Conventional Subsea Pipeline Installation Methodologies,

Potential Failure Modes and Considerations for Installation Engineering

1. Introduction

With the advancement of technology in the offshore construction, pipeline installation methodologies have developed following the needs of the market. Non-conventional methods of pipeline installation have been done in numerous variations such as surface tow, below-surface tow, bottom tow, bottom pull, push pull method, control-depth tow, horizontal directional drilling and many more. However, the conventional techniques are largely still dominated by the results-proven methods such as S-Lay, J-Lay and Reel Lay methods.

This article focuses on the discussion of conventional methods, highlighting the potential failure modes and considerations needed to engineer the solutions as applicable.

In their explicit terms, S-Lay and J-Lay relate to the shape of the pipe curvature during the laying process as shown in Figure 1 below. Reel lay, on the other hand, specifies the laying process where the pipe is spooled out from a reel drum, straightened then laid over a ramp, as shown in the same figure.

Each of these conventional methods poses their own advantages and challenges from their inherent potential failures, but they can be negated or overcome when taken into considerations during the installation engineering.

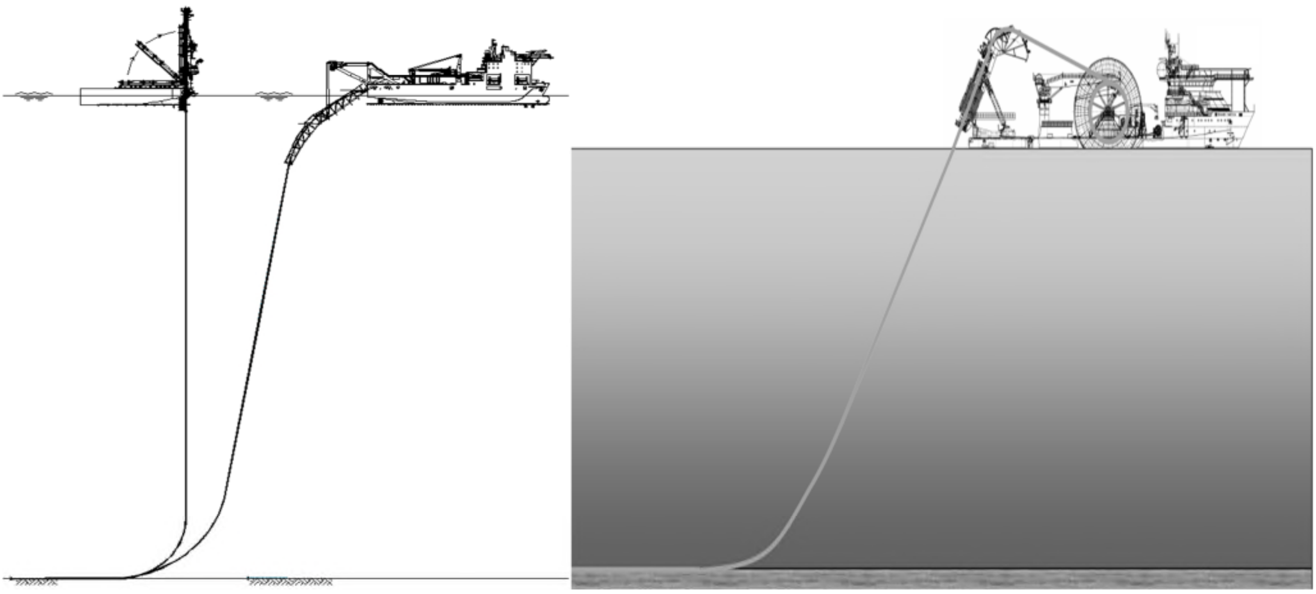

Figure 1 J-Lay, S-Lay and Reel-Lay Pipeline Installation Methods

2. S-Lay

2.1 S-lay Overview

Based on the tensioner capacities and categories of station keeping ie. Anchor mooring or dynamic positioning (DP) capabilities there are numerous S-Lay pipelay vessels in the world – two of which are shown below – *EMAS AMC's* 405 Tonnes DP Pipelay Vessel *Lewek Centurion* and *Allseas'* 1050 Tonnes DP Pipelay Vessel *Solitaire*.

