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Free Span Rectification by Pipeline Lowering (PL) Method

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Abstract

Surface laid pipelines experience free spans due to various reasons such as uneven seabed, local scour or a storm event. If free span lengths are beyond acceptable limits, vortex induced vibrations (VIV) can cause the pipeline to undergo fatigue damage and severely reduce the pipeline's design life. Thus pipelines need to be periodically monitored to ensure that there are no free spans that are beyond the acceptable length. When such free spans are identified, these need to be rectified immediately to avoid fatigue damage to the pipeline. Rectifying unacceptable free spans in existing pipelines are a constant battle for operators around the world.

Free spans on existing pipelines are commonly rectified by grout bags. While this method is considered to be a standard and cheap solution, it often does not provide a long term solution to free spans. It is often the case that the pipeline whose free spans are rectified by grout bags needs further free span rectification the following year. The onset of more free spans and the need for rectification cycle often continues annually when grout bags are used to rectify free spans.

This paper presents a new approach named the "Pipeline lowering (PL) method" for free span rectification. This unique solution will ensure the free span rectification is a long term solution compared to grout bags that may be affected by scour and wave loadings. The solution involves lowering the crests of the free spans such that the pipeline follows the natural seabed profile while ensuring the pipeline integrity is not compromised at any stage. The lowering operation is carried out solely by fluidizing the seabed soil by a mass flow excavator and the pipeline lowers under its self-weight. A laboratory demonstration and successful field implementation of PL method for free span rectification are presented in this paper.

This paper provides vital technical knowledge on free span rectification by PL methodology for pipeline engineers, contractors and operators who need to ensure free spans are rectified safely and efficiently. This new methodology is a cost effective and elegant solution.

Introduction

Free spans refer to the sections of underwater pipelines that are unsupported by the seabed. Surface laid pipelines can experience free spans due to various reasons such as uneven seabed or local scour. If free spans lengths are beyond acceptable limits, vortex induced vibrations (VIV) can cause the pipeline to undergo fatigue damage and severely reduce the design life of a pipeline. Thus pipelines need to be periodically monitored to ensure that there are no free spans that are beyond the acceptable limit in length. When such free spans are identified, they need to be rectified immediately to avoid fatigue damage to the pipeline.

Free spans primarily occur when the scouring action of underwater currents alters seabed topology in the vicinity of a pipeline. Free spans have been proven to adversely affect subsea pipeline when the lengths of free spans exceed acceptable critical lengths. The objective of this paper is to propose a new method of free span rectification known as Pipeline Lowering (PL) method. This is an efficient and long term solution as the free spanning section of the pipeline is lowered and is made either to follow the natural seabed profile or buried in the seabed.

Free spans on existing pipelines are commonly rectified by grout bags. While this method is considered to be a standard and cheap solution, it often does not provide a long term solution to free spans. It is often the case that the pipeline whose free spans are rectified by grout bags needs further free span rectification the following year. The onset of more free spans and the need for rectification cycle often continues annually when grout bags are used to rectify free spans.

Free spans on pipelines are often created,

A. When there is a storm event which causes a scour
B. When natural waves and currents cause local scour below the pipeline (Figure 1).
C. Due to seabed topology (Figure 2)

If the free span is caused due to (A), then a grout bag solution is suitable, but if the free span caused due to (B) or (C), then the grout bags may not provide a permanent solution. Rectification of free spans using grout bags may not be the most cost effective solution in the long run for free spans due to (B) or (C). Past experience in projects has shown that free spans tend to reappear in pipelines that were rectified by grout bags. This is because the introduction of grout bags may induce vortex currents that in turn results in scour that lead to the onset of free span. Furthermore, grout bags are prone to settlement or can get washed away.

Local scour below a pipeline is a common cause for creation of free spans. The scouring process beneath a pipeline can be categorised into five key stages; onset of scour, tunnel erosion, lee-wake erosion, equilibrium stage, and scour lateral growth.

