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On the Structural Integrity of S-Lay Method of Pipeline Installation

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Abstract This study presents a design template to analyse and check the structural integrity of subsea pipelines installed by S-Lay method. A typical static configuration of the pipeline in equilibrium with wave, current, drag, etc forces was considered in the structural analyses of the installation method. In the template, two scenarios namely: the laying of a single-pipe and the laying of a pipe-in-pipe, were considered. The template developed which was based on a Microsoft Office Platform also considered the lay barge/vessel specifications, met Ocean data, the pipe parameters, critical parameter, and the pipe-lay equipment specifications. The output results from the template include; catenary parameters, tension in pipe, stresses at subsea level and maximum deflection during installation. Typically, with applied top tensions T_T of 1177.2kN and 1842.4kN on a pipeline of length 36 m, maximum deflections of (0.26m) and (0.17m), respectively were obtained. The results obtained by the user-friendly template developed corroborate those obtained by manual calculation for the relevant deflections, stress and catenary models for the structural integrity of the pipeline for an S-Lay installation.

Keywords: *Single Pipe (SP), Pipe in Pipe (PIP), Subsea stress, Structural integrity*

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1. Introduction

Exploitation of offshore oil and gas wells requires the presence of pipelines along the sea floor for transportation of the products. These flowlines are the subsea pipelines used to connect a subsea wellhead with a manifold or the surface facility. The flowlines may be made of flexible pipe or rigid pipe and they may transport petrochemicals, lift gas, inject water, and chemicals [1]. Subsea flowlines are major components of oil and gas production, and the need to safely install these pipelines is of great concern, hence, the selection of the most appropriate installation method is critical.

Pipe laying systems involve all techniques and methods required to efficiently install pipelines on a seabed to ensure the flow assurance requirements without jeopardizing its structural integrity. Pipeline damage and failure can occur in the process of its laying from vessel to seabed [2].

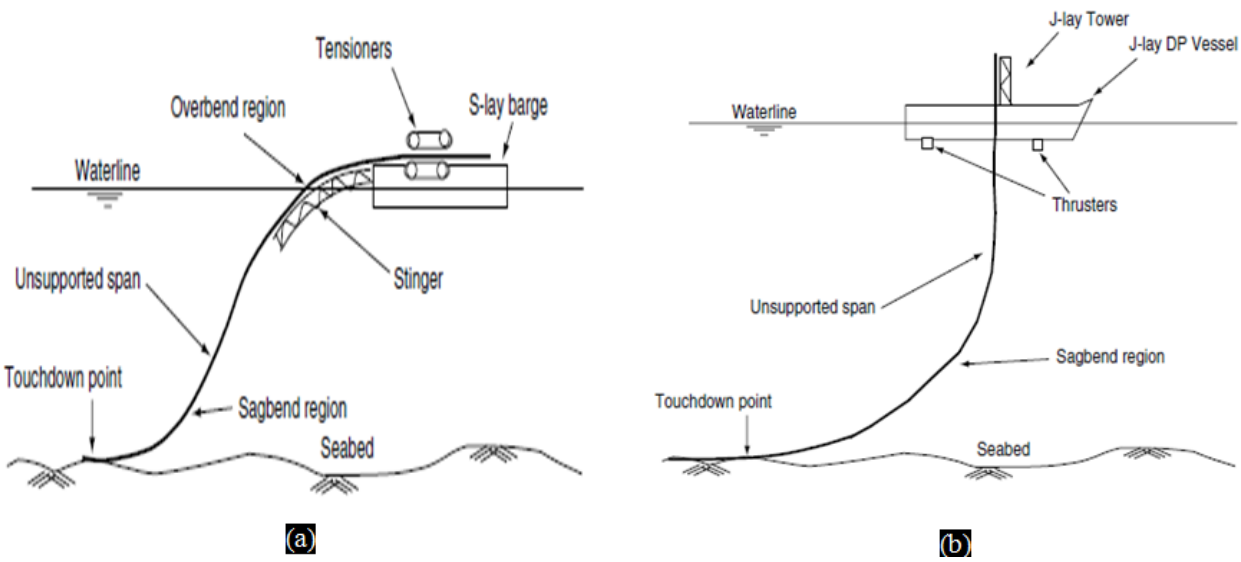

Figure 1. Pipeline Installation by (a) S-Lay and (b) J-Lay Method [3]

When laying pipeline along the floor of deepwaters, the challenge of avoiding pipe-kinking and excessive-bending, while staying within the stress limits of the pipeline is ever present and difficult to overcome. This problem results from the difficulty in lowering very long continuous lengths of pipeline, typically ranging in hundreds of meter (feet), from the surface of the water body to the floor, under a controlled movement. Various systems have been devised to facilitate control of the long lengths of pipe line during the laying thereof in deep bodies of water [4].