Figure 2 EMAS AMC's Lewek Centurion

Figure 3 Allseas' Solitaire

In S-lay installation method, pipe joints are assembled (by welding or mechanical connectors) in a continuous process, with near-horizontal assembly carried out over several stations along the firing line until the pipeline reaches the end of the pipelay vessel or stinger (ref. Figure 4). Typically this method is used for pipe diameter from 4 to 60 inch.

Pipeline S-Lay profile and stress/ strain are defined by the applied tension as well as vessel and stinger configuration (ref. Figure 5)

Figure 4 S-Lay Typical Process (Clockwise from Top Left): (a) Welding; (b) Welding Inspection/ Test; (c) Going through Tensioner; (d) Pipeline Going through Stinger before Lift-Off

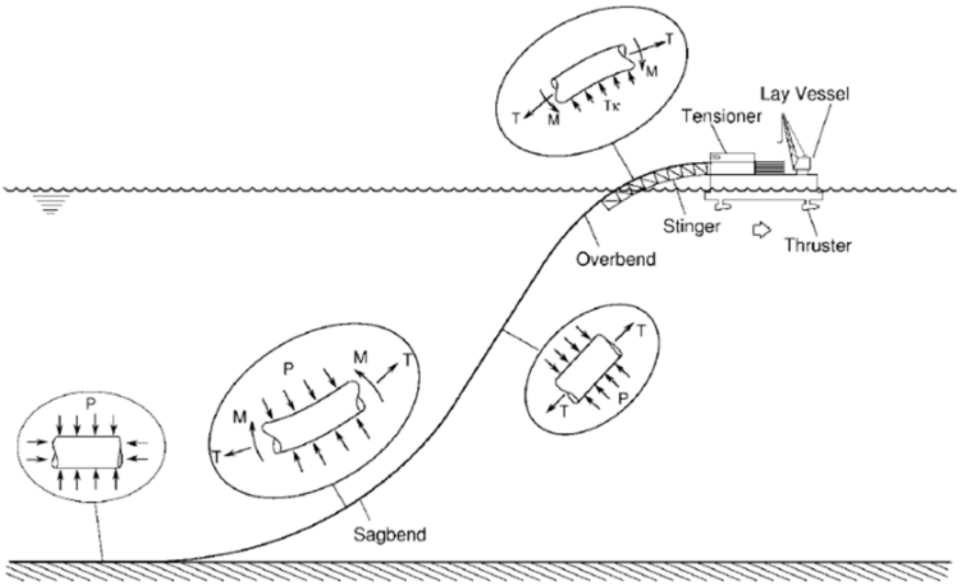

Figure 5 S-Lay: Forces in the Pipeline

2.2 Potential Failure Modes during Installation

During the pipelaying process the pipeline is subjected to large local forces when the suspended pipe weight is held the pipelay vessel tensioners and the roller supports (ref. Figure 5). Primary high stress locations can be identified below:

- Overbend section – in the vessel stern section as well as stinger, where pipeline bends following the vessel roller and stinger curvature up to the inflection point. At this section the pipeline is subjected to point-load forces which may lead to local deformation (dent) and global deformation due to the incorrect roller support settings. At the stinger section – particularly the last stinger roller where the pipeline lifts off, the pipeline is subjected to dynamic excitation resulting from environmental forces and vessel motion response.
- Sagbend section – pipeline section primarily controlled by the vessel tensioner at the bottom section up to the touch down point on the seabed. If necessary, pipe weight can be controlled by use of buoyancy modules.

2.3 Considerations in Engineering

The pipelay S-curvature is defined in the installation engineering phase by designing a suitable installation configuration ensuring safe and practical installation. As a minimum the engineering involved aims to define the following:

Vessel and Equipment Configuration – involves definition of vessel and stinger geometry and required lay tension to maintain a pipe behavior according to the applicable Client or industry standards. Typically the outcome specifies:

- Required tension and barge setting within the vessel workability;
- Expected roller loads for a particular case and vertical clearance from the supports, if any;
- S-Lay suspended span length (catenary) and the distance of touch down point to the vessel. This is particularly important to enable profile check during lay ie. via ROV monitoring or beacon, if applicable;

Definition of maximum allowable sea state – involves definition of operational window based on each vessel's specific motion response and the environmental condition at the project location. With an optimal installation analysis, vessel workability can be expanded hence reducing the vessel offshore downtime. Typically the outcome specifies:

- Maximum recommended environmental sea states for pipeline installation, allowing Contractor to strategize the abandonment and recovery procedure when needed;
- Maximum recommended pipeline standby or slow lay rate – this is applicable in situations where vessel encounters downtime due to mechanical breakdown, or other reasons where the pipelay needs to be suspended;

With detailed analysis, pipeline failures, particularly at the most probably sections – overbend or sagbend – can be avoided. Pipeline installation will be carried out only at the favorable weather conditions avoiding excessive vessel motions by close monitoring of the weather forecast data. In the event of storm, the pipeline abandonment can be planned according to the designed sequence avoiding pipeline overstress/ strain.

2.4 Deepwater S-Lay – Challenges in Installation

With the current development in deeper waters, the challenges which come with the pipeline installation have evolved. These include, but not limited to:

- Longer catenary leading to increase in the pipe tension required;

- Higher bending moment and strain;
- More stringent line pipe requirements owing to higher hydrostatic (collapse) pressure in deeper waters ie. preference of seamless line pipe manufacturing which has lower fabrication tolerance, pipe manufacturing supplementary requirement, etc;
- Requirement of buckle arrestor design;
- Installation criteria specifically for deep water pipelines owing to the challenges in the event of pipelay failures in deep water conditions ie. emergency flooded condition, tension variations, pipeline rotation, and so on.

On a higher level of ultra-deep pipeline installation, engineering initiatives have also been investigated enabling pipeline construction in such condition ie. reduction (or removal, where possible) of conservatisms; as well as consideration of the increased allowable strain level in the overbend. For instance, *DNV OS F101* recommends the simplified overbend criteria at 0.25% strain for an X65-grade pipeline. This recommendation has the embedded factors which can be re-explored – some studies justify the use of less conservative criteria such that it is possible to increase the strain level in the overbend region to 0.35% (or even 0.5% with some considerations in place) without detrimental effects to the pipeline serviceability. It is also not uncommon to re-investigate the optimization of stinger design, specifically in its geometry and length, achievable radius through roller support settings for load distribution.

3. J-Lay

3.1. J-lay Overview

Similar to S-Lay pipelay vessels, there are numerous pipelay vessels equipped with J-Lay tower capable of pipeline installation at deep to ultra-deep waters. With the nature of the pipelay vessel typically J-Lay pipelay have the Dynamic Positioning (DP) station-keeping capability. Out of many vessels in the market, Figure 6 and Figure 7 are some of the prominent ones – *Saipem's* 750 Tonnes Semisubmersible *Saipem 7000* and *Subsea 7's* 937 Tonnes *Seven Seas*.

Figure 6 Saipem's S 7000

Figure 7 Subsea 7's Seven Seas

J-Lay installation technique has been proven over several deepwater projects. During laying, the pipe joints are pre-welded into 2 (double), 3 (triple), 4 (quad) or six-pipe joints depending on each vessel's capability, in near-vertical ramp with fewer work stations (typically welding, NDT and field joint coating) along the J-tower. This method has been used for pipe diameter from 4 inch up to 32 inch.

Figure 8 J-Lay Typical Process (Clockwise from Top Left): (a) Upending of Pre-Assembled Quad Joints (b) Line-Up in the J-Lay Tower and Clamped; (c) Welding (and NDT) in Vertical Position; (d) Preparation of Next Proceeding String; (e) Snapshot of Travelling Clamp; (f) Going through Hang-Off Clamp.

J-lay pipelay sequence although appears more complicated with the complex handling system in the tower - lifting pipe stalks from horizontal position into J-lay configuration for welding connection and NDT, followed by field joint coating (ref. Figure 8); offers the following advantages:

- Pipeline is laid in more natural configuration ie. less bending;
- Pipe stresses are well within the elastic limit;
- Less requirement of tension to hold the pipeline resulting in reduced bottom tension. The decrease of bottom tension helps the reduction of free spans;
- Less susceptible to weather conditions;
- Vessel is free to choose an optimal heading to minimize environmental forces;
- Technique is suitable for pipeline tied in to other structure ie. in-line structure, PLET, etc.

