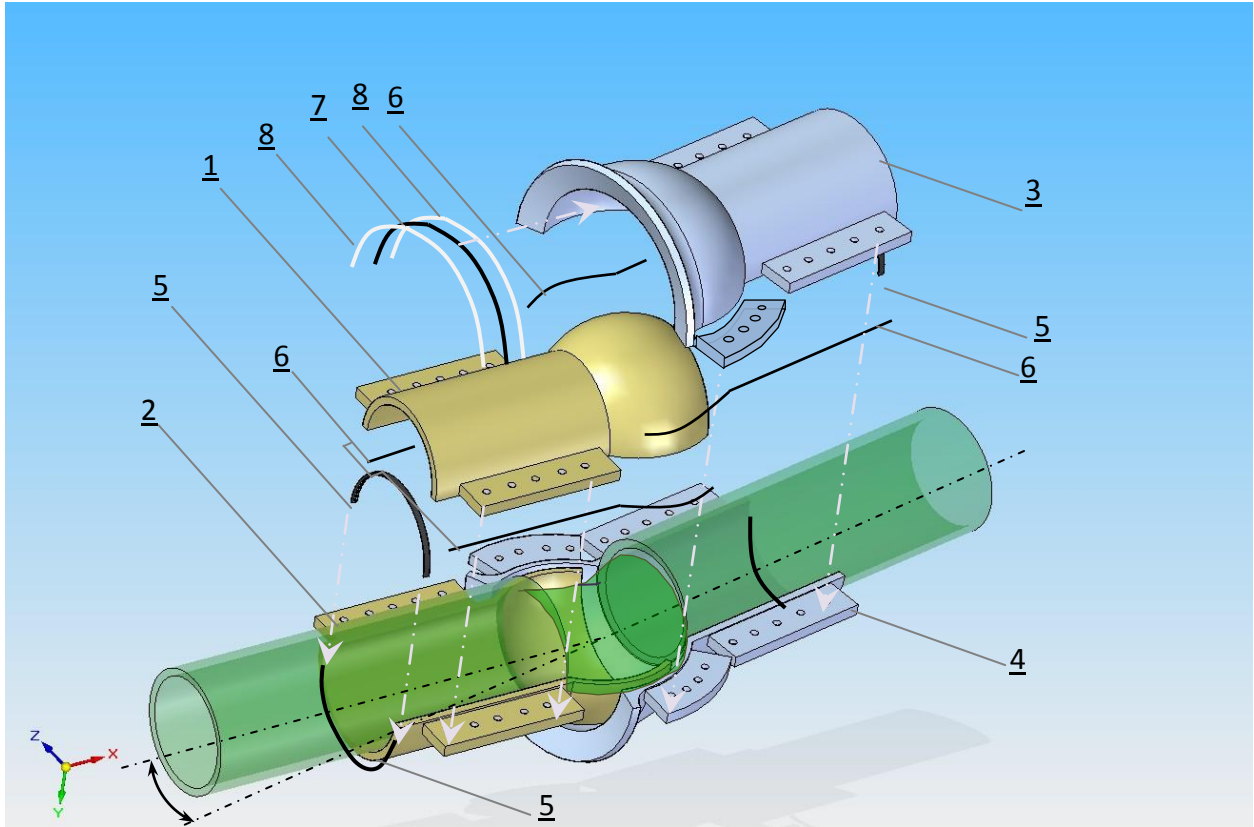


Figure 1.

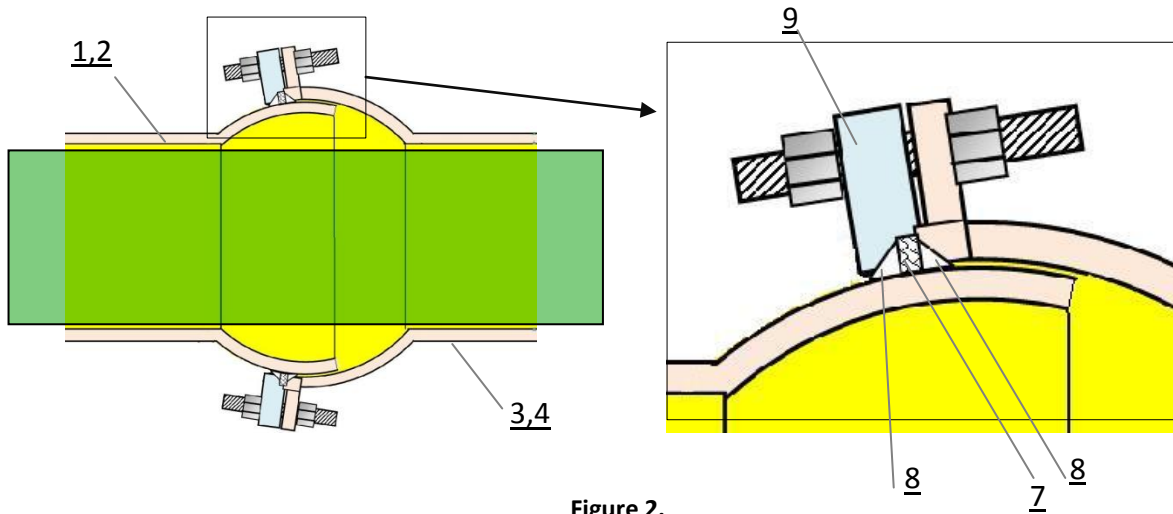


Figure 2.