Pipeline installation can be safely carried out by; S-lay, J-lay, Reel lay and Tow methods. Each method has its applicability depending on a number of prevailing conditions such as sea depth, pipe size, cost effectiveness, bending and strain occurrence, as well as, their respective installation constraints. Corrosion control techniques envisaged can also influence choice of pipe-lay methods. S-lay and J-lay method are reportedly the most commonly applied method [5].

In S-lay method, single lengths of steel pipes are welded together at their ends, inspected and coated onboard a laybarge (lay-vessel) before laying. The barge gradually moves forward while the welded, inspected and coated pipe stretch prepared above slowly exits the barge stern through the firing line controlled by the stringer at the lower section and pipe tensioners at the upper section. This in-situ fabrication advantage is not readily feasible with other laying methods [6]. Hence, the pipe is eased off the stern, curving downward through the water until it reaches the touchdown point. After touchdown, as more pipes are played out, it assumes an “S-shaped” curve as in Figure 1(a)unlike the J-lay technique in Figure 1(b) [7]. During installation, the pipe system is bent under its weight into a stretched “S-curve”, causing bending stresses in the pipe. For shallow water depth, the pipe is sufficiently stiff and the weight (per unit of length) is sufficiently low, and these stresses remain low enough without need for further precautions [8]. However, laying pipes in deep water with considerable current necessitating a heavy pipe in a way that the bending stresses become so high that the pipe would buckle. To reduce bending stress in the pipe, a stinger is used to support the pipe as it leaves the barge. To avoid buckling of the pipe, a tensioner must be used to provide appropriate tensile load to the pipeline. This method is used for pipeline installations in a range of water depths from shallow to deep [7].

Herdiyanti[5] investigated installation analyses of S-Lay and J-Lay methods for various water depths 800 – 4000m and pipe sizes OD > 24 inch by using SIMLA program. The results showed that the relevant parameters for the S-Lay method included: vessel tension capacity, stinger length, stinger curvature, overbend region strain and bending moment at the sagbend. Unlike the S-Lay, the J-Lay method reduces any horizontal reaction to the laybarge equipment and was proven useful in deeper water applications. This however requires vessels with dynamic positioning capabilities, as anchorages are often unfeasible in this domain due to safety concerns. The tension capacity of the existing vessels is the only factor that limits the layability by the J-Lay method. On the contrary, the S-Lay method is not only limited to the vessel tension capacity but also to strain criteria in the overbend area. The required top tension for the J-Lay method is lower than for the S-Lay method. However S-Lay has higher production rate compared to J-Lay, causing the S-Lay method to be more efficient to install long pipelines. Accordingly, Rigzone[9] reported that S-lay can be performed in water depths up to 6,500 ft (1,091m) and as many as 4 miles (6km) pipeline per day can be installed.

The strain in the overbend region depends on the stinger configuration. The stinger configuration is controlled by the stinger radius and departure angle. Increasing the strain in the overbend region can be achieved by reducing the stinger radius. In the J-Lay method, the requirement to satisfy the strain criteria in the overbend region can be eliminated. However, since the bending moment in the sagbend area is quite higher compared to the S-Lay method; it is necessary to provide sufficient tension to avoid excessive bending that may cause pipelines buckling.

The required top tension for the J-Lay method is lower than for the S-Lay method. The difference in required top tension is higher with increasing water depths and pipeline diameters. However the S-Lay method has a higher production rate compared to J-Lay, causing the S-Lay method to be more efficient to install long pipelines.

Using higher steel grade could increase the possibility of pipeline installation in deeper water both for S-Lay and J-Lay method. The reason is because the required wall thickness is decreased as increasing the steel grades. Besides, the maximum permissible strain in the overbend region is increased as the steel grade increases.

