Cost Effective Free Span Rectification for Offshore Pipelines

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ABSTRACT: Offshore pipelines often experience free spans due to uneven seabed, local scour or a storm event. When free span lengths are beyond acceptable limits, vortex induced vibrations (VIV) can cause pipelines to undergo fatigue damage and severely reduce the pipeline's design life. Therefore, surface laid offshore pipelines are periodically surveyed to ensure that there are no free spans that are beyond the acceptable limit. When such free spans are identified, they are rectified immediately, often by grout bags. While grout bag use is a standard solution for free span rectification, it does not always provide a long-term remedy to free spans. Often lines 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. This paper presents a cost effective long-term free span rectification method known as "Pipeline Lowering." This unique solution will ensure the free span rectification is a long-term fix compared to grout bags that may be affected by scour and wave loadings. This paper provides vital technical knowledge for pipeline engineers, contractors and operators who need to ensure free spans are rectified safely and efficiently.

KEYWORDS: Free span rectification, Pipelines, Seabed, Mass flow excavator

1. INTRODUCTION

Subsea pipelines can experience free spans due to uneven seabed or local scour. Free spans are sections of underwater pipelines that are unsupported by the seabed (Figure 1). If free spans lengths are beyond acceptable limits (DNV RP F105), vortex induced vibrations (VIV) can cause the pipeline to undergo fatigue damage and this could severely reduce the design life of a pipeline (Figure 2). Thus, pipelines are periodically surveyed to ensure that there are no free spans that are beyond the acceptable limit in length. When such free spans are identified, they are rectified immediately to avoid fatigue damage to the pipeline.

Free spans on existing pipelines are commonly rectified by grout bags. While this method is considered as a standard solution, it is not necessarily the long-term fix 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.

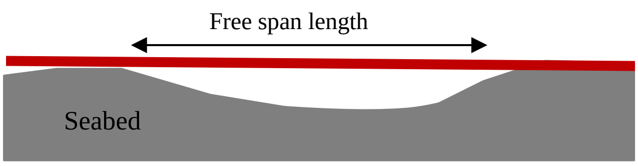

Figure 1 Typical profile of free span in seabed

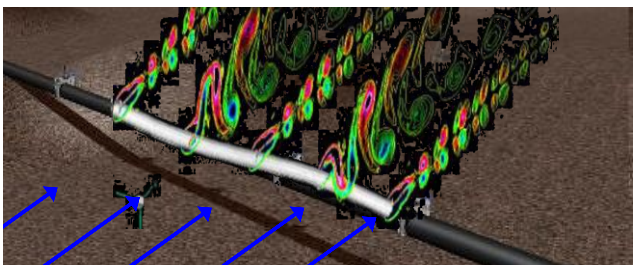

Figure 2 Typical vortex induced vibrations (VIV) on free spans

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 3).
C. Due to seabed topology

If the free span is caused due to (A), then a grout bag solution is suitable, but if the free span is 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). Operators' experience in projects has shown that free spans often 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 more onset of free spans. Furthermore, grout bags are prone to settlement or can get washed away as they are alien to the natural topography in equilibrium with currents and waves.

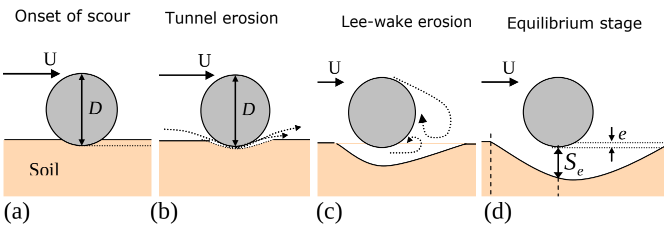

Figure 3 Schematic of onset of scour processes leading to formation of free spans

Free spans primarily occur when the scouring action of underwater currents alters seabed topology near 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 relatively 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.

2. BACKGROUND

When a free span in identified in a pipeline, it is important that the fundamental cause for onset of free span 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. Seabed mobility assessment (Thusyanthan et al. 2013) can provide insight into whether the seabed is stable or not about soil mobility. Local scour below a pipeline is a common cause for creation of free spans (Sumer et al.2001). 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 (Figure 3).

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).

