Research Progress in Mechanical and Manufacturing Engineering Vol. 3 No. 1 (2022) 444-450
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RPMME

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

Finite Element Analysis of Pipeline Upheaval Buckling with different Initial Imperfections

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DOI: https://doi.org/10.30880/rpmme.2022.03.01.046
Received 15 Nov. 2021; Accepted 15 April 2022; Available online 30 July 2022

Abstract: Upheaval buckling is among the most common issues endangering the safe functioning of subsea pipelines, and it is caused by temperature and inner pressure increases. The finite element approach was used to investigate the upheaval buckling behaviors of five groups of pipeline segments with varying initial imperfection shapes in this research. ANSYS is utilized to create and analyze five imperfection models to forecast the critical buckling temperature, Mises stress distribution along the pipeline and the position of post-Upheaval Buckling. The afore mentioned models are subjected to two analytical approaches that combine static and dynamic processes. Linear analysis is applied to carry out the assessment to the pipeline. The findings are in good agreement with previous test data. The obtained result shows that the post-buckling position is at the midpoint of pipeline segment which satisfies with recent investigation. Next, Mises stress distribution have been studied for the five groups of pipeline imperfection and comparison between them have been made successfully. The critical temperature for triggering buckling has been achieved by using the buckling load multiplier generated through ANSYS Eigenvalue Buckling. Finally, a comparison is made between the outcomes of this study and earlier studies, revealing the approaches towards the Upheaval Buckling assessment.

Keywords: Upheaval Buckling, Imperfection, ANSYS, Eigenvalue Buckling

1. Introduction

Subsea oil and gas industry mainly use pipeline to transport hydrocarbons from production facility to a receiving terminal as the most effective and efficient system for their production. High installation costs are required for pipeline burial but to prevent mechanical damage due to extensive trawling, it was done to insure high pressure and temperature of hydrocarbon flow [1]. Global upheaval buckling (UHB) is a compressive instability phenomenon which is caused by compressive effective axial forces and vertical out-of-straightness while operating oil and gas pipelines at high temperature and pressures. This phenomenon will cause the pipeline to get unstable and result in significant large vertical upward displacement of the buckled section or in the worst case, leakage and damage to the pipeline might occur. In subsea oil and gas operation, it is necessary to operate at high temperature to avoid condensation occurring in the pipelines, or the separation of various low-temperature constituents from the flow. The high operating pressures are also needed to gain high

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flow rates. Pipelines are normally laid at the surrounding environment temperature with zero axial tension or unrestrained pipe. The unrestrained pipe will expand due to the difference between the operating temperature and pressure. However, the axial expansion is restrained by the axial friction of the soil, thus inducing significant compressive axial loads in the pipe wall. The pipe is at risk to compressive buckling as being a long thin member and the buckling sometimes occurs at the location of an initial out-of-straightness of the pipe centerline. The burial pipeline tends to buckle vertically, with the pipe appearing from the soil and structuring an extended loop, while the laid on surface pipeline tend to buckle horizontally. The term imperfection refers to such an out-of-straightness. The imperfection increases in magnitude if an axial load is applied to the pipe meanwhile buckling occurs as the axial load increases until some critical combination of load and displacement.

2. Methodology

2.1 Modelling and setup

In this study, the scope is focused on simulating and comparing the upheaval buckling position, Misses stress distribution and critical temperature of pipeline setups. For that, the 3D model of the setup will be created in Design Modeler. A 3-dimensional linear pipeline is created and laid on a seabed. There is the thermal expansion on both side of the pipeline that will created axial compression and distributed load as a downward force acted on the Y-axis of pipeline. Figure 1 shows the setup for the simulation while Table 1 and Table 2 summaries the parameter setup.