The structural analysis of an offshore pipeline under construction and installation deals with the computation of deformations, internal forces, and stresses as a result of external loads and the structural properties of the pipe. A short pipe section, like a single pipe joint appears to behave much like a rigid body, whereas a long pipe of several hundred meters is very elastic and behaves almost like a string. Hence, the pipe string behavior is highly dependent on the water depth. For the structural analysis, it is considered as a continuous beam, a tension member, a compression member, a pressure pipe, an externally loaded conduit, and a suppression element. The static and dynamic loads due to the construction methods and the environment are numerous and varied [10].

Analysis of the frictional forces between the pipeline coating and the tensioner pads is required to ensure adequate holding forces for all conditions. This may require load testing of pipeline joints in the tensioner prior to laying. [11]. The pipe is modeled by use of Abaqus FEA software as a geometrically non-linear elastic beam supported by a vessel and its stinger in the overbend region and by the seabed in the sagbend region. This method for tensioner modeling based on friction contacts between the pipe and the tensioner. Contact interactions between the pipe and rollers, as well as between the pipe and the seabed, are also considered. The proposed frictional model of a tensioner gives some advantages in comparison to the commonly used models.

Katsikogiannis [12] set-out to accurately quantify pipeline rotation during installation of pipelines with inline structures by S-lay method. A sequential model is built based on mechanical principles in order to solve the pipelay and rotation problem simultaneously and identify the effect of the plastic strains and residual curvature on

the rotation phenomenon. The model includes also mitigation measures (buoyancy modules) and their effect in the reduction of total rotation as well as the effect of soil friction. The validity of the pipe-laying model is verified by means of a comparison with results obtained from the commercial finite element software OFFPIPE. Rotation results are verified by results observed in actual projects.

Some pre-installation analyses are required before site mobilization. Installation analyses are need to cover the expected range of water depths, environmental conditions, lay vessel draughts, trims, ramp/roller/angle settings, and upper and lower tensioner ranges (corresponding to the upper and lower tensioner control settings), and any variations in pipe stiffness and weight [13]. This study considered SP and PIP pipelines with a view to determine the tensions at the critical points, subsea stresses and maximum deflection of the pipeline during installation in other to maintain its structural integrity.

2. Materials and Methods

It is obvious that the pipe lay tension is the most important and significant parameters needed to be controlled during pipe laying operations. In the template design, the research-design approach is herein focused on the S-lay method for pipeline installation with specific emphasis on installation tensions, subsea stresses, and maximum deflection generated during installation. In other to simplify the analytical modelling process for installation, the process has been divided into Input, Processing and Output sections.

2.1. Design Input Data

The case study for this study is a steel pipeline with outer diameter OD – 762mm (30in), wall thickness t_w – 14.2mm (0.559in), Inner diameter ID - 733.46 mm (28.88in), specified minimum yield strength SMYS σ_y – 448MPa, steel density – 7850kg/m^3, Youngs modulus of elasticity E – 207GPa.

a) Single Pipe (SP) parameters utilised include: Fusion Bonded Epoxy (FBE) coating thickness - 0.5 mm, Fusion Bonded Epoxy (FBE) density – 1300kg/m^3, Concrete coating thickness - 0.5mm, concrete density – 2250kg/m^3.

b) Pipe-in-pipe (PIP) input parameters used include: Fusion Bonded Epoxy (FBE) coating thickness - 0.5 mm, Fusion Bonded Epoxy (FBE) density – 1300kg/m^3, Concrete coating thickness - 0.5 mm, concrete density – 2250kg/m^3, density of Izoflex – 250 kg/m^3, Coating density – 900kg/m^3, Inner pipe thickness - 19.1mm, Outer diameter of Izoflex - 355.9 mm, Outer diameter of coating – 403mm, Air gap diameter - 377.4mm, Outer pipe thickness - 10.3mm, Coating thickness – 25mm, thickness of Izoflex – 16mm.

c) Lay-Barge and Pipe laying equipment parameters utilised include: Length of inclined firing line – 50 m, Ramp angle - 3°, Stringer radius - 240 m, Overbend radius – 300m, Stringer chord length (from marriage point, MP to lift-off, LO) – 6m, Roller friction - 0.1, Pipe tensioners capacity (60ton x 2) 120ton (≈12x10^{4}N).

d) Critical parameter parameters include: Marriage point angle - 4°, Water level angle - 7.9^o, Lift off angle - 8.7^o, Lift-off below water level - 0.5m.

e) MetOcean Parameters used as input parameters include: Installation water depth – 6m, Sea-water Density – 1025kg/m^3.