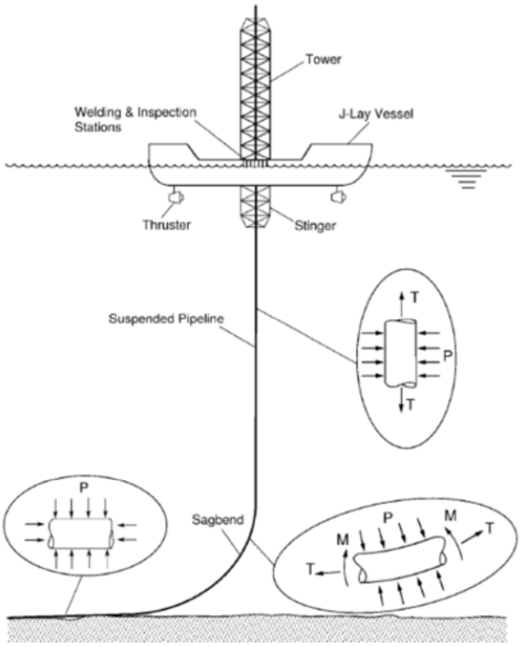

Figure 9 J-Lay: Forces in the Pipeline

3.2. Potential Failure Modes during Installation

Comparing to S-Lay method of installation, J-Lay exposes less potential failure – in such configuration there is no overbend section hence all potential failures related to overbend are eliminated.

During the pipelaying process the primary high stress location is constrained to the sagbend section (ref. Figure 9) which is primarily controlled by the vessel tensioner or hang-off clamp, depending on the J-Lay tower design. Note that, as the water depth increases, the designed wall thickness increases to resist the hydrostatic (collapse) pressure.

3.3. Considerations in Engineering

The J-lay profile is defined in the installation engineering phase by the selection of right equipment ie. Planning of work stations, tension or clamp settings, J-tower angle, ensuring safe and practical installation. As a minimum the engineering involved aims to define the following:

Vessel and Equipment Configuration – involves definition of J-lay tower angle and required lay tension or clamp settings to maintain a pipe behavior according to the applicable Client or industry standards. Typically the outcome specifies:

- Required tension or clamp settings within the vessel workability;

- The required J-Lay Tower angle;
- Roller layouts at the J-Lay Tower (Ref. Figure 10)– distance between rollers and the gap settings allowing a pre-defined maximum lateral movement;
- Expected clamp loads for a particular case;
- J-Lay suspended span length (catenary) and the distance of touch down point to the vessel;
- Vessel offset sensitivity – in deepwater conditions, an additional analysis is typically required to define an allowable vessel offset (excursion) to verify the effect of unsynchronized vessel movement and the line payout.

Definition of maximum allowable sea state – In J-lay installation analysis, the definition of operational window is similar to S-lay analysis as described in Section 2.3, however, where applicable, the definition of maximum sea states can be associated with the allowable heave amplitude or velocity of the J-Lay Tower.

