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PipelineReeling

Thar M. Badri[1,a*], ZahiranizaMustaffa[1,b]and Mohammed Badri Taufiq[2,c]

[1]Civil Engineering Department, UniversitiTeknologi PETRONAS,Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia.

[2]Mechanical Engineering Department, Collage of Engineering, The University of Mustansiriyah,Alrosapha, 46007 Almustansiriyah, Baghdad, Iraq.

[a]t.albarody@ymail.com, [b]zahiraniza@petronas.com.my, [c]moh.badri55@yahoo.com

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Abstract. The reel laying offshore pipeline installation method is known to be easier and cost effective, but the method may induce some plastic deformation into the pipe, thus affecting the strength and ductility of the pipe material. However, the design and modeling ofapplied bending loads to the pipe during spooling of (initially straight) or laying of (initially bent) pipe has become a great challenge and are addressed in this study,sifting parametrically pipelines stiffness. It is demonstrated that rigid pipeline requires higher spooling loads, but indeed rigidity improves the laying effort without the need of applying tension, thus making it more tractable during the straighteningstage. The paper also emphasizes on pipe free-end deformations and offset of bending, which extends the findings of previous works on spooling or laying control.

Introduction

Reel pipe lay is a conventional method of installing pipelines in the ocean, when the pipeline is wound on a massive reel mounted on the deck of a pipe lay barge [1]. Pipelines are generally spooled onto a reel at an onshore spool-base facility. The first commercial application of reeled pipeline technology was available by *Santa Fe Corporation* in the early 1970s[2]. Althoughthis technology provides a safer and more stable work environment,faster installation,less weather dependency, spooling pipe up of to 18inch diameter and less labor costs, it exhibits several disadvantages that require proper analyses and solutions. These include pipeline being deformed plastically twice, when spooled onto a reel and when straightened. Wounding pipeline allows compression in the positive bending side whichcauses wrinkles, and tension in the negative bending side which results in some thinning of the pipe wall. Thinner pipe wall results some losses in the yield strength especially in some localized areas which may trigger*Bauschinger effect*.Spooling of pipe can also cause some lossesin the stiffness, resulting in ovalization which eventually may lead to upheaval bifurcation "buckling". Therefore, more time is requirednot only to lay the pipes, but also to remove the buckles [3-10]. Wounding an elastic pipe in large variances (of laid angle) at a reel lay system requires:

1. The installation reel holds the pipe tension.
2. A set of rollers that pipe will rout.
3. A tower has a pipe straightener.

The straightener, however, is assumed to bepivoted and mounted to rails that allow the whole straightener to slide. Therefore, examining the plastic-deformation (*e.g.* offset of reeling) that occurs in reeled pipeline is ideal in order to provide better design for spooling or laying mechanism, for which the steps can be further elaborated to: (i) simulate the deformation and the bending offset, (ii) draw these deformations versus reeling applied load, and (iii) examine different stiffness of the pipeline. Three types of material were tested in the present analysis as listed in Table 1.

Table 1. Materials properties[10, 11]

Material	E_1GPa	E_2GPa	E_3GPa	G_{13},G_{12}GPa	G_{23}GPa
Gr−Ep1	137.9	8.96	8.96	7.2	6.2
Br−Ep1	206.9	20.6	20.6	6.9	4.1
SteelS97	206.0	206.	206.	7.9	7.9
	YMPa	υ_{12}	υ_{13}	υ_{23}	ρkgm^{-3}
Gr−Epb	1500	0.30	0.30	0.49	1450
Br−Epc	1420	0.30	0.25	0.25	1950
SteelS97	990	0.27	0.27	0.27	7850

$_1$ At120°CCure andV_f= 60% (fabric)
$_2Y$= Ultimate strength

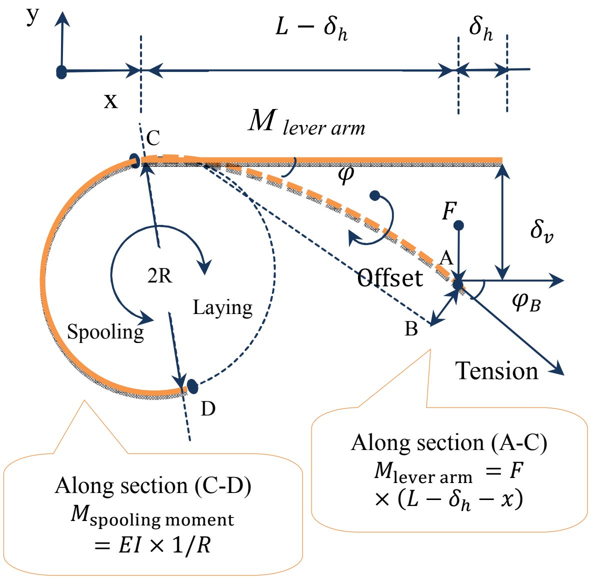

Figure 1.Schematic of pipeline reeling mechanism.