a) Onset of scour
A seepage flow is created in the soil beneath the pipe due to the pressure difference between upstream and downstream side of the pipe (oscillating pressure difference in case of waves). Onset of scour occurs when this seepage rate is high and causes piping in the soil.
b) Tunnel erosion
At this stage, the gap between the pipe and the bed remains small. A substantial amount of water is diverted to the gap leading to very large velocities in the gap. For a gap of 5% of pipe diameter, the bed shear stress just below the pipe can be amplified by a factor of 4. This results in high rate of scour as violent jet of sand and water. As the gap grows larger, the velocity reduces and the tunnel erosion stabilises.
c) Lee-wake erosion
Tunnel erosion is followed by lee-wake erosion. This is caused by vortex shedding. When the gap between the pipe and the bed reaches a certain value, vortex shedding will begin to occur. Vortices sweep the downstream bed as they pass and hence increase the bed shear stressed momentarily to higher values along the lee side (up to 4 times). This will lead to higher erosion in the lee side (downstream) of the pipe.
d) Equilibrium stage
The scouring process finally reaches a steady state in which the bed shear stress beneath the pipe becomes constant and equal to its undisturbed value (ambient bed shear stress).

It is important that the fundamental cause for onset of free spans is investigated fully before a rectification solution is chosen. Seabed mobility assessment results can provide insight into whether a free span is due to natural wave and current conditions or not.

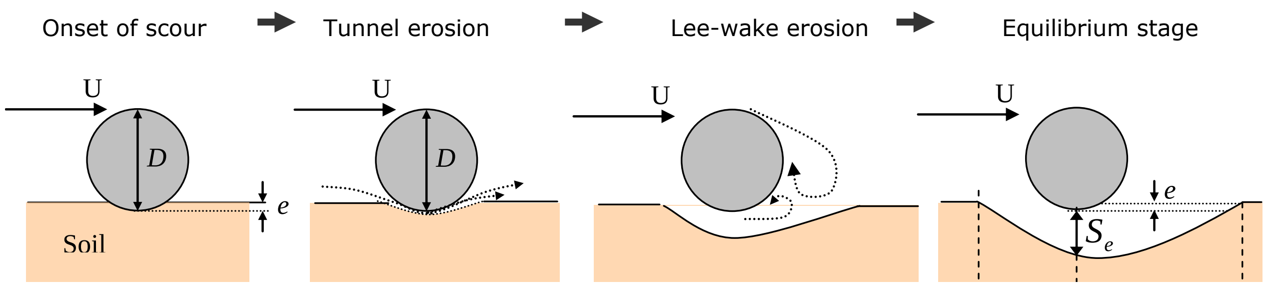


Figure 1: Onset of scour leading to formation of free spans.

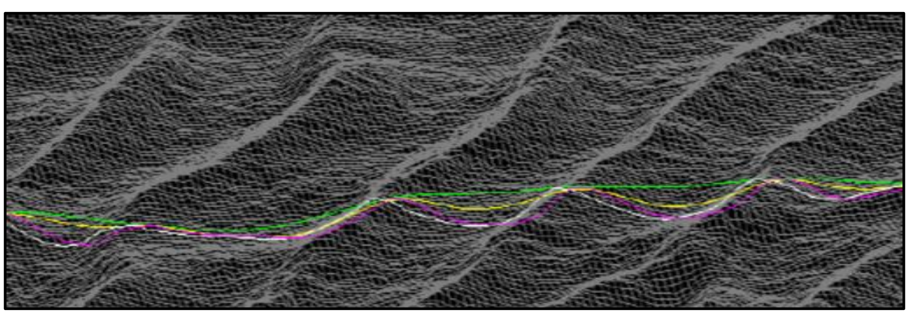


Figure 2: Illustration of a pipeline free spans due to seabed topology (pipeline shown under empty, flooded and operating conditions)

Overview of free span rectification process

An overview of current industry practice on free span identification and rectification is schematically shown in Figure 3 below.

Figure 3: Typical Free span rectification process

a. **Free span survey & span identification**
A survey is performed along the length of a pipeline to identify the quantity and the parameters of the free spans. Parameters such as free span length, height of pipeline above seabed and the geography of the seabed in the vicinity of the seabed are recorded. Data gathered during this phase can be used for further engineering analysis in the next step.

b. **Engineering Assessment**
Conventionally, the free span rectification is solely based on the grout bag placement method and the engineering assessment consist of evaluating the number of grout bags required to rectify each of the identified free spans.

c. **Rectification Planning**
Using the data from the engineering assessment, the exact steps to be taken to rectify the free spans is mapped out in this phase. If there are multiple free spans, the sequence in which the free spans are to be rectified is also determined.

d. **Free Span Rectification**
The rectification of the free spans is executed in accordance to the pre-determined plan put in place during the "rectification planning" phase.

e. **Post Rectification Survey**
When rectification of the free span rectification is complete, a survey is performed to ensure that the final position of the pipeline is such that free span is rectified. In this phase, it is possible to install monitoring devices such as accelerometers to monitor the displacement of pipelines where free spans are expected to recur.

