International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Optimization of Offshore Pipeline

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Abstract: ***This research work mainly concern with the structural improvement of offshore pipeline using rectangular stiffeners placing then at the angle of 45^o to each other around the circumference of pipe. Strength of the offshore pipelines were determined taking different length of buckle arrestors by gradually increasing the length of stiffener by placing them at different location along the length of pipe using finite element analysis. Secondly, the model with maximum resistance towards buckling is further optimized for the stiffener height. Different models where examine by decreasing the height of stiffeners and with respect to the height the buckling load is been determine. Finally suggesting model which has equivalent strength against buckling by increasing width and decreasing height of buckle arrestors. Therefore, using finite element method structure analysis is been done of different models thereby achieving optimum models primarily based on the strength and another one by reducing the weight.***

Keywords: pipeline, finite element analysis, buckling load, stiffener

1. Introduction

Oil and gas production occurs offshore every continent. Offshore production was responsible for about a third of global oil production and about a quarter of the world's natural gas supply.

A pipeline system can be a single pipe, pipe-in-pipe, or bundled system. Normally, the term of subsea flow lines is used to describe the subsea pipelines carrying oil and gas products from the wellhead to the riser base; the riser is connected to the processing facilities (e. g., a platform or a floating production storage and offloading vessel (FPSO). The subsea pipelines from the processing facilities to shore are called export pipelines, while the subsea pipelines from the platform to subsea equipment used to transfer water or chemical inhibitors are called water injection or chemical flow lines.

The design of offshore pipeline is mainly based on a limit state design. In limit state design all fore see able failure scenarios are considered and the system is designed against the failure modes that provide the lowest strength capacity. This thesis is concerned with the offshore pipeline buckling issues. Major failure of Offshore pipeline is due to buckling phenomena. The simulation presented in this thesis considered models made of SS304 stainless steel of offshore pipeline without and with rectangular buckle arrestors. Subsea pipelines are used for a number of purposes in the development of subsea hydrocarbon resources, as shown in Figure 1.1. A pipeline system can be a single pipe, pipe-in-pipe, or bundled system. Normally, the term of subsea flow lines is used to describe the subsea pipelines carrying oil and gas products from the wellhead to the riser base; the riser is connected to the processing facilities (e. g., a platform or a floating production storage and offloading vessel (FPSO). The subsea pipelines from the processing facilities to shore are called export pipelines, while the subsea pipelines from the platform to subsea equipment used to transfer water or chemical inhibitors are called water injection or chemical flow lines.

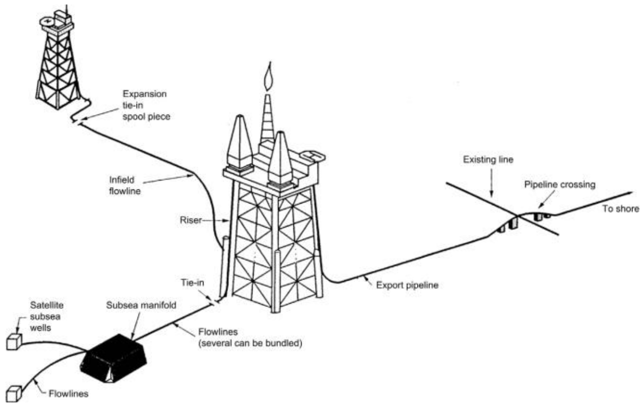

Figure 1.1: Subsea pipelines

2. Pipeline Design Analysis

Pipeline stress analysis is performed to determine if the pipeline stresses are acceptable, in accordance with code requirements and client requirements during pipeline installation, testing, and operation. The analysis performed to verify that stresses experienced are acceptable includes;

- Hoop stress.
- Longitudinal stress.
- Equivalent stress.
- Span analysis and vortex shedding.
- On-bottom stability analysis.
- Thermal expansion analysis, including tie-in design.
- Global buckling analysis.
- Crossing analysis.

The first of the three design stages is the initial wall thickness sizing. These initial sizing calculations should also be performed in conjunction with the hydrostatic collapse/propagation buckling calculations from the installation analysis. The analysis methods for pipeline design are briefly discussed next, as an introduction to separate chapters.