3. FREE SPAN RECTIFICATION BY PIPELINE LOWERING (PL) METHOD

Pipeline lowering (PL) method (Thusyanthan et al.2014) provides a relatively new approach for free span rectification. The solution is by lowering the crests of the pipeline free spans such that the pipeline profile follows the natural seabed profile, while ensuring the pipeline integrity is not compromised at any stage of the lowering process. This unique solution ensures the free span rectification is an effective long-term solution compared to grout bags which can be affected by scour and wave loadings. The pipeline lowering operation is carried out solely by fluidizing the seabed soil using mass-flow or controlled-flow excavators (MFEs or CFEs) and the pipeline lowers under its self-weight. Figure 4 demonstrates the PL method of free span rectification.

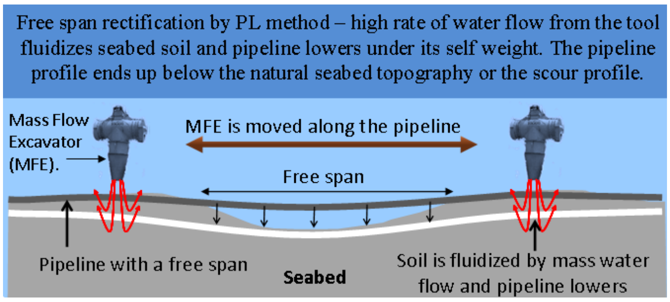

Figure 4 Overview of free span rectification by PL method

To successfully implement the PL method, the following key assessments needs to be performed.

A. <u>Geotechnical assessment of the seabed soil</u>
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 not possible or ineffective. If the seabed is cohesive with over 25kPa undrained shear strength, then the PL method may not be effective.

B. <u>Engineering assessment of pipeline stresses</u>
To assess whether the pipeline can be lowered without compromising its integrity, an engineering assessment of current and allowable pipeline stresses need to be undertaken. The allowable pipeline stresses assessment 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
   where SMYS is Specified Minimum Yield Strength. These limits could be further reduced by the ECA assessment of the pipeline joints.

C. <u>Pipeline survey & engineering assessment capability</u>
Ensuring that the Integrity of the pipeline is not compromised throughout the pipeline lowing operation is critical for the execution 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 5 illustrates typical longitudinal stress components that need to be considered when performing pipeline stress assessment.

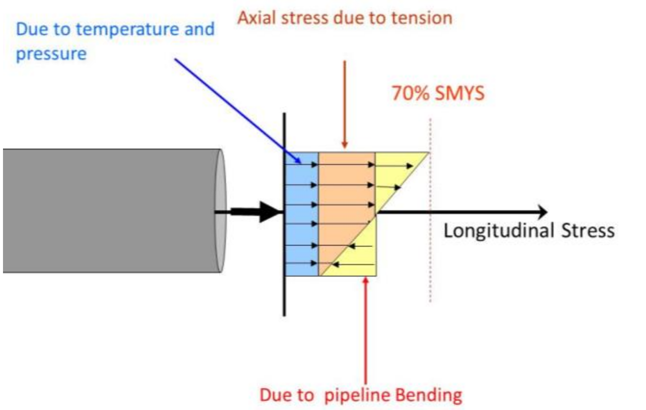

Figure 5 Pipeline stresses due to operating conditions

4. PROJECT EXAMPLES

Two project examples of where pipeline lowering method was successfully implemented is provided below.

<u>Project A</u> - Pipeline lowering method was successfully applied to lower a 16-inch live gas subsea pipeline by 6m in Indonesia (Thusyanthan et al. 2014). A 16" live gas pipeline was crossing a shipping channel and was buried about 3m below seabed. 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 was kept fully operational. The pipeline lowering methodology was employed 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 world's first such lowering. The initial top of pipe (TOP) position and final TOP position after 14 lowering passes are shown in Figure 6.

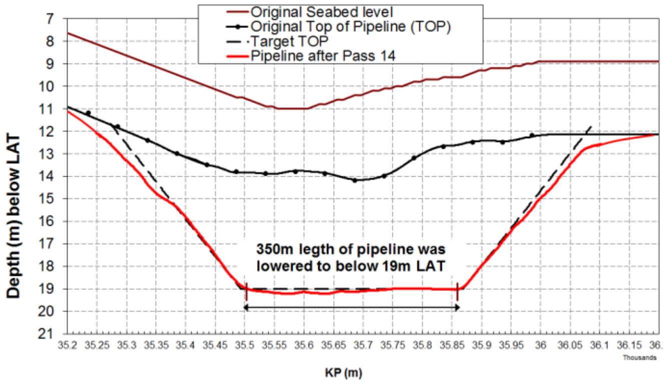

Figure 6 Pipeline stresses due to operating conditions

Project B - 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. Example of a single location is provided Figure 7.