Free span rectification by Pipeline Lowering (PL) Method

Pipeline lowering (PL) method provides a new approach for free span rectification. This unique solution will ensure the free span rectification is a long term solution compared to grout bags that may be affected by scour and wave loadings. The solution involves lowering the crests of the free spans such that the pipeline follows the natural seabed profile while ensuring the pipeline integrity is not compromised at any stage. The lowering operation is carried out solely by fluidizing the seabed soil by mass flow excavators and the pipeline lowers under its self-weight.

In order to implement the PL method, the following key assessments needs to be performed.

- Geotechnical assessment of the seabed soil to evaluate excavation rates.
- Engineering assessment of allowable pipeline stresses and hence the allowable single pipeline lowering depth
- Pipeline survey & engineering assessment capability to ensure that the pipeline integrity is not compromised during and after pipeline lowering operations.

Geotechnical properties of seabed soils need to be assessed to ensure that the seabed soil can effectively be removed by a mass flow excavator. i.e PL method may not be practical if the seabed conditions are such that mass flow excavation is in-effective.

In order to identify whether the pipeline can be lowered without compromising its integrity, an engineering assessment of allowable pipeline stresses would need to be undertaken. This would be based on,

1. Pipeline properties and operating conditions
2. ECA (Engineering Critical Assessment)

Under ideal conditions, the following are allowable pipeline stress limits, in accordance to ASME B31.8.

- Longitudinal Stress : 80% of the SMYS
- Combined Stress : 90% of the SMYS

These limits often would be further reduced by the ECA assessment of the pipeline joints.

Integrity of the pipeline throughout the lowing operation is critical for the implementation of the Pipeline Lowering (PL) method. Accurate pipeline survey and real time engineering stress assessment capability need to be in place before the pipeline lowering operation. This is to ensure that the pipeline stresses are assessed at regular intervals during the lowering stages and maintained within the acceptable levels. Figure 4 illustrates typical longitudinal stress components that need to be considered when performing pipeline stress assessment.