Pipeline Stress Checks

ISSN: 2319-7064
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1)1.5.1 Hoop Stress

Hoop stress (sh) for a thin wall pipe can be determined using the following equation, as shown in Figure 1.4:

$$\sigma_h = (p_i - p_o)\frac{D}{2t}$$

where:

pi = internal pressure
p_o = external pressure
D = outside diameter of the pipeline
t = minimum wall thickness of the pipeline

Depending on the code or standard, the hoop stress should not exceed a certain fraction of the specified minimum yield stress (SMYS).

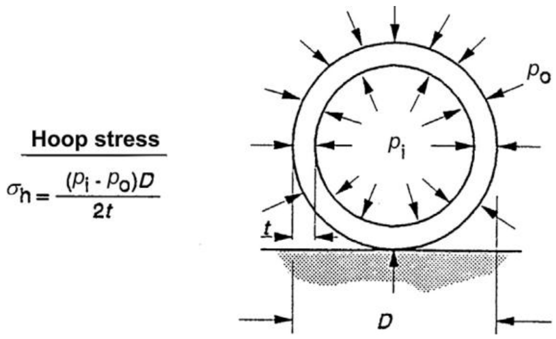


Figure 1.2: Pipe hoop stress

2)1.5.2 Longitudinal Stress

The longitudinal stress (s_l) of pipeline is the axial stress experienced by the pipe wall and consists of stresses due to

○ End cap force induced stress (sec).
○ Bending stress (s_b).
○ Thermal stress (s_t).
○ Hoop stress (s_h).

The longitudinal stress can be determined using the following equation:

$$\sigma_l = \sigma_{ec} + \sigma_b + \sigma_t + \nu\sigma_h$$

The components of the longitudinal stress are illustrated in Figure 1.5. It should be ensured that sign conventions are utilized when employing this equation (i. e., tensile stress is positive).

Equivalent Stress

The combined stress is determined differently depending on the code/standards utilized. However, the equivalent stress (se) can usually be expressed as:

$$\sigma_e = \sqrt{\sigma_h{}^2 + \sigma_l{}^2 - \sigma_h\sigma_l + 3\tau_{lh}{}^2}$$

where

s_h = hoop stress
s_l = longitudinal stress
s_{lh} = tangential shear stress
For high pressure pipes with D/t ratios less than 20 and ignorable shear stresses, the equivalent stress may be calculated as

$$\sigma_e = \sqrt{\frac{1}{2}\left[(\sigma_h - \sigma_l)^2 + (\sigma_l - \sigma_r)^2 + (\sigma_h - \sigma_r)^2\right]}$$

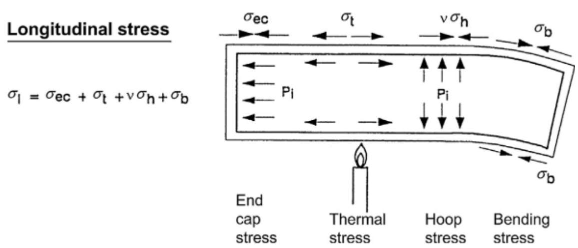


Figure 1.3: Longitudinal stress of pipeline

Where the radial stress, s_r, varies across the pipe wall from a value equal to the internal pressure, pi, on the inside of the pipe wall, to a value equal to the external pressure, po on the outside of the pipe. The magnitude of the radial stress is usually small when compared with the longitudinal and hoop stresses; consequently, it is not specifically limited by the design codes.

3. Methodology

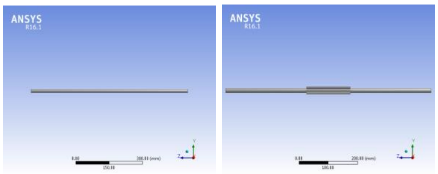
The design of offshore pipeline is mainly based on a limit state design. In limit state design all fore see able failure scenarios are considered and the system is designed against the failure modes that provide the lowest strength capacity. In the present study of offshore pipeline different model were designed to demonstrate the behaviour of buckling load with respect to suggested design. Offshore pipelines suffers allot of buckling and failure occurs due to buckling, hence finite element analysis has been conducted.

