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# Application of a Grouted Sleeve to Remediate Damaged Subsea Pipeline

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## Abstract

This paper describes the method and equipment developed to allow ROV installation of a grout-filled reinforcement sleeve on a damaged 18” subsea gas pipeline at a water depth of 2,300 ft. The Williams Canyon Chief pipeline was damaged by an accidental anchor drag that pulled pipeline 1,500 feet out of its original path, bent the pipeline to an unknown radius, and left a significant dent in the side of the pipe as well. The damage did not result in a leak and the pipeline was allowed to continue to operate at reduced pressure while repair plans were developed.

Extensive research and testing determined that the pipeline could be returned to normal operating pressure if the dent could be restrained from flexing due to changes in pipeline pressure. Laboratory testing confirmed that cement grout inside a steel sleeve installed around the dent would provide the necessary reinforcement.

A specially designed, ROV friendly repair clamp was developed to match the pipeline curvature that was estimated by side scan sonar imaging. The clamp was fabricated as a straight cylinder but the ends were angled and positioned off-center to account for the pipeline curvature. The clamp was split horizontally so that all clamping screws were vertical. An articulated spreader bar, ROV operated pull-down winches, and a large syntactic buoyancy module allowed the ROV to control the entire installation after the equipment spread was landed on the seafloor.

A project specific metrology tool that measured the curvature of the pipeline at 24 points was built and landed on the pipeline. A ROV video record of the gauge readings was then used in the shop along with the metrology tool to fabricate a dimensionally correct mock-up of the pipeline. This mock-up was then placed into the repair clamp to confirm that it would fit on the pipeline.

## Introduction

In 2005 the Canyon Chief pipeline was hooked by an anchor. At a depth of 2,300 feet, the anchor dented the 18”- 7/8” wall pipe and pulled it 1500 ft away from its original path. ROV inspection at the time of the accident indicated that the pipeline was not leaking. However, in the interest of safety, the pipeline pressure was lowered to about 800 psi and allowed to continue in operation while a remediation method was developed. It was hoped that after remediation, the pipeline could be returned to the full 3,200 psi safe operating pressure.

This remediation project was started with minimum information. Available information included data from a measuring pig run that showed the actual dimensions of the dent, an ROV picture of the dent (Figure 1) that showed that the pipe was clean and the coating was mostly intact, and a sonar image of the bend in the pipeline. This image (Figure 2) was overlaid with scale circles that provided an estimate that the radius of the bend was between 35 and 80 feet.

## Analysis and Testing

Pipeline theory, verified by an extensive testing program, confirmed that the failure mode for this pipeline with this dent was not separating or bursting the pipeline at the location of the dent but instead failure would likely occur due to metal fatigue at the margins of the dent. Increasing the pressure in the pipeline would cause the dent to flex outward only to collapse when the pressure was reduced. Over time, flexing due to normal pressure changes could lead to a fatigue failure. Dimensions of the dent determined during the pig run provided measurements for making accurate samples of the damage. These samples were then pressure tested to destruction to confirm that the weakest part of this pipeline was the longitudinal weld seam. Additional strain gage testing also confirmed that flexing of the dent could be prevented with epoxy or cement grout injected into a steel sleeve that was bolted around the pipe. Cement grout was found to perform better than epoxy in preventing movement of the dent. In addition the ability to mix the grout on the surface and the extended setting time made cement grout the clear choice for this application.

## Grout Sleeve Design

An ROV-installable grout sleeve design was developed that would accept the full range of bend radii of 35 to 80 feet. The 28 inch inside diameter of the sleeve was selected to provide a minimum of 3 inches of grout around the pipeline at the minimum estimated radius. The ends of the sleeve were then cut at an angle to match the likely exit angle of a 45 foot radius. Openings in the end plates were also offset to improve the fit on the pipeline. The sleeve was then split horizontally so that vertically-positioned, cone-head screws would provide an ROV-friendly method of closing the sleeve around the pipeline (Figure 3). It was recognized that the center of gravity of a horizontally split sleeve would change significantly as the sleeve opened and closed. In order to minimize this effect, the spreader bar connecting legs were attached at specific positions with one pair of legs attached to the top half of the sleeve and one pair attached to the bottom half of the sleeve. This articulated arrangement moved the spreader bar horizontally as the sleeve opened and closed.