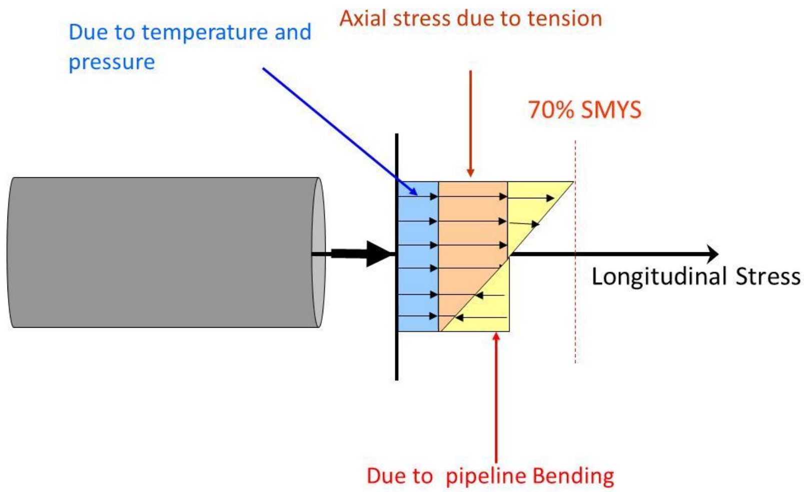


Figure 4: Typical Pipeline Longitudinal Stress components

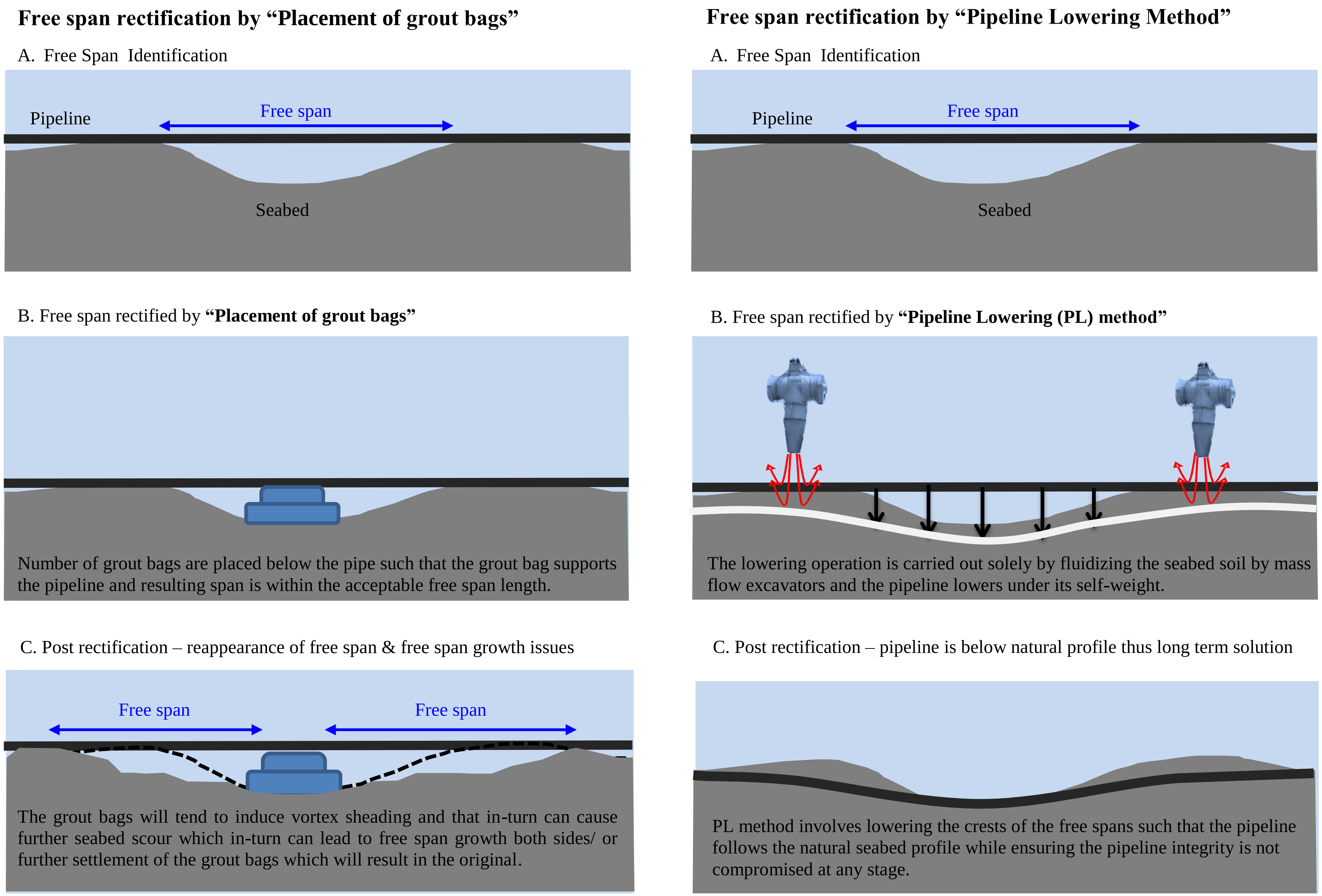
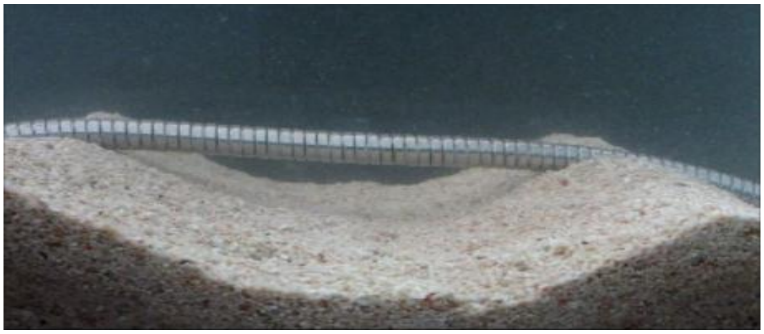


Figure 5: Comparison of free pan rectification methods: Placement of grout bags method Vs Pipeline lowering method

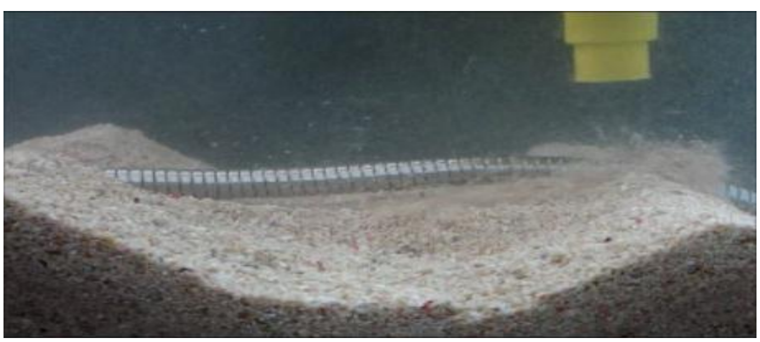
Model Demonstration of Pipeline lowering (PL) method