The material used for pipeline and buckle arrestors for finite element analysis is steel (SS304) with the following values of properties shown in the table below-

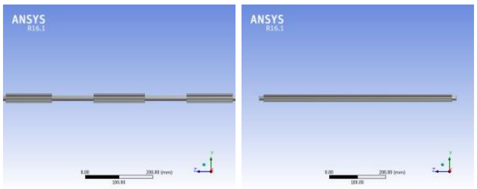
Table 1.1: Material Details

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

The pipeline model geometry consist of pipe with inner diameter 13 mm and outer diameter 16 mm and length 700 mm in figure (a) which is common for other models. Figure (b, c & d) consist of stiffener in discontinuous manner gradually increasing the length of stiffener. Stiffener length is 150 mm in figure (b), 420mm in figure (c), 670 mm in figure (d). There were eight rectangular stiffener of 2 mm width and 5 mm height are placed at 45° to each other on the outer periphery of shaft.

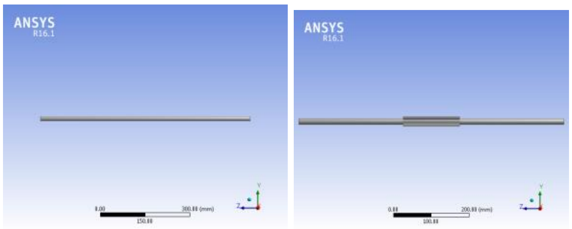


(a) (b)



(c) (d)

Figure 1.4: finite element model of pipeline (a) without stiffeners (b) stiffener of length 150 mm (c) stiffener of length 420 mm (d) stiffener of length 670 mm



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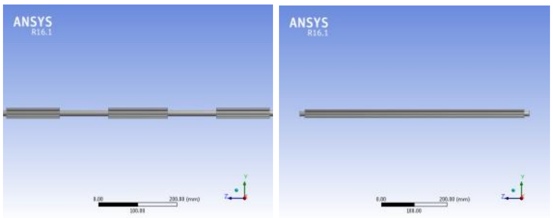


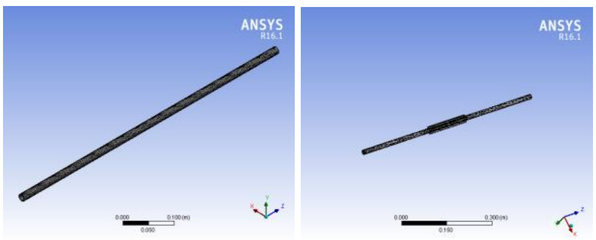
(c) (d)

Figure 1.5: finite element model of pipeline (a) without stiffeners (b) stiffener of length 150 mm (c) stiffener of length 420 mm (d) stiffener of length 670 mm

The meshing details of different pipeline model is given in table below-

Table 1.2: Nodes and element details

Pipeline Model	Buckle Arrestor Dimensions		
	Length	**Element**	**Nodes**
Model 1	Without stiffener	5540	35548
Model 2	150	4621	9005
Model 3	420	6453	12448
Model 4	670	6722	12613



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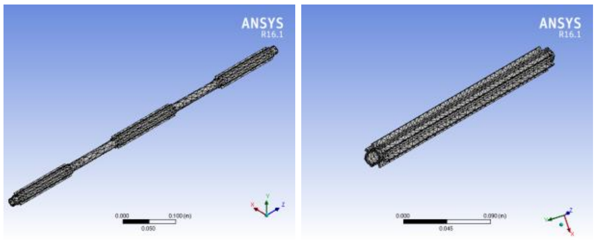


(c) (d)

Figure 1.6: Mesh models of (a) without stiffeners (b) stiffener of length 150 mm (c) stiffener of length 420 mm (d) stiffener of length 670 mm

The boundary conditions for the analysis at the one end are u = 0, v = 0, w = 0 & hx - 0, hy - 0, hz - 0 and for the loading side are u = 0, v = 0, w - 0, hx - 0, hy = 0, hz = 0. All the models are examined under axial compressive load of 1 N.