The close spacing of the 48 screws required to hold the sleeve closed required that a special torque wrench be designed to tighten the screws. The screws were made with a reduced diameter between the head and the start of the threads. This arrangement allowed the screws to be threaded into the top half of the sleeve during deployment. After the sleeve was closed with hydraulic cylinder powered hinges, turning the screws allowed them to drop out of the threads on the top half of the sleeve and into the threads in the bottom half of the sleeve. The reduced diameter of the screw and the internal thread diameter in the top half provided additional guidance to assure that the threads aligned in the bottom half of the sleeve. Finally, the grout fill pipe was mounted in the bottom center of the bottom half of the sleeve. The top half of the sleeve incorporated three ROV-operated vent valves. During grout filling, water inside the sleeve was forced out of the vent valves. When the ROV observed good, clean grout exiting the vent, that valve was closed. This method allowed confirmation that the sleeve was completely filled with cement grout.

Finite Element Analysis of the pipeline-grout sleeve system determined that expansion of the pipeline due to increased internal pressure would apply an expansion force through the grout that the sleeve would see as an internal pressure of 750 psi. However, it was recognized that the seals in the sleeve would not see a pressure due to expansion of the pipeline. Instead they would only see the pressure of the cement grout during injection. Therefore it was accepted that some leakage of the seals during the hydrotest could be allowed. The grout sleeve itself is not a pressure-containment but is simply a strong-back for the grout. This fact simplified sealing of the sleeve on the pipeline and allowed a novel end seal arrangement. This arrangement kept the corners of the end seals at the horizontal split line pulled back away from the pipeline until after the sleeve was closed around the pipe.

## Deployment Plan

It was also recognized that the most critical time during an offshore operation is the time when the crane or lowering line on the vessel is connected to a fixed object on the sea floor. To mitigate this risk, the grout sleeve was deployed with a buoyancy module and a suppressor weight (Figure 4). The buoyancy module was sufficient to suspend the grout sleeve above the sea floor. This method allowed the assembly to be landed on the sea floor next to the pipeline and then quickly disconnected from the vessel. Once this package was on the sea floor the ROV was in complete control of the installation. A pair of ROV-operated winches mounted on the spreader bar were then used to pull the grout sleeve down onto the pipeline (Figure 5). Later these winches were used to provide a controlled assent for the spreader bar and buoyancy module after the grout sleeve was disconnected.

## Metrology Tool

A special metrology tool (Figure 6) was built to measure the pipeline curvature in the area where the grout sleeve would be installed. This ROV-operated tool was deployed on a skid that was disconnected from the lowering line after it landed on the sea floor. The ROV then docked with the tool and positioned it on the pipeline by centering it on the dent. The ROV powered two pair of hydraulic arms on the tool to clamp the tool on the pipeline. The ROV could then disconnect from the tool and make a video record of the readings on twenty equally spaced mechanical gages (Figure 7) that rested against the pipeline at five selected positions along the length of the tool. After the tool was recovered to the workshop, short sections of pipe were fitted into the tool and positioned to duplicate the gage readings from the sea floor. These short sections were then welded together, removed from the tool, and laid into the open grout sleeve to confirm clearance around the pipe (Figure 8) and the exit angle of the pipe from the sleeve.