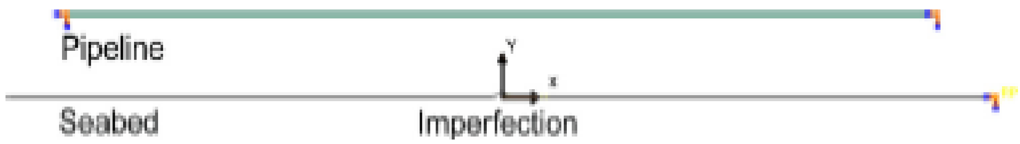


Figure 1: Setup for simulation

Table 1: Parameter for pipeline model

Parameter	Value
Diameter, D (mm)	214
Wall thickness, t (mm)	14.3
Length, L (m)	200
Young's Modulus, E (MPa)	207000
Poisson ratio, ν	0.3
Thermal expansion coefficient, α	$1.10x10^{-5}$
Submerged weight, q (N/m)	1500

Table 2: Parameter for seabed initial imperfection

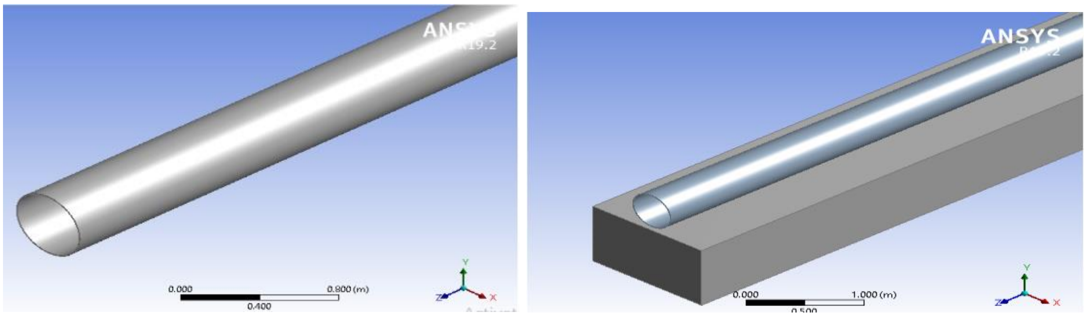
Imperfection	Wavelength, L_0 (m)	Maximum height, w_0 (m)
0.1m	100	0.1
0.2m	100	0.2
0.3m	100	0.3

0.4m	100	0.4
0.5m	100	0.5

A total of five different pipeline initial imperfection setups are used for this study to observe and differentiate the position of upheaval buckling, the Misses stress distribution and the critical temperature between different setups. The downward force per unit applied on pipeline segment is modeled by identical and evenly distributed linear loads with its value 1500 N/m [2]. The change of temperature is 200 °C which is used to model the axial loads caused by both change of temperature and internal pressure. The load step used in the analysis is 10 load steps to configure the whole temperature and distributed load changes. Inner and external pressure are varying from 1.5 MPa to 15.0 MPa and 1.0 MPa to 10.0 MPa respectively.

2.2 The geometry

The model was created in Design Modeler by referencing the parameters mentioned previously. The circular tube of pipeline is created with outer diameter of 214 mm and wall thickness of 14.3 mm that produced a thin cylinder pipeline. This is to accommodate the fact that the thermal expansion will be in both side of the pipeline. The seabed also be created to place the pipe on its so that the upheaval buckling could be simulate. The seabed is created with 200 m of length, 1.3 m of width and 0.8 m of height. When creating the seabed, the wavelength, L_0 and maximum height, w_0 for five imperfections are considered in order to accommodate the pipeline imperfections. So, basically, imperfections can be describe as the change of maximum height, w_0 and wavelength, L_0. The wavelength, L_0 maintains its value of 100 m for five imperfections and the maximum height, w_0 varies its value from 0.1 m to 0.5 m with increment of 0.1 m for five imperfections.



Pipeline Pipeline in contact with seabed

Figure 2: Geometry of pipeline

2.3 Model validation

In the research of (Zhang & Duan, 2015), the same pipeline model also has been taken to validate the proposed Finite Element Model [4]. The in place step procedure for model setup is considered to verify the research. Firstly, the beginning of in place step of the procedure can be observed in figure below. The pipeline propagates downward to the seabed as the gravity is applied. At the end of this step, initial imperfection of pipelines is established (both 2 mm and 30 mm imperfections) which is deferred from this research but similar in term of in place step. Figure 3 shows the end of the pipeline is pinned and the symmetrical pipeline respectively.