2.2. Processing

Input data is processed to determine the generic tension, subsea stresses, and maximum deflection point during installation and operation, using well established analytical models. Other parameters necessary for tensions and subsea stresses processing include Pipe cross-sectional area, weight of pipe in air and submerged, second moment area of steel pipe.

2.2.1. Catenary Parameters

Catenary, being the shape assumed by a perfectly inextensible chain of uniform density hanging between two supports, was popularized by Thomas Jefferson [14] in his December 23, 1788 correspondence from Paris to Thomas Paine regarding his choice of bridge for his new country. In this study the catenary equations(Eq. 1-6) were used to compute tensions and subsea stresses during installation. Figure 2 shows the free-body diagram of the catenary touchdown-end illustrating resultant forces acting on the pipeline to determine loads for horizontal tension T_H;

Residual tension in line, T_H was given by Eq.(1) as:

$$T_H = T_{LO} - W_{sub} \times (D - h_{LO}). \quad (1)$$

From the lay barge this horizontal tension T_H is given by Eq.(2):

$$T_H = T_{LO} \times \cos(\cos(\theta_{LO}). \quad (2)$$

Equating and rearranging for the tension at lift-off, T_{LO} therefore;

$$T_{LO} = \frac{W_{sub} \times (D - h_{LO})}{1 - \cos(\theta_{LO})}. \quad (3)$$

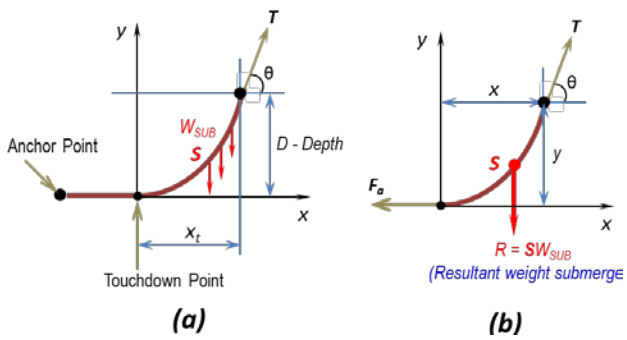

Figure 2. Catenary Touchdown-end(a) schematic and (b) Free Body diagram

(a) Length of Catenary

- Radius of curvature at touchdown (R_{TD}) becomes;

$$R_{TD} = \frac{T_H}{W_{sub}}. \quad (4)$$

- Span length L_s:

$$L_S = \frac{T_H}{W_{sub}} \tan(\theta_{LO}). \quad (5)$$

- Horizontal distance from touchdown to lift-off, L_{TD}:

$$L_{TD} = \frac{T_H}{W_{sub}} \sinh^{-1}(\tan(\theta_{LO})). \quad (6)$$

(b) Tensions at Critical Points along Pipe

- Tension at water level, T_{WL}:

$$T_{WL} = \frac{2 \times T_1 + W \times R \begin{bmatrix} \mu(\sin\phi_1) - (\sin\phi_2) \\ -\cos(\phi_1) + \cos(\phi_2) \end{bmatrix}}{1 - \mu \sin((\phi_1 - \phi_2)/2)} - T_1. \quad (7)$$

- Tension in pipe at marriage point; point 1 is now T_{WL} and point 2 is T_{MP}, W= W_{air} and tighter radius (R_S or R_B):

$$T_{MP} = \frac{2 \times T_{WL} + W \times R \begin{bmatrix} \mu(\sin\phi_1) - (\sin\phi_2) \\ -\cos(\phi_1) + \cos(\phi_2) \end{bmatrix}}{1 - \mu \sin((\phi_1 - \phi_2)/2)} - T_{WL}. \quad (8)$$

- Tension in pipe at pressure tensioner PT point; point 1 is now MP and point 2 is PT, W= W_{air} and R_B:

$$T_{Pt} = \frac{2 \times T_{MP} + W \times R \begin{bmatrix} \mu(\sin\phi_1) - (\sin\phi_2) \\ -\cos(\phi_1) + \cos(\phi_2) \end{bmatrix}}{1 - \mu \sin((\phi_1 - \phi_2)/2)} - T_{MP}. \quad (9)$$