Analytical Model

Considering φas the slope of reeling and $s$as the arc-coordinate of the beam between the fixedside to free–end (see, Fig. 1), the curvature at any point on the beam k, can be written as,

$$k = \frac{1}{R} = \frac{d\varphi}{ds} = \frac{M}{EI} \tag{1}$$

The bending moment at any pointswith respect to Cartesian coordinates (x,y) as shown in Fig. 1 is given by,

$$\mathrm{M(s)} = F \times (L - \delta_h - x) \tag{2}$$

where$F$ is the point load applied at the free end. According to Eqs. (1)and(2), the bending equation of a uniform cross-section beam is,

$$\frac{\mathrm{d}\varphi}{\mathrm{ds}} = \frac{F}{EI} \times (L - \delta_h - x) \tag{3}$$

Taking into account $\cos(\varphi) = \mathrm{d}x/\mathrm{d}s$ in a beam undergoing large deformation, and differentiating Eq. (3) with respect to s, the differential equation that governs the large deformation of a cantilever beam under the free -end point vertical loads can be obtained as in the following form,

$$\frac{\mathrm{d}^2\varphi}{\mathrm{d}s^2} = \frac{F}{EI}\cos(\varphi) = 0 \tag{4}$$

Using the dimensionless variables, $\zeta = s/l$ and the dimensionless end-point load, $\alpha = Fl^2/EI$, the original equation becomes,

$$\frac{d^2\varphi}{d\zeta^2} - \alpha\cos(\varphi) = 0, \qquad \varphi(0) = 0, \qquad \varphi(1) = 0. \tag{5}$$

The dimensionless exact vertical and horizontal displacements at the free -end point of the cantilever beam are given by,

$$\frac{\delta_v}{l} = 1 - \frac{2}{\sqrt{\alpha}}\big(\mathrm{E}(\mu) - \mathrm{E}(\varphi,\mu)\big) \tag{6}$$

$$\frac{\delta_h}{l} = 1 - \sqrt{\frac{2\sin(\varphi_B)}{\alpha}} \tag{7}$$

where $E(\mu)$ is the complete elliptic integral of the second kind, $E(\varphi,\mu)$ is the incomplete elliptic integral of the second kind, $\varphi_B = \varphi(1)$ is denoted as the rotation angle of the beam at free end point, and,

$$\mu = \sqrt{\frac{1+\sin(\varphi_B)}{2}}, \qquad \varphi = \sin^{-1}\left(\frac{1}{\sqrt{2}\mu}\right)$$

The incomplete and complete elliptic integral of the second kind are then defined as,

$$\mathrm{E}(\varphi,\mu) = \int_0^{\varphi} \sqrt{1-\mu^2\sin^2(\vartheta)}\,d\vartheta, \ \text{ and } \ \mathrm{E}(\mu) = \mathrm{E}\left(\frac{\pi}{2},\mu\right).$$

For infinitesimal deflection, we can assume that the linearized form of Eq. (6) is according to,

$$\frac{d^2\varphi}{d\zeta^2} - \alpha = 0, \qquad \varphi(0) = 0, \qquad \varphi'(1) = 0. \tag{8}$$

The corresponding solution that gives the linear result of the Eq. (8) is then,

$$\varphi(\zeta) = \frac{\alpha}{2}(2-\zeta)\zeta, \qquad \xrightarrow{\text{yields}} \varphi_B = \frac{\alpha}{2}\,. \tag{9}$$