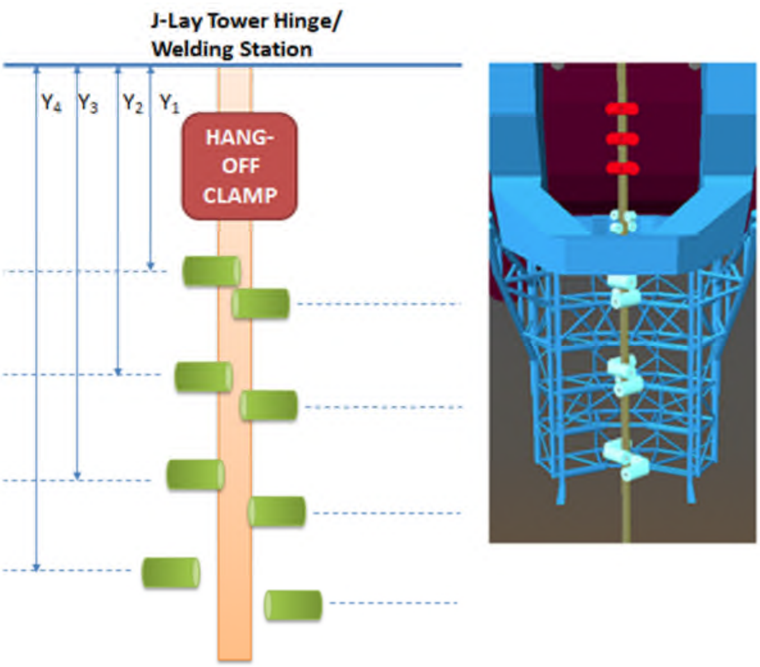

Figure 10 J-Lay Tower – Roller layout

4. Reel-Lay

4.1. Reel-Lay Overview

Reel Lay pipelay vessels are equipped with giant reel (s) or carousel(s) mounted on a vessel, typically for flexible or rigid pipeline installation of smaller diameter lines up to approximately 16 inch line. Figure 11 is *EMAS AMC's Lewek Express* 3,000 Te pipe capacity while Figure 12 shows the latest flagship vessel – *EMAS AMC's Lewek Constellation* having 4,800 Te of reeled rigid pipes.

Reel-Lay pipeline installation techniques go hand in hand with the spool base facility (Ref. Figure 13 and Figure 14) where the pipe joints are pre-assembled (welded, tested, field joint-coated) in the onshore facility before they are spooled onto the giant reel.

Figure 11 EMAS AMC's Lewek Express

Figure 12 EMAS AMC's Flagship Vessel Lewek Constellation

Figure 13 EMAS AMC's Spool base, Ingleside, United States

Figure 14 EMAS AMC’s Spool base, Halsvik, Norway (Artist’s Impression)

Reel Lay installation technique moves the majority of the offshore activities ie. welding, tests and inspections to onshore. The pipe joints are assembled in a well-controlled area with minimum or no motions or disruptions, then spooled onto the reels on the pipelay vessel to be deployed offshore. Where required by the Project, the reel vessel transits back to the spool base facility to load up more pipe reels before returning to the site to complete the pipeline installation. With this method the offshore labor costs and installation time are greatly reduced.

Figure 15 Reel Lay Typical Process (Clockwise from Top Left): (a) Welding and NDT within Spool base; (b &c) Reeling onto Reel Vessel; (d) Packing onto carousel.

Reel Lay installation method offers the following benefits:

- Welding and fabrication carried out onshore within the spool base facility;
- Greater assurance on weld quality as they are tested onshore;
- Move offshore critical paths to onshore resulting in faster lay rate compared to S-Lay or J-Lay installation methods;
- More economical installation method for pipeline up to 16inch, limited by pipe material properties and reel size;

4.2. Potential Failure Modes during Installation

The process of reeling (at spool base), unreeling and straightening (offshore) of pipeline (ref. Figure 16) exposes the pipeline to the following phenomena. Detailed studies and considerations need to be incorporated since the design stage to take such phenomena into account.

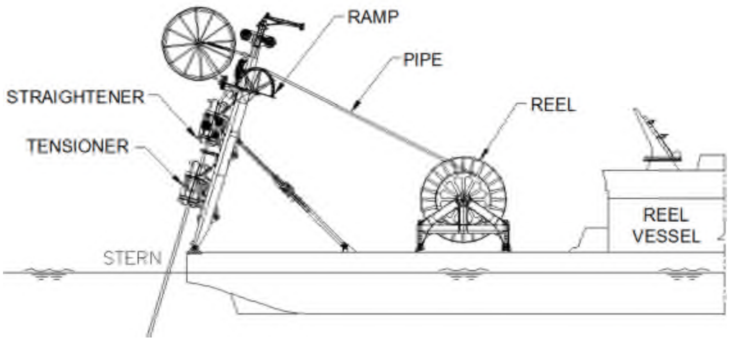

Figure 16 Reel Lay Process during Pipelay

- When the pipeline is spooled (reeled) it undergoes an initial plastic bending, subsequently at offshore during the unspooling process the pipeline undergoes reverse plastic bending. At the end of the system prior to tensioner and lift-off the pipeline is subjected to plastic deformation when it passes through the tensioner. This process exposes the pipeline to permanent plastic deformation, which is an irreversible phenomenon which modifies the pipe mechanical and fatigue properties, typically identified by the large cumulative plastic strains.
- For mechanically lined pipes it is reported that these plastic strains may trigger wrinkle formation in the pipe – this has called for extensive studies by researchers in the industry;
- The process of reeling and unreeling increases pipe ovality (ref. Figure 17 – ovality is calculated by the difference of maximum and minimum pipe diameter), which affects the pipeline hydrostatic collapse capacity;
- Another failure mode which may appear during the reeling process is crushing of pipes which have been laid beneath. This is ensured by maintaining sufficient back tension required for packing.

