

# Initial Imperfection Design of Subsea Pipeline to Response Buckling Load

Abdul Khair Junaidi,<sup>a</sup> and Jaswar Koto,<sup>a,b,\*</sup>

<sup>a</sup>Department of Aeronautic, Automotive and Ocean Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia

<sup>b</sup>Ocean and Aerospace Research Institute, Indonesia

\*Corresponding author: jaswar,koto@gmail.com and jaswar@mail.fkm.utm.my

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## ABSTRACT

Oil and gas transportation in subsea operation continues to the extreme depth. Harsh environment in deep water lead to a challenge for especially pipeline design. The pipelines are operated at high pressure and high temperature in order to be able to transport the crude oil from the well to the end termination of loading. Such condition, the pipelines are subjected to axial compressive forces which will cause the pipelines to expand, consequently the pipelines tend to buckle for certain size and distance from the initial of pipeline. The sleeper is one of method to control the pipeline expansion by insertion of bar underneath the pipeline. The sleeper results initial imperfection for pipeline which forms a curvature. The magnitude of curvature is designed comply with DNV OS F101 where the design load will accommodate the combination load works on pipeline and the curvature configuration will validate by using ANSYS 14.

**KEY WORDS:** Pipeline Expansion; High Pressure; High Temperature; Axial Force.

## NOMENCLATURE

$API$	American Petroleum Institute
$D$	Pipe Diameter
$t$	Wall Thickness
$\Delta p$	Pressure Difference

$\Delta T$	Temperature Difference
$\mu$	Axial coefficient of friction
$\mu_L$	Lateral coefficient of friction
$W$	Submerge weight of the pipeline
$A$	Cross-sectional area of steel
$E$	Young's modulus
$I$	Second moment of area
$k$	Constants are dependent on the particular mode of buckling, taken from Hobbs and Liang
$L_a$	Anchor length of moving portion of pipeline
$\sigma_h$	Hoop stress = $PD/2t$

## 1. INTRODUCTION

Crude oil production continues to the extreme depth of water. At this depth, the technical challenge of subsea system will be tight to comply with existing codes, moreover extreme pressure and temperature of crude oil is needed to transport from wet well to termination of loading. The pipelines are subjected to axial compressive forces which will cause the pipelines to expand, consequently the pipelines experience a deformation to buckle for certain size. Pipeline expansion should be allowed to accommodate the lateral movement of pipeline. Buckling is instability of pipeline structure that may be going to a failure if the curvature of buckling mode exceeds the pipeline strength.

## 2. RESEARCH OBJECTIVE AND STRATEGY

The objective is to provide acceptance design for subsea pipeline which focus on buckling mode related to load response due to pressure and temperature. To be able to understand the buckling phenomena, an initial imperfection of pipeline at designated location along the line will be defined. The selection of material, pipe wall thickness and pressure containment corresponds to the limit state design of pipeline which refers to API RP 1111 and the

load effect to the structure will comply with DNV OS F101.

### 3. LITERATURE REVIEW

Design of pipeline is required accurate test result for local buckling collapse subjected to bending loads which exceed the limit state of bending moment capacity. The minimum wall thickness is determined based on maximum allowable stress under design pressure. The design of pipeline is aimed to keep in safe during construction and operation and meet the life time period. The anomalous value of the axial tensile and compressive strain was obtained on the pipe test. Difference result derived from the test on pipe to the simple bending theory become design factor parameter to contribute to the understanding of crucial limit state for the design of onshore and offshore pipeline (F. Guarracino, 2007).

Subsea pipeline system operates under high pressure and high temperature (HPHT). Due to soil restraint, the pressure and thermal expansion can generate a significant level of compression that can cause global buckling in the pipeline. Global buckling is generally in lateral direction, although it can be started as an upheaval buckling. The two methods are applied to control the pipeline thermal expansion and lateral buckling by utilizing sleepers and buoyancy along the pipeline route. It uses two parallel positioned sleepers space in short distance. To further assess the pipeline buckling response and assist the selection of the thermal mitigation method, a series of numerical analysis were performed for a wet insulated single pipeline (WISP) through finite element analysis (FEA). The FEA model length was set for 3,000 m. Buoyancy length and buoyancy force are analysed against the critical buckling. The presented study indicated that both sleeper and buoyancy section can be the viable solutions for thermal load mitigation. (Jason Sun, Pauljukes, 2012.)

