Applied Mechanics and Materials Vols. 353-356 (2013) pp 3280-3283
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doi:10.4028/www.scientific.net/AMM.353-356.3280

Wounding Composite Pipeline with Internally Pressurized Conditions

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Keywords: Compliant pipe, Composite pipeline, Reeling pipe, Large deformations.

Abstract. Although installing offshore pipelines by reel-laying method is eases and cost-effective, still conceal some of plastic deformation into the pipeline which may, in combination with ageing, affect strength and ductility of the pipe material. Therefore, reeling pipelines that internally pressurized is addressed in this study sifting parametrically pipelines stiffness to prevent the ovalization and bifurcation produces during spooling of (initially straight) or laying of (initially bent) pipe. A combination of composite materials is examined and number of bending cases at the limit of ovalization and bifurcation is investigated. It is demonstrated that composite pipeline exhibit more bending stability than Steel. Results on the strain energy release in the reel lay system are presented, extending the findings of previous works on the methods of spooling and laying mechanism.

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]. Although, reel technology provides; A safer and more stable work environment; Faster installation; Less weather dependency; Spooling pipelines up to 18" in diameter; Less labor costs. Still some of disadvantages of the reeling method need to solve and it could be summarize as; 1) The pipeline is deformed plastically twice, when spooled onto a reel and when straightened; 2) Wound pipeline exhibit compression in the positive bending side cause wrinkles and tension in the negative bending side cause some thinning of the wall result in loss of yield strength in localized areas which brought a *Bauschinger effect*, Fig. 1; 4) Spooling of pipeline cause some loss of stiffness result in ovalization may lead to upheaval bifurcation "buckling". Therefore, amount of time require when laid the pipeline, to remove the buckle [3-6]. In order to wound elastically pipeline in large variances of laid angle, the reel lay system should consists of:

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

Therefore, examining the plastic-deformation (*e.g.*, the offset of reeling) that occurs in reeled pipeline is ideal in designing of reel mechanism and need to; 1) Simulating the bending offset; 2) Drawn these offsets versus applied reeling loads examining pipes at different stiffness; 3) Study the stress that generated by the rapid release of strain energy during reeling of internally pressurized pipe; 4) Discover the pressure condition for bending pipeline elastically "beyond the elastic zone but before the ultimate point".

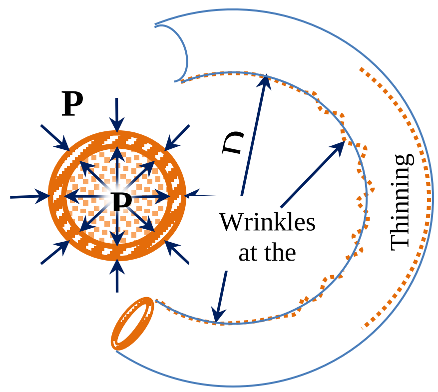

Fig. 1, Ovalization in reeling mechanism due to inward stresses.

Compliant pipe model

Considering φ be the slop of reeling, and *s* is the arc-coordinate of beam between the fixed side to free end *e.g.*, see Fig. 2, the curvature at any point of the beam respectively, k, can be written as:

$$k = \frac{1}{R} = \frac{d\varphi}{ds} = \frac{M}{EI} \quad (1)$$

The bending moment at any point in respect of Cartesian coordinates (x, y) shown in Fig. 2 is given by:

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

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

$$\frac{\mathrm{d}\varphi}{\mathrm{ds}} = \frac{\mathrm{F}}{\mathrm{EI}} \times (\mathrm{L} - \delta_\mathrm{h} - \mathrm{x}) \quad (3)$$

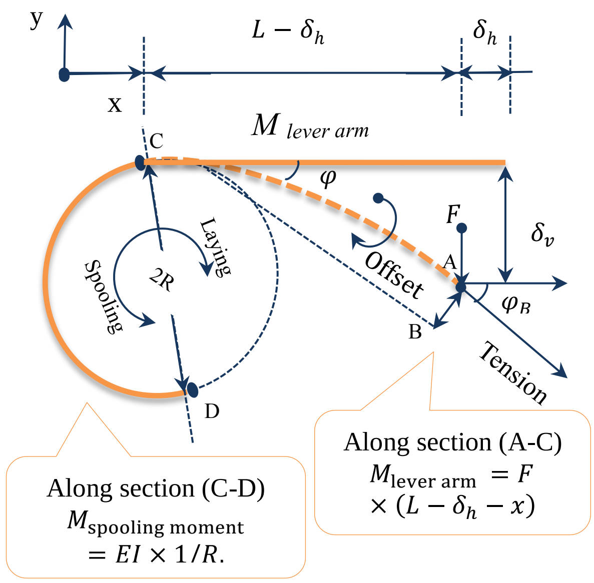

Fig. 2, Schematic of reeling mechanism.