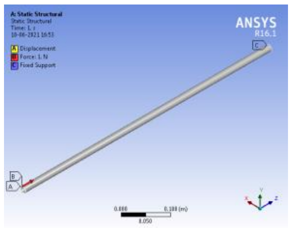


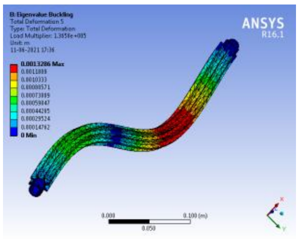
Figure 1.7: boundary condition of (a) without stiffeners

4. Result and Discussion

Model 4 with stiffener length 670 mm gives best performance among other models as shown in above comparison. Therefore considering Model 4 for further analysis which is based on stiffeners height based optimization for weight reduction. Total length of stiffener in model 4 is 670 mm. Initial height of buckle arrestor is 5 mm which gives buckling load as 136.69 kN and total deformation 1.3286 mm and weight is 7.7764 kg. Later reducing height of stiffener to 4 mm gives buckling load of 113 kN with total deformation of 1.0742 with weight 6.95 kg will reduces weight to 11.59 % of pipeline model of stiffener height 5 mm. Next taking arrestors height 3 mm and width 2 mm has 91.73 kN buckling load to resist to buckling and deformation of 1.006 mm and weight 6.12 kg which lesser the weight 26.9 %. Lastly decreasing height to 2 mm with width 2 mm gives buckling load 73.8 kN with deformation 1.309 mm has weight 6.04 kg decreases 46.8 % of weight of model 4 shown in table and figure 2 and 3. The buckling load with stiffener height 5 mm gives higher value as compared with buckle arrestors of different height. Stiffener with height 2 mm gives comparatively equivalent total deformation as stiffener of height 5 mm whose buckling load is much less than other models but when is compare with model 1, 2 and 3 it has higher value of buckling load with less weight. Therefore, proceeding with model of stiffener height 2 mm and width 2 mm by changing width from 2 mm to 3 mm

Table 1.2: Summary of pipeline model buckling analysis with respect to height

Stiffener Height (mm)	5	4	3	2
Stiffener Width (mm)	2	2	2	2
Thermal Conditions	Without	Without	Without	Without
Load Multiplier	1.37E+05	1.13E+05	91732	73802
Total Deformation (Buckling)	1.3286	1.0742	1.006	1.3094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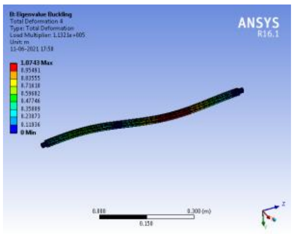
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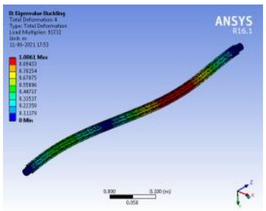
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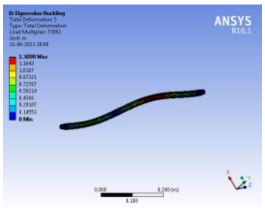
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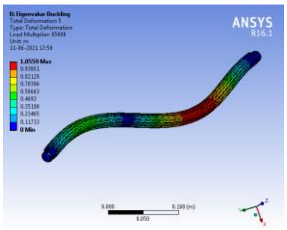
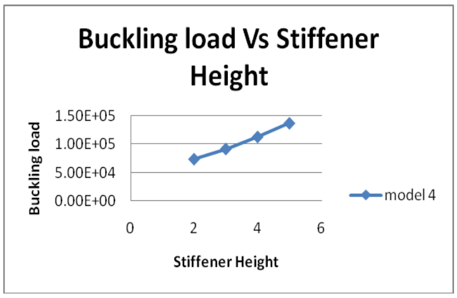
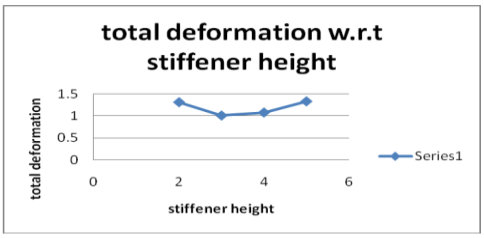