### 4. METHODOLOGY

This section gives detail descriptions of the methodology used in this research as shown in Figure.1. The following step covers the theoretical backgrounds for the areas that need to be considered when carrying out the analysis with ANSYS 14. Most important subjects related to the analysis are the temperature and pressure loading on the pipeline.

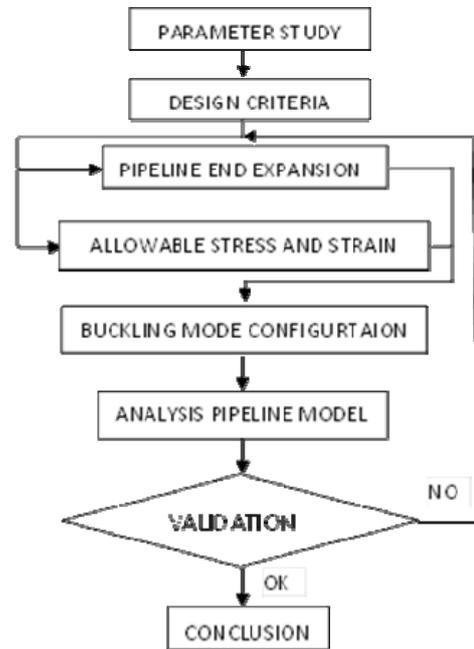


Figure.1: Flowchart of simulation.

#### 4.1 Configuration of Buckling Mode

When this expansion is restraint by axial friction between the pipeline and the soil furthermore an axial force will develop to be lateral movement in the pipeline. Subsea pipelines could buckle upward or sideway direction. The direction of movement will depend on the pipe-soil resistance. The effective axial force in the pipeline is given by:

$$P_0 = (1 - 2\nu) \frac{\pi}{4} D^2 \Delta p + \pi D t E \alpha \Delta T \quad (1)$$

The configuration of the buckle can be calculated by solving the following expression for buckle length  $L$ ,

$$P_0 = P + k_2 \mu W L \left[ \sqrt{1 + k_2 \frac{E A \mu^2 W L^5}{\mu (E I)^2}} \right] \quad (2)$$

$P$  = Compressive effective axial force within the buckle, given by

$$P = k_1 \frac{E I}{L^2} \quad (3)$$

The maximum amplitude of the buckle can be determined

$$y = k_4 \frac{\mu L W L^4}{E I} \quad (4)$$

The maximum bending moment is calculated by

$$M = k_5 \mu L W L^4 \quad (5)$$

Table 1: Lateral Buckling Constant

Mode	$k_1$	$k_2$	$k_3$	$k_4$	$k_5$
1	80.76	$6.391 \times 10^{-5}$	0.5	$2.407 \times 10^{-3}$	0.06938
2	$4\pi^2$	$1.743 \times 10^{-4}$	1.0	$5.532 \times 10^{-3}$	0.1088
3	34.06	$1.668 \times 10^{-4}$	1.294	$1.032 \times 10^{-2}$	0.1434
4	28.20	$2.144 \times 10^{-4}$	1.608	$1.047 \times 10^{-2}$	0.1483

#### 4.2 Pipeline Expansion

The amount of the pipeline expansion is an important design factor used in designing absorption devices such as loop or sleeper. The movement of pipeline expansion due to internal pressure and temperature are normally occurred in the pipeline, but the impacts of expansion movement will affect the pipe length at the end of pipeline. Forces result from internal load and temperature can be calculated as follow:

Force due to temperature change;

$$F_t = \alpha \cdot E \cdot A_s \cdot \Delta T \quad (6)$$

Force due to pressure change;

$$F_p = P \cdot A_i \quad (7)$$

Force due to Poisson contraction;

$$F_v = -v \cdot A_s \cdot \sigma_h \quad (8)$$

Force due to soil friction resistance;

$$F_f = \int_0^x \mu \cdot W_s \cdot dx = \mu \cdot W_s \cdot L_a \quad (9)$$

By equilibrium of the above forces for pipeline can be written:

$$F_t + F_p + F_v = F_f \quad (10)$$

The anchor length can be obtained using the above equation

$$L_a = \frac{1}{\mu W_s} (\alpha E A_s \Delta T + P A_i - v A_s \sigma_h) \quad (11)$$

The stress induced by the thermal and pressure expansion including the end cap effect can be written as:

$$1. \sigma_h = \frac{PD}{2t} \quad (12)$$

$$2. \sigma_{L1} = \frac{P A_i}{A_s} - \frac{\mu \cdot W_s \cdot x}{A_s} \text{if } x < L_a \quad (13)$$

This condition is for unrestrained line that the stress limitation to maintain the expansion stress  $\sigma_e$  should not exceed 0.72% of the SMYS.

$$\sigma_e = (\sigma_L^2 + 4\sigma_t^2)^{0.5} \leq 0.72\sigma_y \quad (14)$$

#### 5. SIMULATION RESULT AND DISCUSSION

A 3D Finite Element model and mesh was created in ANSYS 14 as shown in Figure.2. Before meshing the model, it is needed to define the element type and material properties in each area of element. Table.2 shows dimension and mechanical properties of pipeline. The finite element analysis of ANSYS software will automatically transform into equivalent load to predict the response of buckling load. Three mesh generator tools can be selected in the ANSYS software and a suitable grid will make proper solution.

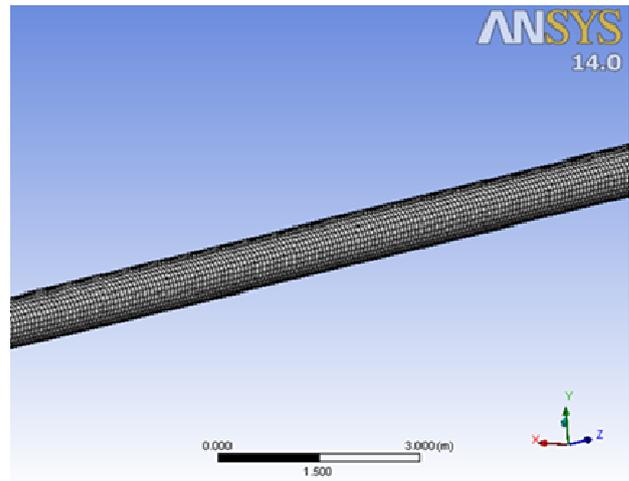


Figure 2: Pipeline Meshing

Table 2: Pipeline Data and Mechanical Properties

Parameter	Unit	Value
Outside Diameter	mm	762
Wall thickness	mm	20*
Pipe Material Grade	-	X80
Steel Density	Kg/m <sup>3</sup>	7850
SMYS	MPa	551
SMTS	MPa	620
Poisson ratio (v)	-	0.3
Young's Modulus (E)	GPa	207
Thermal Expansion Coef.(α)	C <sup>-1</sup>	1.17E-05
Internal Pressure	MPa	15
External Pressure	MPa	10
Internal Temperature	°C	70
External Temperature	°C	10