This section demonstrates the methodology employed when lowering pipeline. The sequence of images below show a free span rectification being performed using the Pipeline Lowering (PL) methodology in a test tank. This demonstration was performed with a miniature flexible steel pipe and a purpose built small Mass Flow Excavator (MFE).



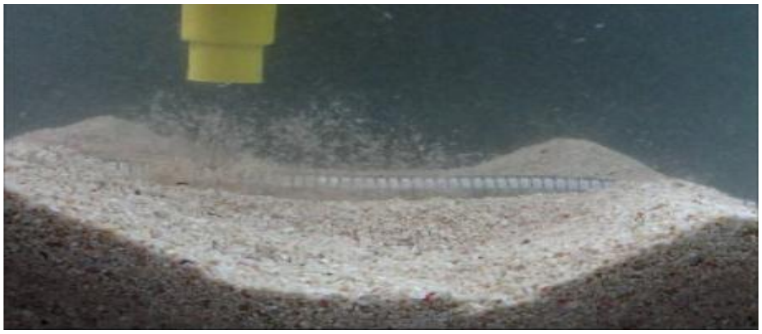
(a) Free span section of pipeline.

(b) Small scale model of Mass Flow Excavator (MFE) is used to fluidize the sand at the left crest. This causes the pipe on the left crest to settle lower into the sand.

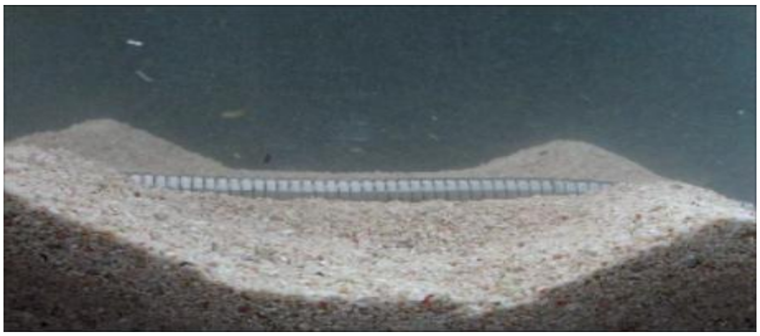


(c) The Mass Flow Excavator (MFE) is used to fluidize the sand at the right crest. This causes the pipe on the right crest to settle lower into the sand.

(d) Pipeline has been lowered at both the crests.



(e) A few passes are made over the central section of the pipeline between the 2 crests.



(f) Pipeline is fully supported by the sand and there is no more free span.

(g) A few more passes are made over the pipeline using the Mass Flow Excavator (MFE).

(h) Top surface of pipeline is now fully flush with seabed with no free span.

Figure 6 (a to h): Demonstration of Pipeline Lowering (PL) in a small scale setup.

Field Demonstration of Pipeline Lowering (PL) method

Two field examples of pipeline lowering method are provided below.

1. Free span rectification by PL method has been successfully executed in the field (China) with silty sand seabed conditions in water depths ranging from 130m to 150m. A total of 86 free spans in a 16" pipeline were rectified in 122 operational hours while ensuring that the pipeline was stable and lying without undue stresses acting upon it. The free span height ranged from 0.5m-1.5m.

   Figure 7 below shows one of the locations where the mass flow excavator had been used to rectify a free span by lowering the pipeline.