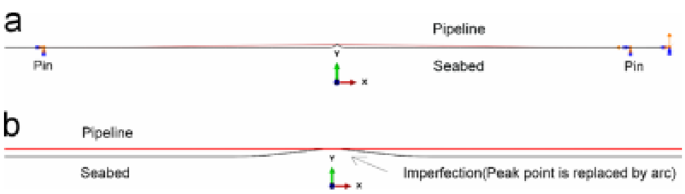


Figure 3: 2D finite element model at the end of in place step

2.4 Meshing

In buckling simulation, meshing is one of the most important step as it determines the accuracy of the calculation outcome. The smaller and the finer the mesh size, the more accurate the result is. However, very fine mesh can result in immensely long calculation time, even for a powerful computer. It may also result in instability or even program crashes. The sweep method with element size of 10 m is applied to the pipeline. Reducing the element size will be causing errors, complicating the case problem and taking a longer time to process. In a way to overcome this is by adjusting the suitable element size. Meanwhile, the body sizing method is used for the seabed with element size of 10 m. The mesh section is referred from [4] which state that Discrete rigid element R2D2 is adopted to model the foundation. The whole foundation is divided into 200 elements.

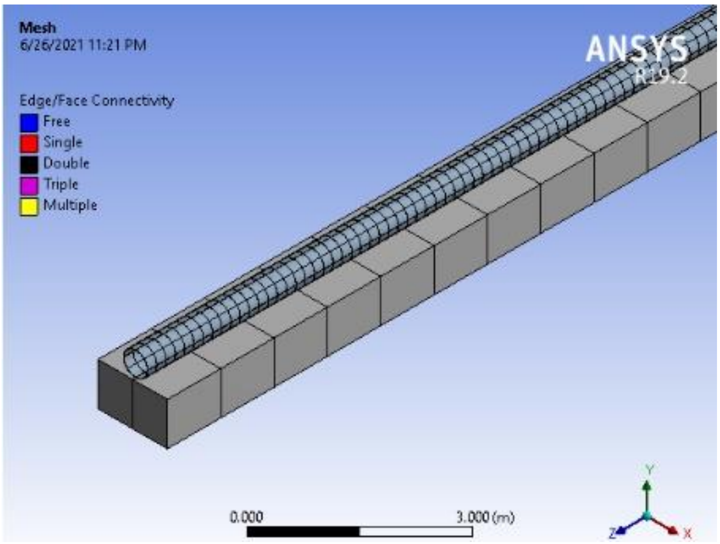
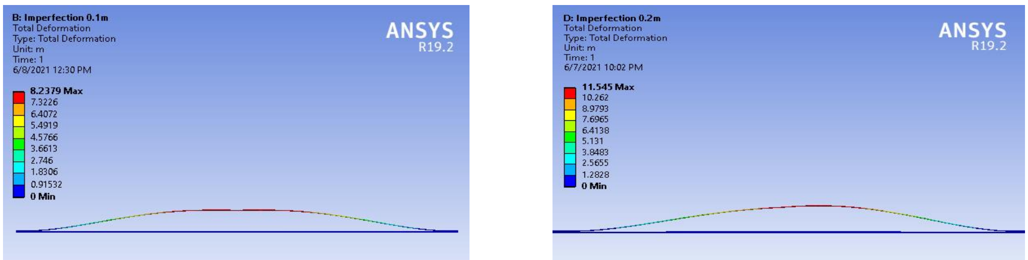