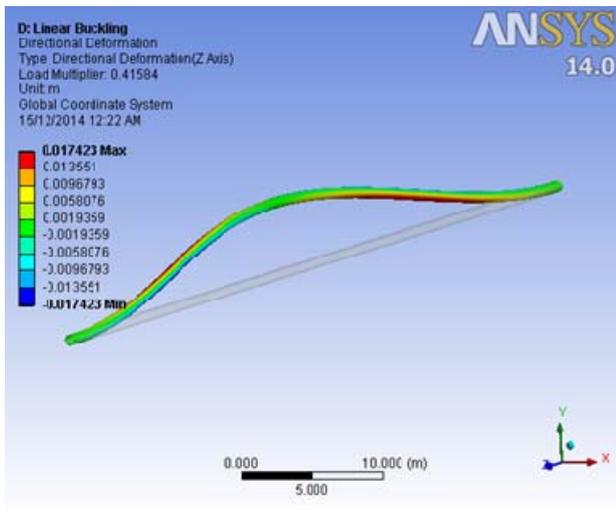


Figure 3: Pipeline Deformation

Figure.3 shows the pipeline deformation due to internal pressure and temperature. The model size is 83.5 m in length. It is seen from the Figure.2 that the large deformation occurred below the slope region of the buckle.

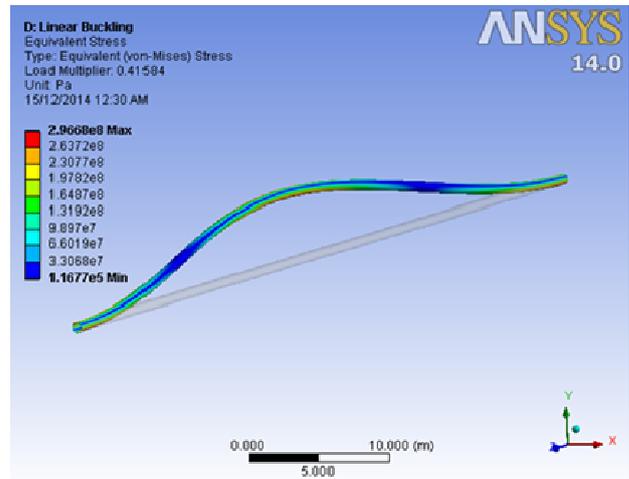


Figure 5: Equivalent Elastic Stress

Figure.5 shows a contour of equivalent stress. The large concentration of stresses are below the curvature and touch own point of pipeline. The ANSYS Solution which is used in the finite element method is to validate the pipeline model and buckling configuration.

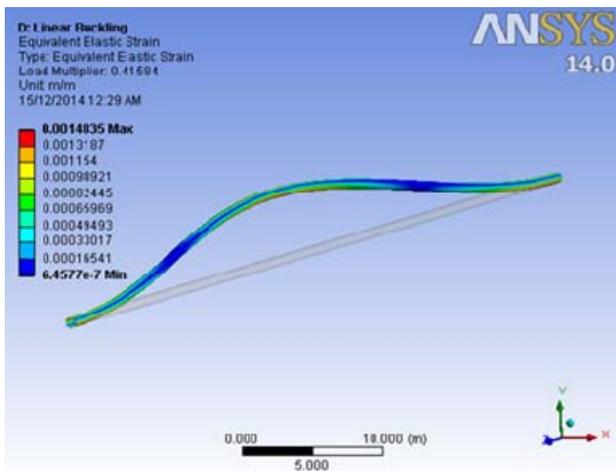


Figure 4: Equivalent Elastic Strain

Figure.4 illustrates the equivalent strain developed in the pipeline due to internal loads. Underneath the curvature and the sleep length are subjected to maximum strain.

## 5. BUCKLING CONFIGURATION

Based upon the calculation results of internal loads, that provide a simple model of one way buckling, the model is described in detail about the magnitude of curvature and maximum displacement of pipeline as shown in figure.6.

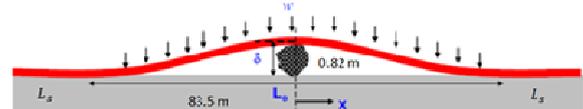


Figure 6: Buckling Configuration

## 6. CONCLUSION

Pipelines experience elongation due to high internal pressure and temperature to transport the crude oil has been studied. The design allows the pipeline expanded lateral or upheaval at designated location to relieve the pipeline expansion. The design is analyzed by using ANSYS to validate the modeling.

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