- Tension in pipe at the end of firing line, T_{FL}:

$$T_{FL} = \frac{L_{FL} \times W_{air}}{Sin(\theta_{PT}) + \mu_{roller} \times \cos(\theta_{PT})}. \quad (10)$$

2.2.3. Subsea Pipe Stresses

At the touchdown point the following stresses are present:

- Hoop stress:

$$\sigma_h = -\frac{(\rho_{sea} \times D \times g) \times OD}{2 \times W \times T_{FL}}. \quad (11)$$

- End cap stress (uses OD of concrete) (σ_{ec}):

$$\sigma_{ec} = \frac{(\rho_{sea} \times D \times g) \times [OD + 2(t_{fbe} + t_{conc})]}{4 \times OD \times W \times T_{FL}}. \quad (12)$$

- Bending stress:

$$\sigma_b = \pm \frac{E_s \times OD}{2 \times R_{TD}}. \quad (13)$$

- Axial force at touchdown F_a(x,y) = (0,0);

$$T - W(D - y) - [\rho_{sea} \times g(D - y) - \pi \frac{OD}{4}]. \quad (14)$$

- Net longitudinal stress σ_1:

$$\sigma_1 = \frac{F_a}{A_s} \pm \sigma_b + \sigma_{ec}. \quad (15)$$

- Equivalent stress σ_{eq}: To obtain the equivalent stress on the pipeline Von Mises Equivalent Stress criterion (Eq. 16) was employed;

$$\sigma_{eq} = \sqrt{(\sigma_1^2 + \sigma_h^2 + \sigma_1 \sigma_h)} \quad (16)$$

- Stress ratio:

$$SU = \frac{\sigma_{eq}}{\sigma_y}. \quad (17)$$

2.3. Output Data for Pipe

Output data would include catenary parameter, length of the catenary, the tension in pipe (water level, lift-off point, marriage point, firing line) and the subsea stresses (hoop, axial force at touchdown, net longitudinal stress, bending and end cap force). For the PIP pipe system the weight in air and water, areas (inner and outer pipe, inner coating, air gap) and second moment of area of steel pipe were obtained. Allowable applied tension is estimated from the weight of the tensioner on the lay barge to determine the feasibility of installation.

A template (Figure 3) [15] based on Microsoft Excel platform was developed to facilitate the simulation of the study in which the designer is only required to input the design specifications stated in section 2.1. These are processed using the formulations in section 2.2 to give the output parameters specified above - section 2.3.

2.3.1. Static Analysis for Deflection Curve

The governing equation for a vertically tensioned pipeline with the assumption of weight not defined due to the applied tension at the top. Using the Bernoulli-Euler (Classical) beam Theory [16]:

$$EI \frac{d^4u}{dy^4} - T(y) \frac{d^2u}{dy^2} - W_{SUB} \frac{du}{dy} = f(y). \quad (18)$$

For tensioned pipe in water, the governing equation becomes (weight is negligible):

$$EI \frac{d^4u}{dy^4} - T(y) \frac{d^2u}{dy^2} = f(y) \quad (19)$$

where:

f(y) the Morrison Equation for the drag force on the pipeline is:

$$f(y) = \frac{1}{2} \times \rho_{sea} \times C_d \times OD \times V^2. \quad (20)$$

2.3.2. Assumptions

Drag coefficient, C_d = 1.2 (variation of C_d with Reynolds number Re, drag coefficient considered in the subcritical regime for smooth pipes).

Velocity; V = 1.0 m/s

$$EI \frac{d^4u}{dy^4} - T(y) \frac{d^2u}{dy^2} = f(y) = \frac{1}{2} \rho C_d \times OD \times V^2. \quad (21)$$

The non-homogeneous differential equation (21) for the deflection u can be solved to obtain the complementary solution and particular solution.

$$u = u(y) complementary + u(y) particular$$

$$u = A_1 + A_2 y + A_3 e^{\sqrt{\frac{T}{EI}}y} + A_4 e^{-\sqrt{\frac{T}{EI}}y} - \frac{f}{2T} y^2. \quad (22)$$

The boundary conditions include:

$$y = 0; u = 0, \frac{d^2u}{dy^2} = 0$$

$$y = L; u = 0, \frac{d^2u}{dy^2} = 0.$$

The result after the application of the boundary conditions is the following equations:

$$u = A_1 + A_3 + A_4 = 0. \quad (23)$$

Equation for deflection:

$$u = A_1 + A_2 L + A_3 e^{\sqrt{\frac{T}{EI}}L} + A_4 e^{-\sqrt{\frac{T}{EI}}L} - \frac{f}{2T} L^2 \quad (24)$$