(e)

Figure 1.8: Contour showing buckling of pipeline of models (w. r. t height) of (a) stiffener of length 670 mm with height 5 mm (b stiffener of length 670 mm with height 4 mm (c) stiffener of length 670 mm with height 3 mm (d) stiffener of length 670 mm with height 2 mm



(a)



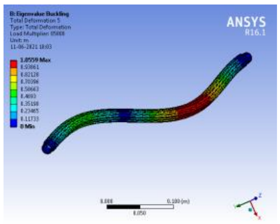
(b)

Figure 1.9: Graph showing (a) buckling load vs. height (b) total deformation Vs stiffener height

Finally the analysis reaches to end where different models were compare to examine strength of buckle arrestors with respect to its length. Further model 4 with better strength value for buckling has been optimize to reduce by reducing its height to 2 mm and increasing its width to 3 mm will raises its buckling load value to 85.8 kN with deformation of 1.056 mm hence increasing its strength by reducing its weight to 6.04 kg which reduces 28.64 % weight of pipeline model 4 with stiffener of 5 mm height. Table 3 and figure 4 shows values buckling load and total deformation of new model also considering thermal condition for five intervals of temperature (0^{o}, 25^{o}, 35^{o}, 45^{o} and 55^{o}).

Table 1.3: Influence of stiffener height buckling behaviour

Influence of Stiffeners Height Buckling Behaviour					
Models	**2 (2MM) new**				
Thermal Conditions	**0**	**25**	**35**	**45**	**55**
Load Multiplier	85808	7105	1643.4	929.11	647.63
Total Deformation (Buckling)	1.056	1.0405	1.0389	1.0386	1.0387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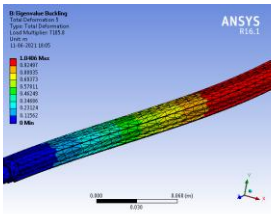
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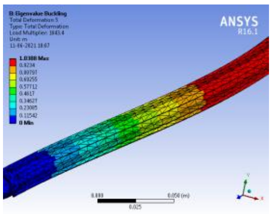
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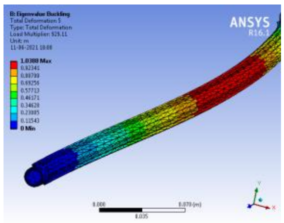
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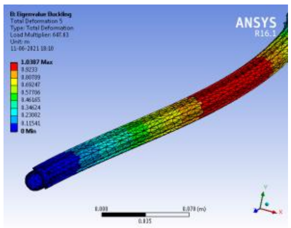
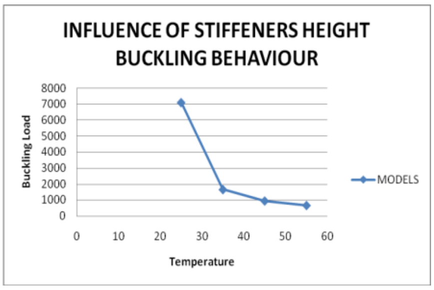

(e)

Figure 1.10: Contour showing buckling of pipeline of models 670 mm length, 2 mm height and 3 mm width (a) without thermal conditions (b) Thermal condition 25^{o} (c) Thermal condition 35^{o} (d) Thermal condition 45^{o} (e) Thermal condition 55^{o}



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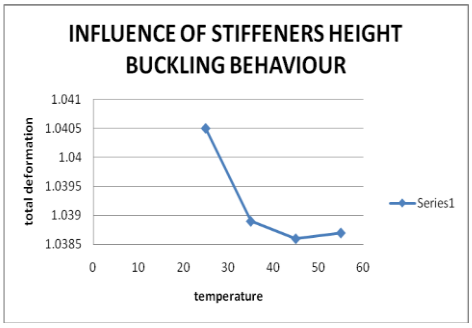

(b)

Figure 1.11:. Graph showing (a) buckling load vs Temperature (b) total deformation Vs Temperature

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