Figure 4: The mesh is created for pipeline and seabed

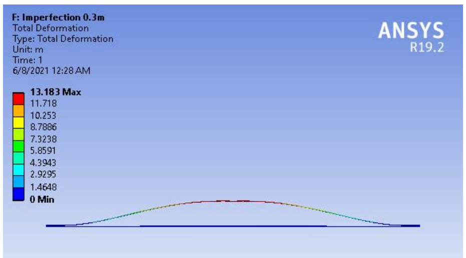
3. Results and Discussion

3.1 The position of Upheaval Buckling

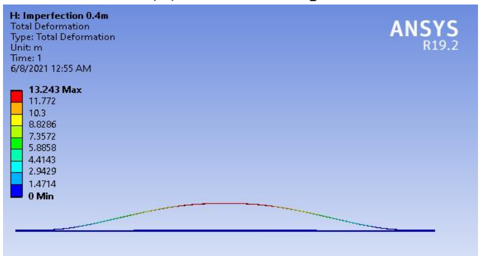
When temperature and distributed load increase, the deformation values for 0.1m to 0.4m pipeline imperfection increase linearly until 0.5m pipeline imperfection, which the deformation value did not increase linearly with the pipeline imperfection value. This deformation result is compared to the [4] and see that the position of upheaval buckling happened at the midpoint of pipeline segment. The upheaval buckling firstly happens on the positions (buckling points) at the left and right side with a certain distance to the midpoint of the pipeline segment. When the temperature and axial force increase, vertical displacement of buckling points also increases and the midpoint begins to move upward, at the same time the maximum stress begins to decline. Until the maximum stress attaining a minimum value, the heights of buckling points and the midpoint are almost the same. It explained that the increasing of temperature and axial force, a local transfer of strain energy occurred from the buckling points to the midpoint of pipeline segment.



(a) 0.1 m setup

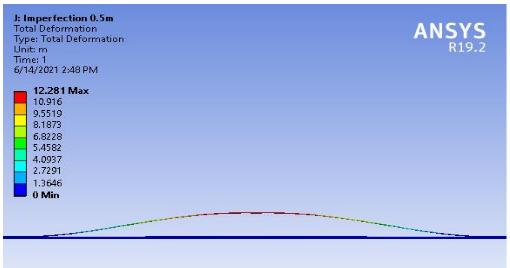


(b) 0.2 m setup



(c) 0.3 m setup

(d) 0.4 m setup



(e) 0.5 m setup

Figure 5: Total deformation contour plot at 200°C and 1500Nm

3.2 Mises stress distribution

The Mises stress is generated in contour plot and graph to show the stress distribution along the pipeline when experience buckling. The stress comparison between the different pipeline imperfections also has been made to investigate the relationship between Misses stress and temperature. Every imperfection setup is not similar in stress distribution due to the pipeline imperfection design that affect the upheaval buckling analysis. The relationship between Mises stress and temperature has been analyzed which is increasing linearly with each other. When temperature reaching its maximum limit of 200°C, the Misses stress also reaching its maximum value same as the relationship getting from research [4].