Let

$$z = \sqrt{\frac{T}{EI}} \quad (25)$$

$$A_1 = -\frac{f}{Tz^2} \quad (26)$$

$$A_2 = \frac{fL}{2T} \quad (27)$$

$$A_3 = \frac{\frac{f}{Tz^2}\left(e^{-zl} - 1\right)}{\left(e^{-zl} - e^{zl}\right)} \quad (28)$$

$$A_4 = \frac{\frac{f}{Tz^2}\left(e^{zl} - 1\right)}{\left(e^{zl} - e^{-zl}\right)}. \quad (29)$$

3. Results and Discussions

3.1. Catenary Parameter

Catenary output parameters obtained from the developed Template (Figure 3) [15] for both SP and PIP include: Horizontal tension T_H - 1858.74kN (SP), Horizontal tension T_H - 1035.25kN (PIP), Total length of submerged pipe - 72.3m (both SP and PIP), Horizontal distance from touchdown to lift off L_{TD} - 72.02m (both SP and PIP), Radius of curvature at touchdown R_{TD} - 472.51m (both SP and PIP).

S-LAY METHOD OF INSTALLATION TEMPLATE					INPUT	OUTPUT	
The S-lay process utilises a horizontal firing line. To continuously lower the pipeline to the seabed the pipeline is laid under tension and adopts the shape of a shallow 'S' curve. To predict the stresses in the lay curve the pipeline can be broken into three sections. The overbend is the upper section of the lay curve where the pipe is laid out from the lay barge/vessel. The free span is found between the overbend and sagbend. The sagbend is the bend of the pipeline at the bottom of the catenary.							
INPUT				**OUTPUT**			
CRITICAL PARAMETERS		**INPUT VALUE**	**UNIT**	**PIPE PROPERTIES**		**OUTPUT VALUE**	**UNIT**
MARRIAGE POINT	θMP	4	deg	CALCULATED PIPE AREA	AS	33525.47651	mm^2
WATER LEVEL	θWL	7.9	deg	SECOND MOMENT OF AREA OF STEEL PIPE	Is	2343865741	mm^4
LIFT OFF	θLO	8.7	deg	WEIGHT OF COATED PIPE IN AIR	Wair	4.96	kN/m
LIFT-OFF BELOW WATER LEVEL	hLO	0.5	m	WEIGHT OF COATED PIPE IN WATER	Wsub	3.933784311	kN/m
				AREA OF INNER PIPE		-1146.23302	mm^2
METOCEAN DATA			**UNIT**	AREA OF IZOFLEX		17087.4528	mm^2
INSTALLATION WATER DEPTH	d	6	m	AREA OF AIR GAP		12384.15373	mm^2
ROW WATER AVERAGE WIDTH				AREA OF COATING		118767.6	mm^2
SEA DENSITY	ρsea	1025	kg/m^3	HYDRODYNAMIC AREA		138534.877	mm^2
PIPE LAY EQUIPMENT			**UNIT**	WEIGHT OF PIPE SUBMERGED		2.190980269	kN/m
PIPE TENSIONERS		120	ton				
BARGE/VESSEL LAYOUT - INPUT DATA			**UNIT**				
LENGTH ON INCLIND FIRING LINE	LFL	50	m	**CATENARY PARAMETERS**			**UNIT**
RAMP ANGLE	θPT	3	deg	HORIZONTAL TENSION	H	1035.253009	kN
STRINGER RADIUS	RS	240	m	TENSION AT LIFT-OFF	TLO	1047.303401	kN
OVERBEND RADIUS	RB	300	m				
STRINGER CHORD LENGTH (from MP to LO)	CH	6	m				
ROLLER FRICTION	μ	0.1					
PIPE IN PIPE WEIGHT PARAMETERS			**UNIT**	**LENGTH OF CATENARY**			**UNIT**

Figure 3. Pipe-in-pipe (PIP) installation analyses template

3.2. Tension at Pipeline Critical points

After imputing input data values from section 2.1 into the Excel Template (Figure 3) [15] the results below showing tensions at different pipe critical points using the S-lay method were obtained.