Taking into account cos(φ) = dx/ds for a beam undergoing large deformation and differentiating Eq. (3) with respect to *s*, the governing equation of large deformation of a cantilever beam subjected to vertical load at free end point is obtained as

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

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

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

The above expressions are not explicit, and difficult to evaluate. However, the traditional analytical nonlinear solver methods such as perturbation; A domain 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 [7] as:

$$\varphi_\mathrm{B} = \frac{\alpha}{2} \times \frac{\mathrm{f}(\alpha)}{\mathrm{g}(\alpha)}, \quad (6)$$

where

$$\begin{aligned} f(\alpha) = {} & 1 + 3.98575 \times 10^{-2}\alpha^2 - 5.41174 \times 10^{-2}\alpha^4 + 5.72575 \times 10^{-3}\alpha^6 + 3.79533 \\ & \times 10^{-4}\alpha^8 - 8.87896 \times 10^{-6}\alpha^{10} + 2.63041 \times 10^{-8}\alpha^{12} - 1.51429 \times 10^{-11}\alpha^{14} \\ & - 2.29142 \times 10^{-15}\alpha^{16} - 3.45006 \times 10^{-21}\alpha^{18} - 7.00678 \times 10^{-28}\alpha^{20}, \\ g(\alpha) = {} & 1 + 0.131524 \times \alpha^2 - 5.99231 \times 10^{-2}\alpha^4 + 2.34466 \times 10^{-3}\alpha^6 + 9.90299 \\ & \times 10^{-4}\alpha^8 - 1.37001 \times 10^{-6}\alpha^{10} + 3.44172 \times 10^{-8}\alpha^{12} - 1.45098 \times 10^{-11}\alpha^{14} \\ & - 2.26721 \times 10^{-15}\alpha^{16} - 3.50731 \times 10^{-21}\alpha^{18} - 7.00678 \times 10^{-28}\alpha^{20}. \end{aligned}$$

Wounding pressurized pipe

Assuming a reel pipeline spooled or laid with internal pressure acting on the pipe wall and exceeds the external loads that cause pipe collapse. Wounding pipeline with internal pressure will provide a pipe of adequate strength. As well as, prevent pipe collapse during reeling due to the variations of physical properties, ovality, bending stresses, and external loads. Plausibly, the collapse pressure will exceed the net stresses everywhere along the pipeline as follows: $(P_o - P_i) \leq f_o P_c$, where f_o is the collapse factor and equal 0.7 for seamless pipe or 0.6 for cold expanded pipe. However, the collapse pressure P_c can be approximated as:

$$P_c = P_y P_e / \sqrt{(P_y^2 + P_e^2)} \quad , \qquad P_c = 2Y(t/D) \,, \qquad \text{or} \;\; P_c = 2E\,(t/D)^3 \,/(1 - v^2) \qquad (7)$$

where E = *Young Modulus*, P_e is the elastic collapse pressure, P_y is the yield collapse pressure, v = Poisson's ratio. While combined bending strain and applied loads should satisfy the following:

$$\frac{\varepsilon}{\varepsilon_b} + \frac{(P_o - P_i)}{P_c} \leq g(\delta) \qquad (8)$$

where ε is the bending strain in the pipe, $\varepsilon_b = t/2D$ is the buckling strain under pure bending, To avoid buckling, bending strains should be limited as $\varepsilon \geq f_s \varepsilon_{max}$ where ε_{max} is the maximum wounding bending strain, and f_s is the bending safety factor. A value of 2.0 for safety factors is suggested. However in reeling mechanisms, the bending strains are well defined and the safety factor can be smaller than 2.0. While the $g(\delta)$ on the right side of Eq. (8), is the collapse reduction factor and equal to $(1 + 20\delta)^{-1}$, here δ is the ovality and can be calculated as;

$$\delta = (D_{max} - D_{min})/(D_{max} + D_{min}),$$

where D_{max} and D_{min} are maximum diameter of the ovalized shape and minimum diameter of the initial shape. However, Eq. (5), is applicable up to *D/t = 50.*

Result and Discussion

Three type of materials are selected in the current examine and the detail on its properties could be found in [8]. Having applied the compliant beam theory, the bending offset at the free end of reeled pipeline is studied. The wounded pipeline was subjected to bending load exceed 500kN. In this fashion, the maximum bending offset that pipeline to be bend elastically is presented in Fig. 3. It is clearly seen that ductile materials appear more applicable to be reeling into small offset as well as small drum in diameter. Fig. 4, an examination on stresses induced into reeled pipeline made of common composite materials and subjected to internal pressure is accomplish. Fig. 4 shows that large diameter pipeline required large strain energy. Therefore, amount of time may require when the pipeline is laid to remove the buckle. However, lying of pipeline without internal pressure will cause some loss of stiffness result in ovalization may lead to upheaval bifurcation "buckling". On the other hand, wounding pipeline internally pressurized indeed prevent ovalization, especially when the internal pressure design equal to collapse pressure or external applied reeling stresses. Although, Fig. 4, shows a rigid behavior for composite pipeline, a rabid release of strain energy that induced into the pipeline during spooling process or laying installations was noticed.