4.3. Considerations in Engineering

The process of reel lay calls for the needs to perform the installation engineering starting at the design phase by ensuring that the pipeline is designed and manufactured to sustain the anticipated loads during installation. As a minimum the engineering involved aims to define the following:

Pipe Design and Manufacture – involves the studies of pipeline properties suitable for reel lay process. Typically this includes, but not limited to:

- Definition of minimum reel-able wall thickness

- More stringent pipe manufacturing specification ie. specification of low fabrication tolerance (control over D/t ratio); low variation in yield stress, low yield to ultimate strength ratio; specification of overmatch of weld properties to avoid excessive strain;
- Definition of maximum allowable cumulative plastic strain.

The above parameters serve as the basis of criteria that Installation Contractor needs to abide, by estimating the cumulative strain build-up and the resultant ovality during each process in the event that it may lead to local buckling or pipe crushing.

Vessel and Equipment Configuration – involves the following definition during the reel process ensuring safe and reliable process which does not compromise pipeline integrity:

- Required back tension during reeling (at yard). This is essential to keep the back tension adequate for packing, but not high as to crush the pipe layers beneath;
- Reels must be held under tension during the reeling-on, transport to site and during reel-off process. The amount of stored energy in larger reels can be massive and failure of a section that maintains this tension can result in uncontrolled release of this energy. When this occurs, the pipe will uncontrollably spool itself off the wheel;
- Definition of straightener capacity to suit pipeline plastic moment;
- Definition of ramp angle to avoid excessive stress in the pipeline and to avoid anchor uplift;
- Other parameters are outcome similar to the previous installation analyses – required tension during lay, suspended span length (catenary) and distance of touch down point with respect to the vessel to enable profile check during lay.

Definition of maximum allowable sea state – In reel lay installation analysis, the definition of operational window is similar to S-lay analysis as described in Section 2.3, however, where applicable, the definition of maximum sea states can be associated with the allowable roll and pitch amplitude of the vessel;

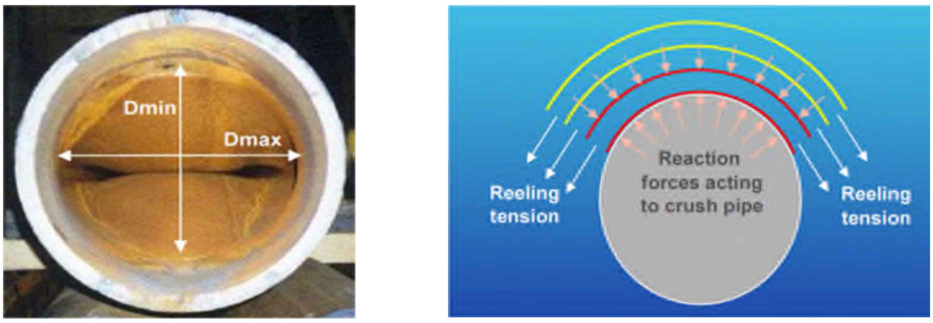

Figure 17 (a) Pipe Ovality; (b) Forces on Pipeline during Reeling Process

2.5 Reel Lay Operation – The Innovative Approach by EMAS AMC's Lewek Constellation

The typical reel lay operations described in this article require reel vessels to transit to the spool base to reel the pipes before going to site, and where quantity of pipes on deck are limited by reel or vessel capacity, the spooling operations become the critical path.

EMAS AMC's Lewek Constellation introduces the innovative approach to have continuous lay operation. While other reel vessels are required to return to the spool base to reload, *Lewek Constellation* utilizes portable reel concept which allows her to stay in the project location while a separate spool barge returns to offload empty reels and reload new pipe reels. This method increases the efficiency of the vessel during the installation campaign by removing the reeling off the critical path and minimizing lay vessel transit time.

For illustration, conventional reel vessel reels pipe at typical 2m per minute to reel which is built on the vessel itself. As such pipe spooling operation can be carried out when the vessel is located at the spool base, making the operation in the critical path. *Lewek Constellation* leads the market by pioneering the new scheme:

- Reel lay vessel needs to have the capability to offload empty reels and reload new reels while maintaining position in the work location. Lewek Constellation is designed with 3000 Te crane capacity which allows her to lift a fully loaded reel in moderate sea conditions offshore;
- Through the use of a dedicated spool barge, pipe spooling can be carried out independently at the spool base while reel lay vessel continues to lay pipes, hence optimizes installation time by removing the delay due to vessel transit time.