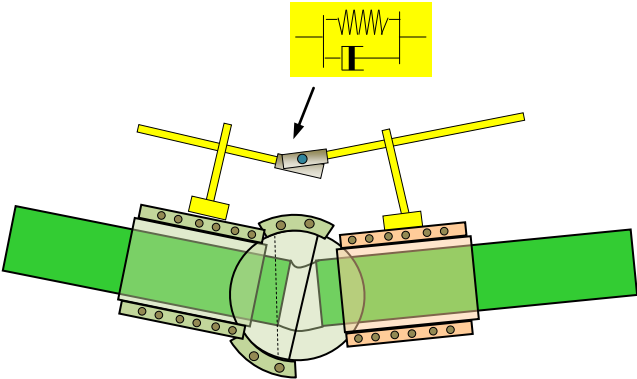


Figure 3.

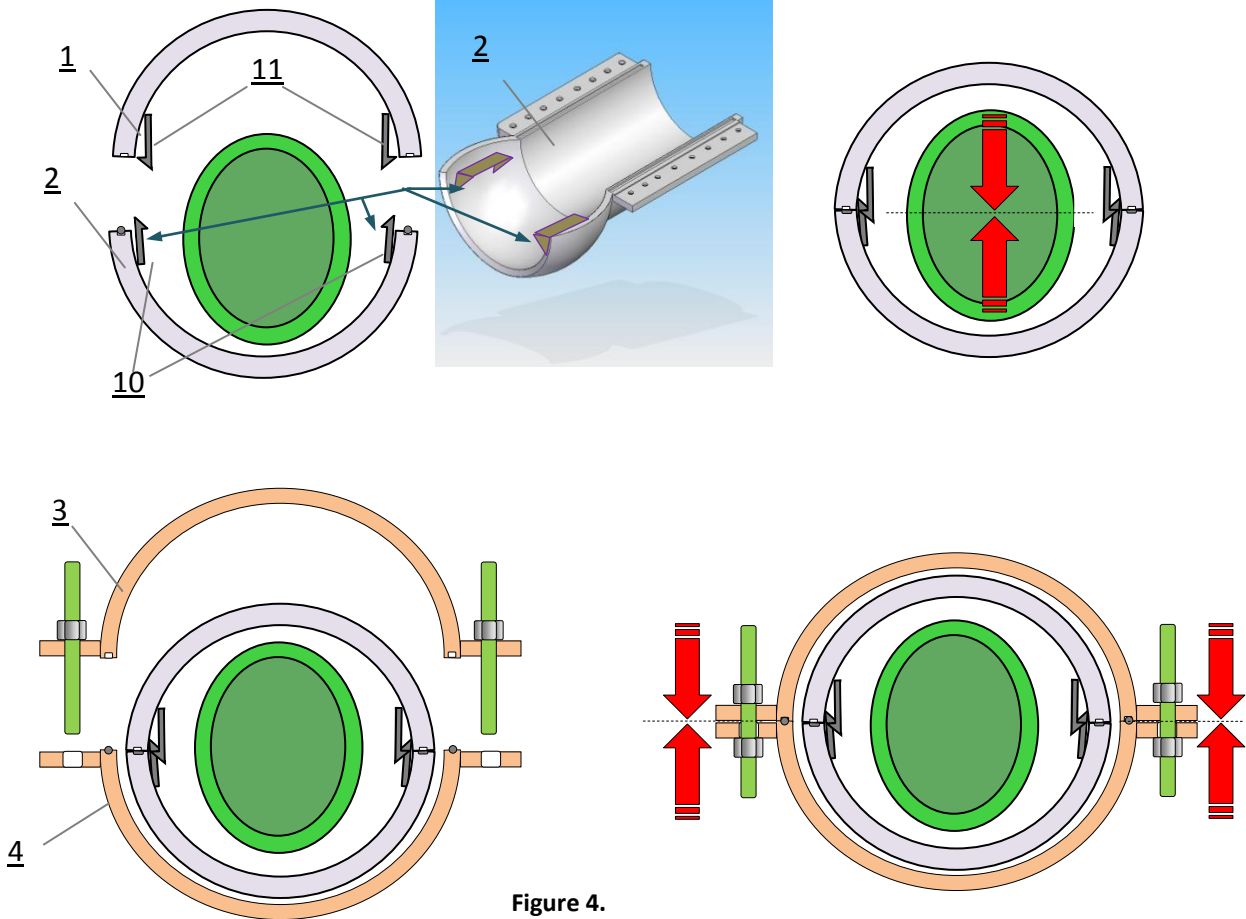


Figure 4.

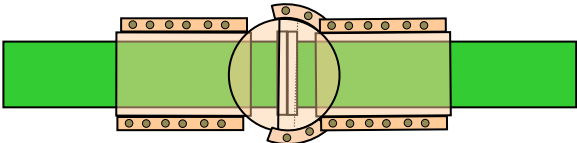


Figure 5.