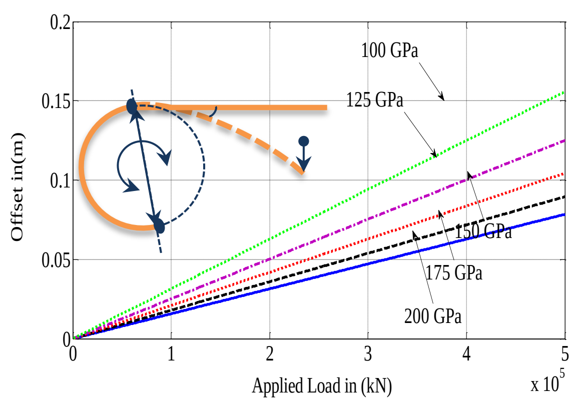

Fig. 3, Simulation shows the plastic deformation of wide range of stiffness that occurs when reeling pipelines of radius equal to 0.15m into drum of dim=6m.

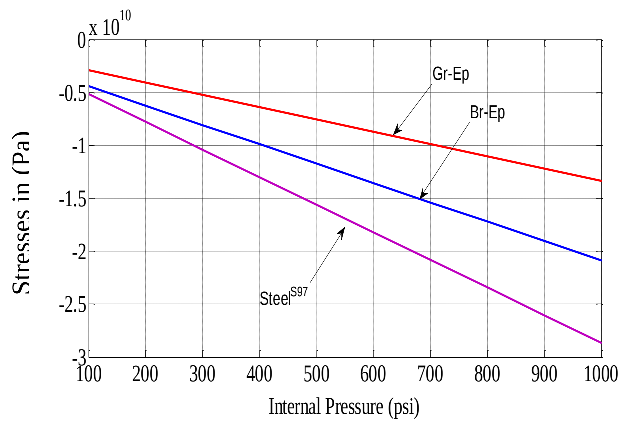

Fig. 4, Buckling stress in pipeline internally pressurized.

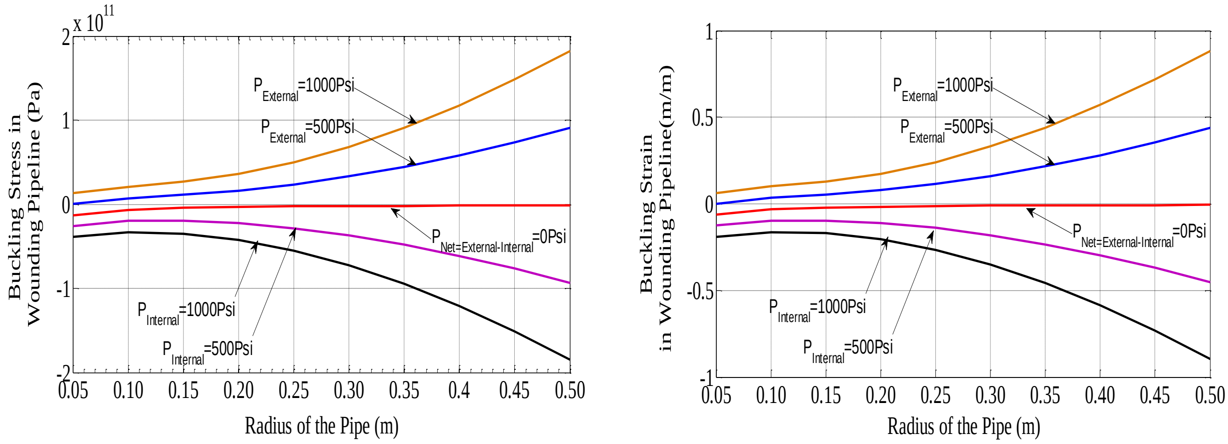

Fig. 5, Buckling stress on the left and strain on the right, that induced into the pipeline during laying installations with and without internally pressurized for Steel^{S97}.

In spite of this, composite pipeline that internally pressurized is found could lay without strain energy relaxation, which speeds up the installation process see Fig. 5.

Cloture

Thus far, the accurate treatment of bending moment that induced into the reel pipeline yielded rather sophisticated displacement and bending offset. A supplement digression on the implication of the effects of pipeline parameters, and material properties on the offset are investigated. Results reveal that composite pipeline exhibit rigid behavior requiring 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. 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.

Acknowledgments

The authors would like to acknowledge Universiti Teknologi PETRONAS (UTP), for sponsoring this work.

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