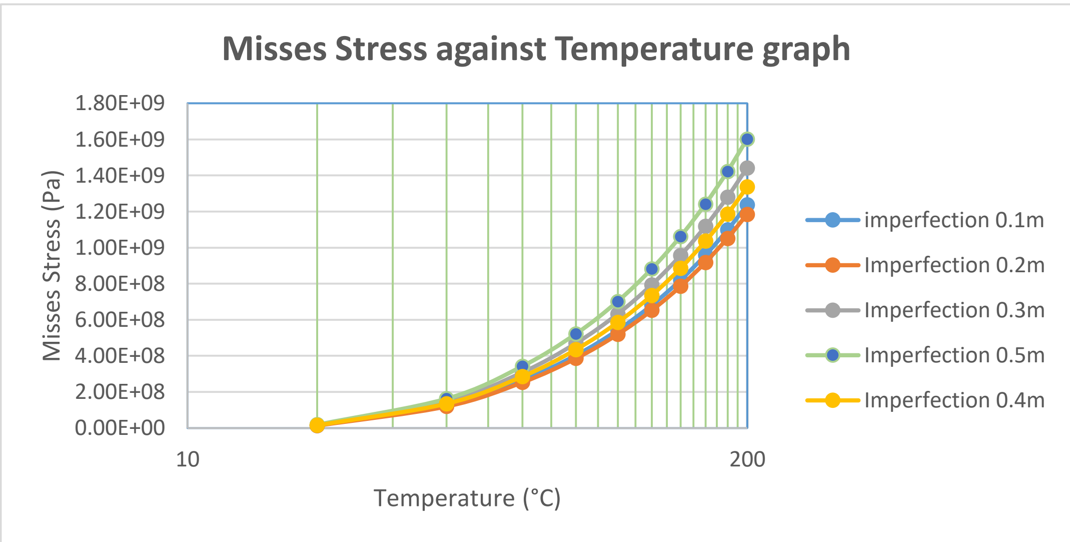


Figure 6: Graph of Mises stress against Temperature for all imperfections setup

3.3 The critical temperature

There is no critical temperature for the imperfections, instead to the temperature of pipeline first-lift-off [4]. The temperature of pipeline first-lift-off refers to the minimum temperature needed to buckle. It does not matter that these values become a part of data. The load multiplier obtained from ANSYS Eigenvalue Buckling is being used to calculate the critical temperature using the critical temperature formulation**.** By comparing to the recent investigation by research [4], there is slightly difference in value of critical temperature for pipeline imperfections. The recent result shows the linear increasing value of critical temperature from 0.1m to 0.2m pipeline imperfection. Then, the value is decreases from 0.2m to 0.3m pipeline imperfection and increased again from 0.3m to 0.5m pipeline imperfection. There is an uneven trend to the value of critical temperature for recent investigation compared to the obtained result. The uneven trend from recent investigation is due to the factor of Out-of-Straightness or in other words is imperfection condition that affected the critical temperature for imperfection 0.3 m. The imperfection for 0.3 m is not well analyzed caused by the factor [4].

Meanwhile, for the obtained critical temperature, the trend is increasing linearly from 0.1 m to 0.5 m pipeline imperfection. For more details, the trend for obtained result and recent investigation can be observed in Figure 7. The relationship for critical temperature against pipeline imperfection is increasing linearly with each other.

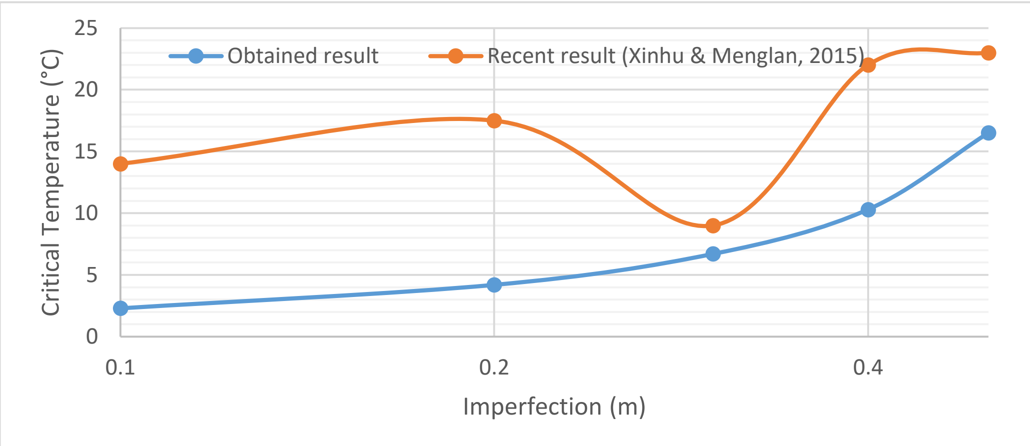


Figure 7: The graph of critical temperature against pipeline imperfection for both result

4. Conclusion

Throughout this analysis, the approached mechanical analysis is used to numerically evaluate the upheaval buckling of different pipeline imperfections. The simulation research was carried out using the linear case procedure used to calculate the quantity. From the aforementioned, we may conclude that upheaval buckling of a pipeline segment with an initial perfection will most likely occur at the midpoint of pipeline segment as the in place pipeline is at middle of seabed. As in case of the position of upheaval buckling, all the imperfections buckled at the midpoint of pipeline segment. The result obtained from the simulation test was compared with the previous research, which created a significant agreement between the parameters and results. The second case which is the Misses stress distribution along the pipeline also has been obtained and acquired the relationship between the stress and temperature. However, the simulation analysis had its own limitation because it demanded very high specification of computer to process the model in discrete way. Therefore, due to this problem, the time limitation of the duration of the project would take a lot of time. The results from the numerical simulations provide a strong understanding of applying the load multiplier from ANSYS into engineering case problem that have been examined and analyze it well. This study proved that ANSYS Mechanical (Static Structural and Eigenvalue Buckling) modeling shown to be very helpful in processing further and more comprehensive numerical study of the buckling phenomenon. Throughout the analysis, there may not be a necessary for pipeline burying or trenching (which is a well-known technique associated to shallow seas) because of the significant expense and skill needed. As a result, installing the pipeline on the seabed is a feasible alternative.

Acknowledgement

The authors would like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia for the support in implementing the research.

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