For Single pipe (SP): Tension in pipe at the end of the firing line T_{FL} - 1629.45kN, Tension in pipe at Pressure tensioner T_{PT} - 1744.56kN, Tension at marriage point T_{MP} - 1804.42kN, Tension at water level T_{WL} - 1842.40kN, and Tension at lift-off T_{LO} - 1880.38kN

For Pipe-in-pipe (PIP): Tension in pipe at the end of the firing line T_{FL} - 719.78kN, Tension in pipe at Pressure tensioner point T_{PT} - 961.73kN, Tension at marriage point T_{MP} - 988.17kN, Tension at water level T_{WL} - 1026.15kN, and Tension at lift-off T_{LO} - 1047.30kN

3.3. Subsea Stresses in Pipeline

When input data values from section 2.1 were processed in the developed Template the subsea stresses below were obtained using the S-lay method of pipeline installation.

For Single Pipe (SP): Hoop stress σ_h - 0.3586MPa, Bending stress σ_b - 166.91MPa, Net longitudinal stress σ_l - 198.99MPa, and Axial force at Touchdown F_a - 1086.51kN

For Pipe-in-pipe (PIP): Hoop stress σ_h- -1.4576 MPa, Bending stress σ_b - 166.91 MPa, Net longitudinal stress σ_l - 200.66 MPa, and Axial force at Touchdown F_a - 1086.51kN

3.4. Equivalent stress and Stress Ratios

The following Von Mises Equivalent Stress σ_{eq} and stress ratios *SU* were obtained from the Template;

For Single Pipe (SP): Equivalent stress σ_{eq} - 198.81MPa, Stress ratio *SU* - 0.4438

For Pipe-in-pipe (PIP): Equivalent stress σ_{eq} - 199.94MPa, Stress ratio *SU* - 0.4464

3.5. Pipeline Deflection

Deflection of the single bare pipe was considered and its distribution along pipe length is shown in Figure 4.

Figure 4 shows the behavior of the pipeline during installation relative to the applied tension. With a top tension of T_T = 1177.200kN at the length of 36m, a maximum deflection (U_{max} = 0.26m) was obtained. Also for the T_T = 1842.397kN top tension at the length of 36m, maximum deflection (U_{max} = 0.17m) was obtained. For the pipe, the maximum deflections occurred at the same point (36m) but at different magnitude. For the first case where less magnitude of tension (T_T< 1177.200kN) was applied, the pipe experienced more deflection while compared to the second case where larger tension (T_T> 1842.397kN) was applied to reduce the possibility of high deflection.

After the pipeline is installed, for the first scenario where T_T = 1177.200kN applied tension, stress concentration will increase at the asperities of pipeline thereby leading to possible fatigue failure or rupture from continuous cyclic stresses. For the second scenario with T_T = 1842.397kN applied tension where the pipeline experienced less deflection, failure is less likely to occur than in the first scenario.

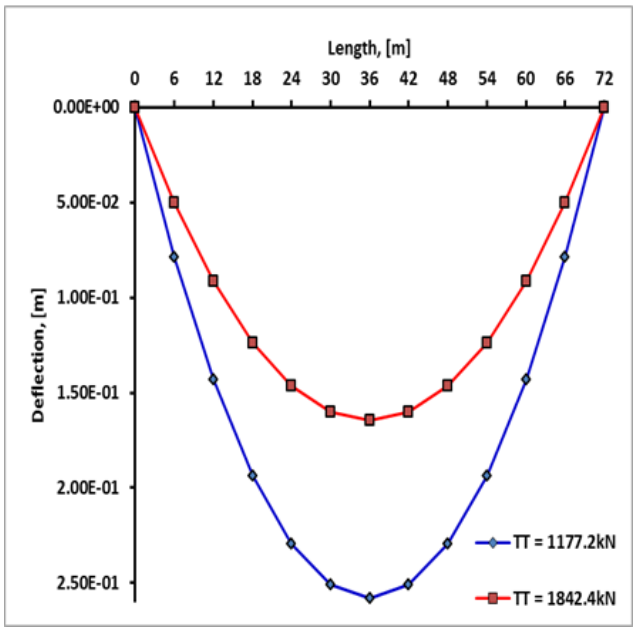

Figure 4. Deflection versus Length of the single bare pipe (SP) for top tension T_T - 1177.200kN and T_T - 1842.397kN

3.6. Template Validation for Single Pipe (SP)

For the purpose of Template validation and establish a unity check on the pipeline integrity for installation operation the template results were compared with those of manualcalculation performed an installation company. The user-friendly Template developed provides easy estimation of the structural integrity of the pipeline for an S-Lay method of installation.