Figure 18 Dedicated Reel Barge – Removing Critical Paths for Reel Vessel

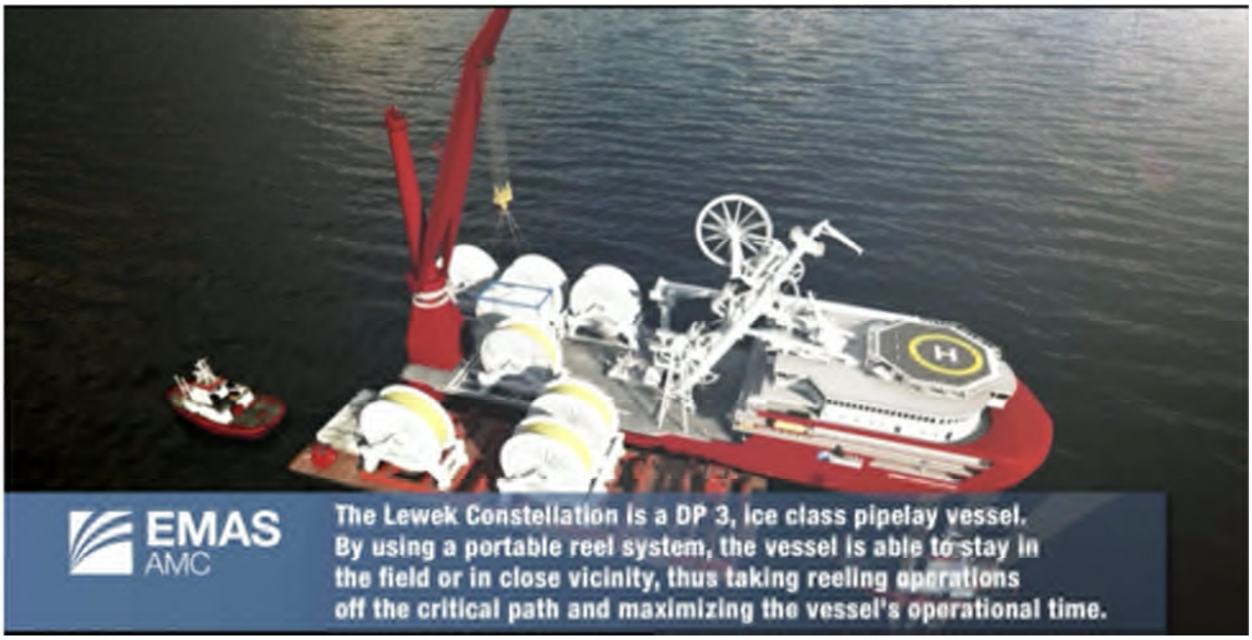

Figure 19 Lewek Constellation and Reel Barge

5. Conclusion

The article describes the conventional pipeline installation methodologies covered in this article, including the potential failure modes and what can be done in the engineering stage for each of methods above. With the benefits and limitations of each method, Contractor investigates each project specifics and recommends suitable installation method for the pipeline.

The article also presents the innovative approach in the reel lay technology by introducing *Lewek Constellation* and the new concepts of portable reels allowing full vessel utilization during the installation time.

Dr. Ng Eng Bin has more than 35 years of experience in the oil and gas industry holding positions in the design, field, project and managerial positions. He specializes in the offshore pipeline design and installation engineering and is presently the Vice President – Engineering (Projects & Operations) of EMAS AMC.

Contact: engbin.ng@emas.com

EMAS AMC is a division of EMAS, a global offshore contractor with a modern and versatile fleet of offshore support and construction vessels, coupled with a 40-year track record of offshore engineering solutions for the entire oilfield cycle. EMAS AMC's growing track record is supported by the first-class engineering capabilities and enabling high-end assets in the ideal position to be the leading global player in the industry. EMAS AMC's broad technical expertise serves the oil and gas needs anywhere in the world with more than 300 experienced engineers in offices in Houston, Texas, Oslo, Norway and Singapore
http://www.emas.com/

EMAS AMC
Together We Deliver

Contact: emas_amc@emas.com