If the large deformation is considered, the φ_B, δ_v, δ_h expressions are not explicit, and difficult to evaluate. The traditional analytical nonlinear solver methods such as perturbation; Adomain decomposition; and δ-expansion method; cannot provide solutions, and one has to solve a nonlinear algebraic equation numerically. An appropriate numerical treatment is performed by [12]as:

$$\varphi_B = \frac{\alpha}{2} \times \frac{f(\alpha)}{g(\alpha)}, \tag{10}$$

where

$$\begin{aligned} f(\alpha) = {} & 1 + 3.98575\times10^{-2}\alpha^2 - 5.41174\times10^{-2}\alpha^4 + 5.72575\times10^{-3}\alpha^6 + 3.79533 \\ & \times10^{-4}\alpha^8 - 8.87896\times10^{-6}\alpha^{10} + 2.63041\times10^{-8}\alpha^{12} - 1.51429\times10^{-11}\alpha^{14} \\ & - 2.29142\times10^{-15}\alpha^{16} - 3.45006\times10^{-21}\alpha^{18} - 7.00678\times10^{-28}\alpha^{20}, \end{aligned}$$

$$\begin{aligned} g(\alpha) = {} & 1 + 0.131524\times\alpha^2 - 5.99231\times10^{-2}\alpha^4 + 2.34466\times10^{-3}\alpha^6 + 9.90299 \\ & \times10^{-4}\alpha^8 - 1.37001\times10^{-6}\alpha^{10} + 3.44172\times10^{-8}\alpha^{12} - 1.45098\times10^{-11}\alpha^{14} \\ & - 2.26721\times10^{-15}\alpha^{16} - 3.50731\times10^{-21}\alpha^{18} - 7.00678\times10^{-28}\alpha^{20}. \end{aligned}$$

Results and Discussion

The bending offset and horizontal deformationof the free -end of reeled pipeline was analyzed in this paper using the compliant beam theory. The pipeline was assumed to be subjected to bending loadapplied at the free tip that exceeds 500kN.With this, the maximum bending offsets for the pipeline to bend elastically are presented in Fig. 2. The figure reveals that ductile materials performs better when reeled under small offset as well as small drum diameter. However, result in Fig.2, reveals that rigidpipelineshave Young's modulus up to 150 GPa required huge amount of load to be supplied during spooling which may cause ovalization. However, if rigid composite pipelines used a rabid release of strain energy mayrelease intoreel system during laying installations. In additional, composite pipeline found could lay without strain energy relaxation, which speeds up the insulation process.

Conclusion

Thus far, the accurate treatment of bending moment that induced into the reel pipeline yielded rather sophisticated displacement and bending offset results. A supplement digression on the implication of the effects of pipeline parameters, and material properties on the offsetare investigated. Results reveal that even if rigid pipeline required higher spooling loads. This, rigidity is indeed improve the laying effort without need of applying tension and be more tractable when the stage is straightening.

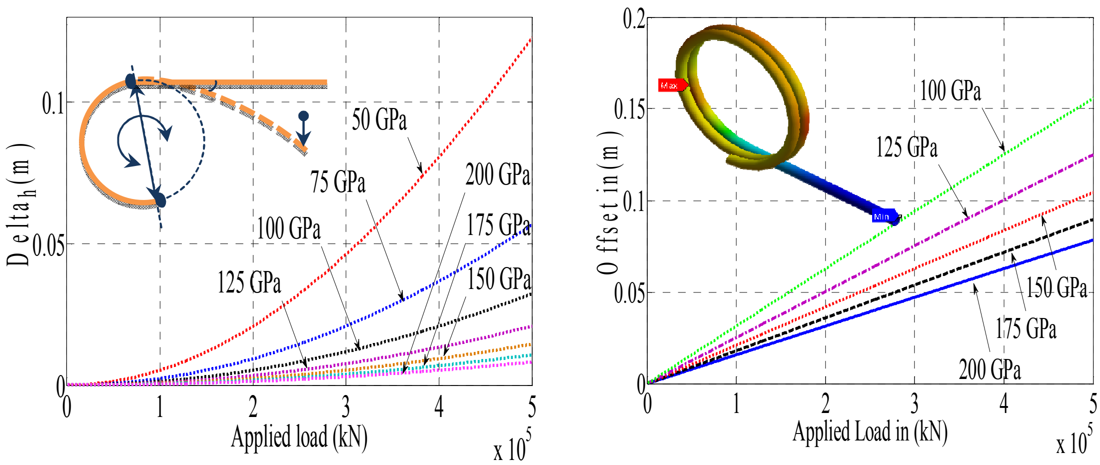

Figure 2. Simulation shows the plastic deformation of wide range of stiffness that occurs when reeling pipelines of radius equal to 0.15 m into drum of dim = 6m.

The previous features are considered of particular interest in designing of composite reel pipeline, or may serve as a reference in developing the wounding pipe.

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