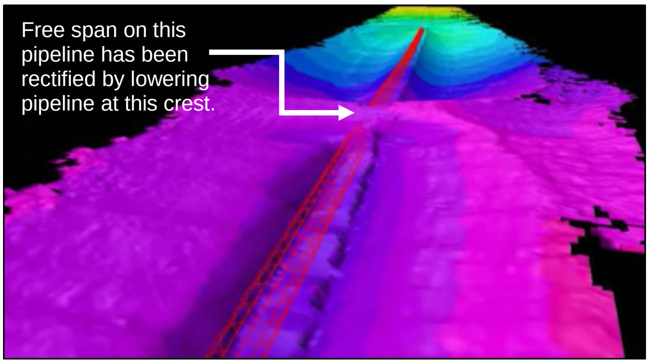

Figure 7 Pipeline stresses due to operating conditions

4. COST COMPARISON STUDY

A cost comparison exercise between free span rectification using grout bags and free span rectification by PL method was undertaken. The seabed condition is assumed to be sands. The cost estimates used were from typical projects in South East Asia.

This assessment is based on realistic costs estimates of,

1. Consumables
2. Tool rental
3. Personnel
4. ROV spread
5. Vessel costs

Survey spread is not included in the cost comparison study.

Figure 8 presents the results of the cost comparison study. The cost comparison shows that the effective savings from PL method increases as the number of spans to be rectified increases. In the current study, the PL method is cost effective when the number of span to be rectified is 10 but not cost effective when it is 5. While the exact number of spans beyond which the PL method becomes cost effective may change from project to project, it needs to be highlighted that free span rectification by grout bags usually requires further rectification annually, whereas the free span rectification by PL method is more permanent solution as the pipeline is lowered to follow the natural seabed profile. Therefore, on the long term, the PL method is always cost effective provided the seabed soil conditions are well suited for PL method, i.e. sandy conditions. It is to be noted that the assessment is based on best estimates and costs can vary depending on the project location, execution time, project specific restrictions etc. Nevertheless, this comparison study provides an overview of cost savings in PL method.

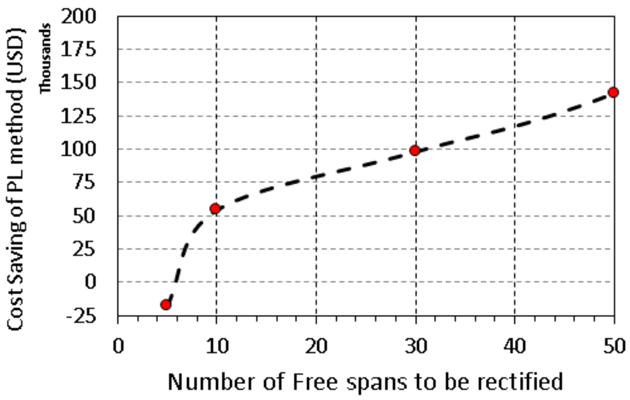

Figure 8 Cost saving from PL Method

5. RECOMMENDED FREE SPAN RECTIFICATON PRACTICE

An overview of current industry practice on free span identification and recommended practice for free span rectification is schematically shown in Figure 9.

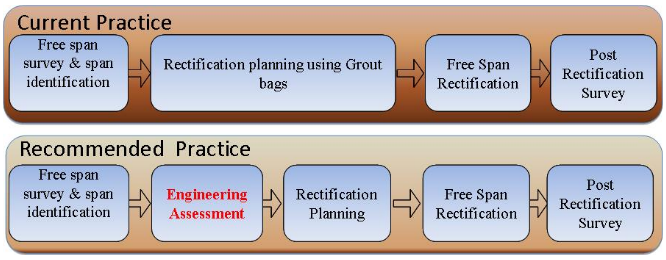

Figure 9 Free span rectification recommended practice

The recommended practice ensures that the cost-effective method for free span rectification is used rather than choosing the gout bag solution as default option. Figure 10 & 11 pictorially demonstrates the PL method in comparison to the convectional grout bag solution. Free span rectification by installation of grout bags may not be an effective long-term remedy under certain seabed conditions.