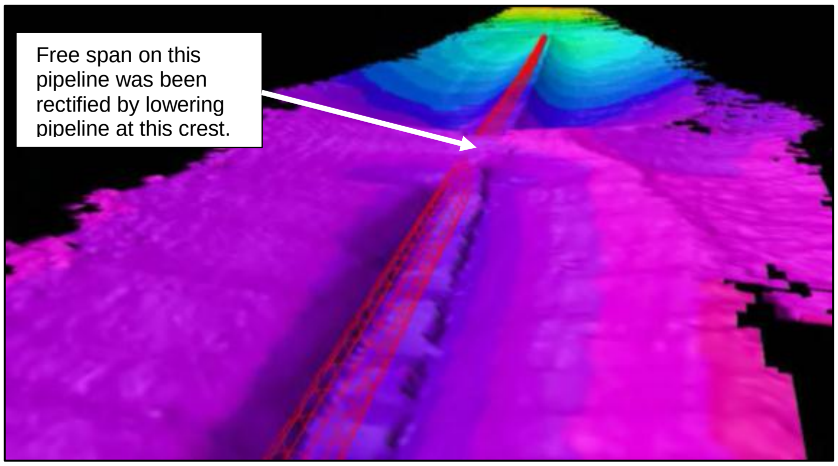


Figure 7: Free span rectification by pipeline lowering method employed in the field

2. Pipeline lowering method was successfully applied to lower a 16inch live gas subsea pipeline by 6m in Indonesia. A 16" live gas pipeline was crossing a shipping channel and was buried at about 3m below seabed. In order for the port to expand and allow bigger vessels to enter the port, the shipping channel needed to be deepened. Thus the pipeline was required to be lowered further 6m for a stretch of 350m where the pipeline crosses the shipping channel. The lowering operations had to be carried out whilst the pipeline is fully operational. The pipeline lowering methodology was followed successfully to lower the pipeline in steps of less than 0.5m per single pass.

   The pipeline was successfully lowered by 6m using a mass flow excavator in 14 passes. This successful lowering of a live gas pipeline by 6m is considered to be world's first such lowering. The initial and final position of the pipeline is shown below. The initial top of pipe (TOP) position and final TOP position after 14 lowering passes are shown in figure below.

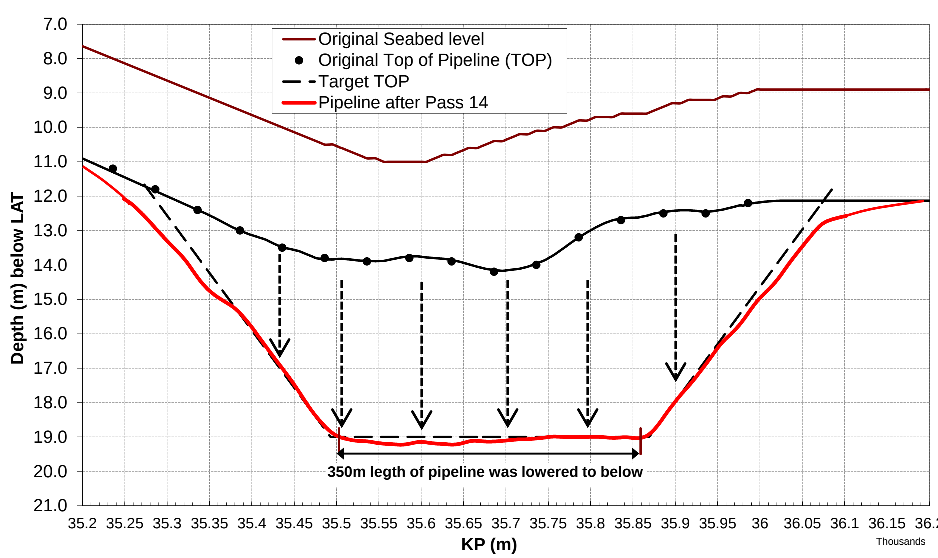


Figure 8: Free span rectification by pipeline lowering method employed in the field

Conclusion

This paper presents an alternative method, known as PL method, for free span rectification compared to the traditional ground bag placement method. The paper highlighted the fact that grout bag solution may not be the best long term solution for free span rectification under certain conditions.

The fundamental cause for onset of free spans should be investigated fully and the rectification solution should be based on the results of such assessment. Grout bags may be suitable solution for free span rectification where the free span was initiated due to storm event, if the seabed is stiff soils or bed rock. The Pipeline lowering (PL) method is suitable in cases where the onset of free spans is due to natural wave and currents. However, the effectiveness of free span rectification by PL method in clay seabed soils reduces with the increase of clay shear strength and in particular PL method is expected to be ineffective in cemented soil. In general, the PL method in clay seabed may not be cost effective if the seabed soil shear strength is above 40kPa.

The Pipeline lowering (PL) method would be preferred and cost effective solution for free span rectification where large number of free spans needs to be rectified in sandy seabed conditions. The PL methodology can also be an effective and cost efficient solution to many other scenarios such pipeline crossing and pipeline lowering for on-bottom stability issues.

Acknowledgement

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