## Offshore Installation

Installation of the grout sleeve required that an access hole be dredged under the pipeline. This hole needed to be about 20 ft long and 4 feet deep to provide clearance for the bottom half of the sleeve to swing closed under the pipeline. It was recognized that the weight of the sleeve plus the cement grout would be around 12,000 lbs, when the buoyancy module was released. Therefore, to prevent the pipe from sagging into the hole we installed an ROV-operated pipe support frames about 30 ft. back from either side of the hole (Figure 9). Each frame consisted of two mudmats and a single, motor-operated grab. These frames did not lift the pipeline but simply added mudmat support. After the grout sleeve was installed, the ROV pulled a fabric grout bag into the hole under the sleeve. This bag was then filled with cement grout to fill the vacant space below the grout sleeve. After the grout was allowed to cure for a few hours, the ROV disconnected the spreader bar from the sleeve and it, along with the buoyancy module and suppressor weight, were recovered to the surface. The pipeline support frames were also released and recovered. The only things left on the sea floor were the grout sleeve and the grout bag supporting it (Figure 10). This remediation action cleared the pipeline for full operating pressure operation.


Figure 1 - Estimating the dent with a straightedge

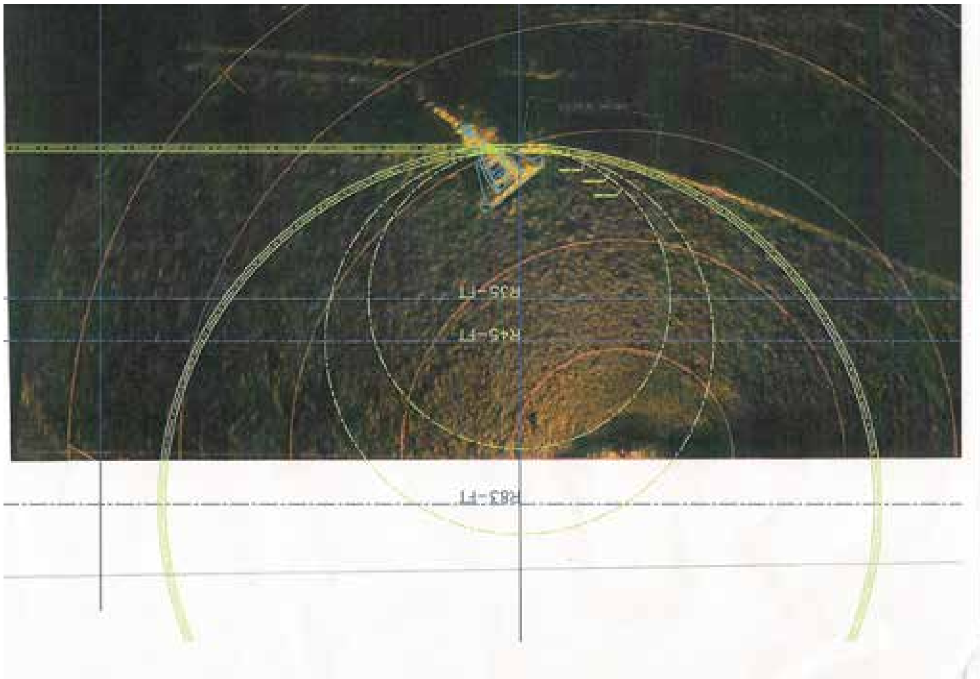

Figure 2 - Estimating the radius of curvature of the pipeline

Figure 3 – Grout Sleeve and Spreader Bar during Factory Acceptance Testing

Figure 4 – Grout Sleeve – Supressor Skid – Buoyancy Module rigged for deployment

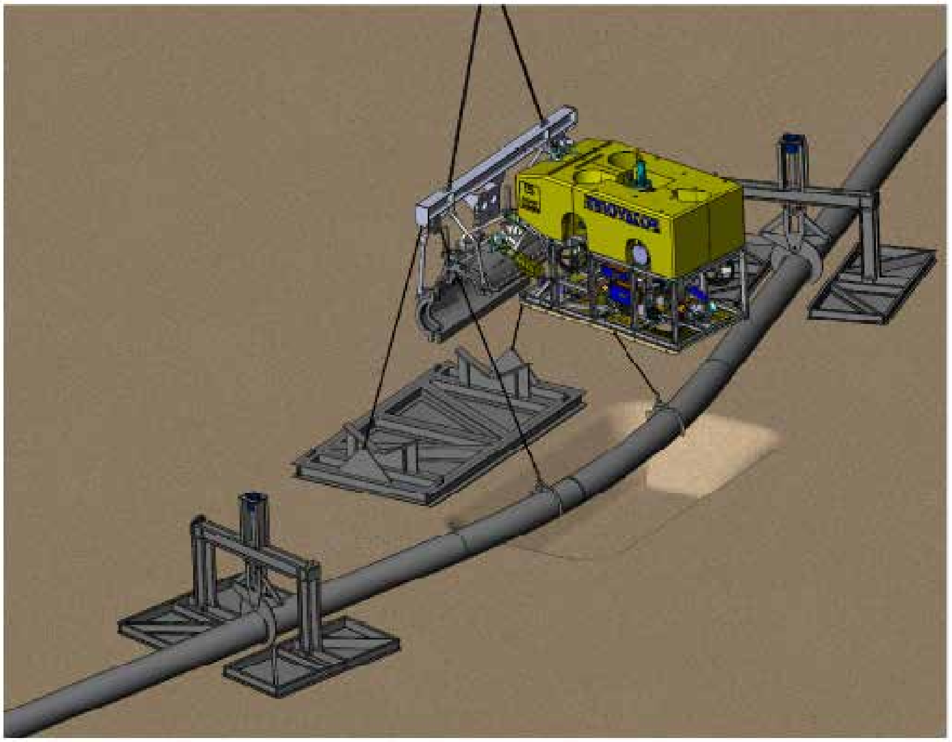

Figure 5 – ROV powers Spreader Bar Winches to pull Grout Sleeve down to pipeline


Figure 6 – Metrology Tool suspended for wet test


Figure 7 – Metrology Tool landed on test pipe

Figure 8 – Fit-up of test pipe fabricated from Metrology Tool measurement

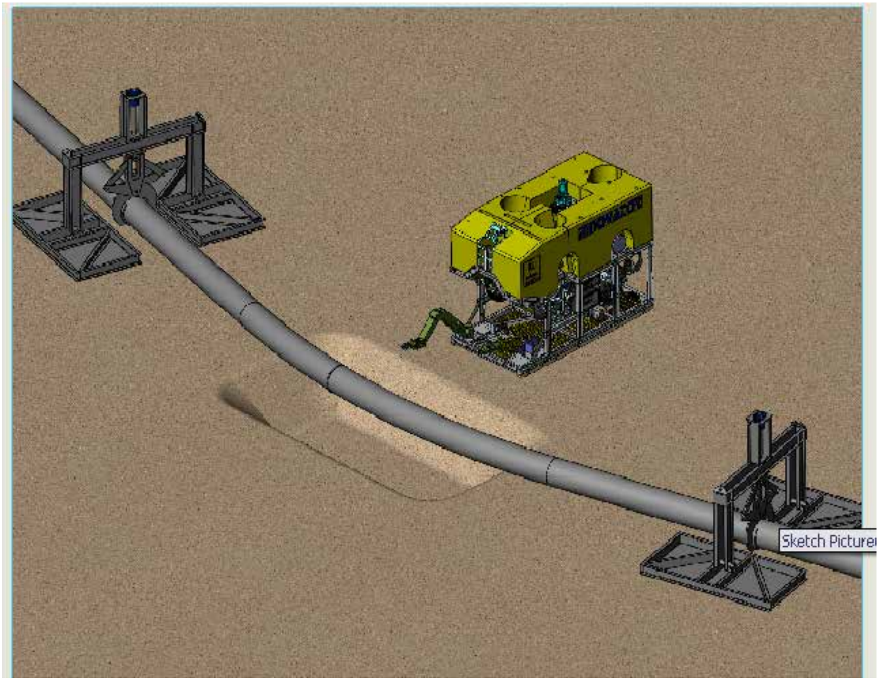


Figure 9 – Pipeline held with Pipeline Support Frames while ROV dredges access hole


Figure 10 – Grout Sleeve and Grout Bag installed on the pipeline