The recommended practice stages are outlined below.

a. Free span survey & span identification

A survey to be performed along the length of a pipeline to identify the extent and the engineering parameters of the free spans. Parameters such as free span length, height of pipeline above seabed and the topography of the seabed near the seabed are recorded. Data gathered during this phase is used for further engineering analysis in the next step.

b. Engineering Assessment

The recorded free spans are compared with allowable free span lengths for the pipe based on engineer assessments. For any free spans beyond the allowable length, a rectification action is required. Conventionally, the free span rectification is solely based on the grout bag placement method. PL method, however, could be a cheaper option in the long term. Thus, an engineering cost assessment need to be carried out to evaluate whether the grout bag solution or PL method is the most cost effective for rectifying the free spans. Root cause of the free spans, seabed soil conditions will be critical in determining the most cost-effective solution.

c. **Rectification Planning**

Using the data from the survey and engineering assessment, the steps required for free span rectification 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**

After completion of the free span rectification, a survey is to be performed to ensure that the final position of the pipeline is such that free span is rectified as planned. In this phase, it is possible to install monitoring devices such as accelerometers to monitor the displacement of pipelines in allowable free spans to be used for fatigue assessment.

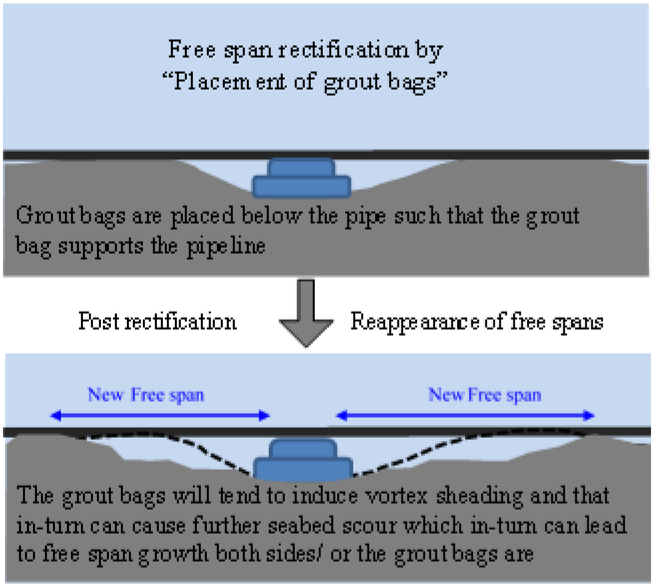

Figure 10 Free span rectification by grout bags leading to further free spans

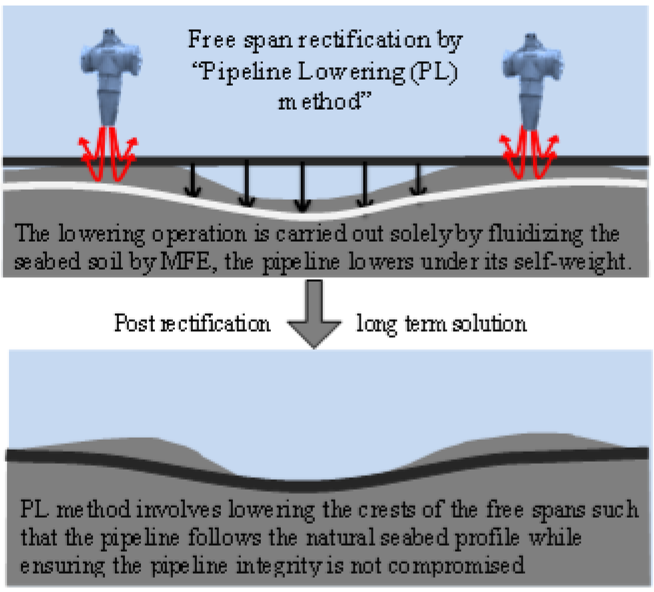

Figure 11 Free span rectification by Pipeline Lowering method

6. CONCLUSION

Free span rectification is a major cost to operators in maintaining offshore pipelines. This paper presents insight into free span rectification by an alternative method, known as PL method, compared to the traditional ground bag placement method. 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 as pipeline crossing and pipeline lowering for on-bottom stability issues. Grout bags may be suitable for free span rectifications where the free spans are initiated due to storm events or in areas where the seabed is stiff soils or bed rock. The fundamental cause for onset of free spans should be investigated fully and the rectification solution should be based on the results of such an assessment. Figure 8 presents the recommend practice for free span rectification.

The Pipeline lowering (PL) method is well suited in non-cohesive soils (sands) and in cases where the onset of free spans is due to natural wave and currents. The effectiveness of free span rectification by PL method in clay seabed soils, however, reduces with the increase of clay shear strength and PL method is expected to be ineffective in cemented soil. In general, the PL method in clay seabed may be less effective if the seabed soil shear strength is above 25kPa.

6. REFERENCES

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