Catenary parameters such as: Horizontal tension, Horizontal distance from TD to LO, Radius of curvature at TD, Total length of submerged pipe showed the same values to the nearest whole numbers for the manual calculationand Template results.

Similar results were obtained on comparing subsea stresses such as: hoop stress, bending stress, net longitudinal stress, and the axial force atTD.

The results of comparing the tension at different pipeline critical points using analytical and Template is shown in Figure 5. Again, the results are comparable and of same order of magnitude.

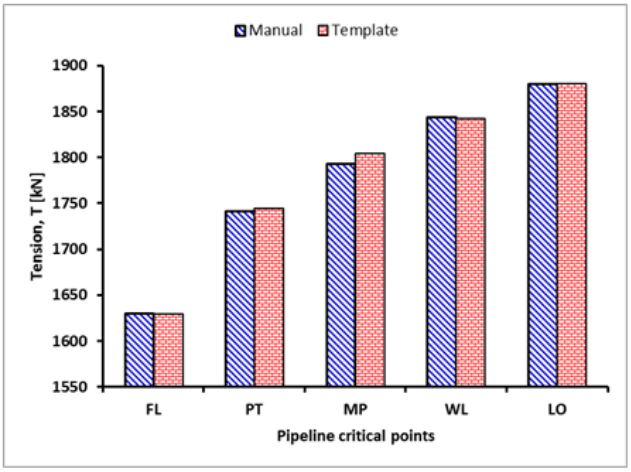

Figure 5. Tension at single pipe (SP) pipeline Critical Points (firing line end - FL, pressure tensioner - PT, marriage point - MP, water line - WL and Lift-off - LO)

Equivalent stress and stress ratio for Single pipe (SP) obtained by analytical solution and the developed Template were compared. The results showed stress ratios of 0.440 and 0.444; as well as, equivalent stress of 199.10MPa and 198.81MPa for analytical and Template, respectively.

4. Conclusion

This study has shown the use of Excel design template developed in this study in the analysis of the pipeline installation without compromising the pipeline integrity. With the template, the stress ratio of the pipe was estimated during installation work-in-progress. Furthermore, from the study of the S-lay method of pipeline it was deduced:

- That such analysis is necessary when installing a SP and PIP using an S-lay pipeline installations method.
- That tensioning affects the deflection of the pipe during installation.
- That the result obtained shows that during installation useful data on the integrity of the pipeline could be obtained and preserved for operational purposes.
- That the stress ratios obtained show an indication of the conformity of the pipeline to design specifications.

Nomenclature

μ -Roller friction
A_s -Calculated Pipe Area, [m^2]
D -Depth of water, [m]
EI -Flexural rigidity, [Nm^2]
$f(y)$ -Force due to ocean currents, [N]
h_{LO} -Height at the lift off point, [m]
L -Discretized Length, [m]
L_{FL} -Length on inclined firing line, [m]
OD -Outer Diameter of Pipe, [m]
R -Stinger radius/ Over-bend radius, [m]
R_{TD} -Radius of curvature at touchdown, [m]
T_T -Applied Top Tension, [N]
$T(y)$ -Axial tension distribution,[N]
T_1 -Tension at lift-off point (T_{LO}), [N]
$t_{conc.}$ -Concrete coating thickness, [m]
t_{fbe} - Fusion Bonded Epoxy coating thickness, [m]
T_{LO} - Tension at lift-off, [N]
T_{PT} - Tension at Pressure Tensioner, [N]
T_{WL} -Tension at water level, [N]
U -Lateral deflection, [m]
W -Weight of the submerge pipe, [kg]
W_{air} -Weight of pipe in air, [kg]
W_{SUB} - Weight per unit length submerged, [kg/m]
W_{sub} -Weight of the submerge pipe, [kg]
$\square_{PT}$ -Ramp angle, [deg]
ρ_{sea} -Sea density, [kg/m^3]
Φ_1 -Angle at the lift-off, [deg]
Φ_2 -Angle at water level, [deg]
FL - Firing Line
PT - Pressure tensioner
MP - Marriage point
WL - Water level
LO - Lift-Off
TD - Touch down

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