Free Span Assessment of Offshore Pipeline by Using Finite Element Method

by

Aqilah Binti Abu Bakar
13677

Final year dissertation submitted in partial fulfillment of
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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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(Dr Zahiraniza Mustaffa)

UNIVERSITI TEKNOLOGI PETRONAS

May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AQILAH BINTI ABU BAKAR

ABSTRACT

Free spanning pipeline is considered a threat towards pipeline that needs to be inspected for its reliability. The main purpose of this research is to investigate the structural integrity of a free spanning pipeline. Finite Element Simulation method is used. Different length of free spanning pipeline will act under different loading (pressure) for the simulation of stress distribution towards the pipeline. The result the free spanning simulation will lead to the result for monitoring or repairing work towards the free span. At the end of this research, finite element modelling (FEM) simulation is proven to be a reliable tool for free spanning pipeline assessment.

ACKNOWLEDGEMENTS

Praise to god, thank for all his blessing; most of all, I want to thank The Almighty for the amazing love that knows no boundaries. Without His blessings, none of my work will be a success.

First and foremost, I have to thank my research supervisor, Dr Zahiraniza Mustaffa. Without her assistance and dedicated involvement in every step throughout the process, this paper would have never been accomplished. I would like to thank you very much for your support and understanding over these past two semesters.

Most importantly, none of this could have happened without my family. To my family – thank you so much. Every time I was ready to quit, you did not let me and I am forever grateful. This dissertation stands as a testament to your unconditional love and encouragement.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Generally, offshore pipelines are used to transport oil and gas. Being a medium of transportation for oil and gas product, pipelines are also used for several other purposes in the development of offshore resources. Bai (2001) states the roles of offshore pipelines as:

- Exporting pipelines
- Flow lines to transfer product from a platform to export lines
- Water injection or chemical injection flow lines
- Flow lines to transfer product between platforms

The ever increasing offshore works due to popular demand call for further simulation to the use of offshore pipelines. In line with that, pipeline monitoring and maintenance activities work vigorously forming integrity management. Integrity management serves as an important part in order to ensure pipeline continuous functionality as pipeline carries a vital role in the transport of energy and impact towards environment in case of incidents and threat. The examples of threats to pipeline are internal and external corrosion, free span, erosion, on-bottom stability as well as external damage.

Today, offshore pipelines have significant role in the development of oil and gas industry. In this industry, most pipelines are laid on seabed by various methods. For example embedded in a trench that is a buried method or laid on uneven seabed, an unburied method. Construction of unburied pipeline is the most common method due to its rapid and economic performance. However, this method exposed the pipelines to several lengths of free spanning through its service life and this may threaten the pipelines safety.

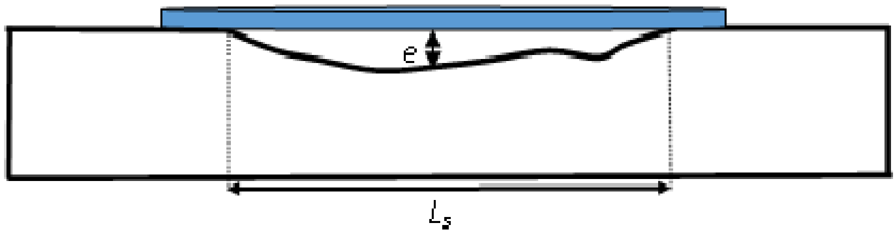


Figure 1: Free Spanning Pipeline

Free span is defined as the gap between the pipe and the supporting seabed. Based on Figure 1, the free span length is noted as L_s while e is the distance between bottom of the pipe and seabed. Bakhtiary et al. (2007) mentioned that free spanning in offshore pipelines mainly occurs as a result of uneven seabed topography as well as local scouring due to turbulence by flow and instability. Thus, it can be safely concluded that free spanning existence for unburied pipeline is completely predictable.

Thus, this research presents the reliability of free spanning pipeline by using Finite Element Modelling (FEM). In this research, the free span that requires monitoring or repairing work will be distinguished.

1.2 Problem Statement

In a pipeline, the number of free span occurring varies with length of pipeline. In most cases, number of free span is high when the length of pipeline is longer. As the free span occurring is big in number, the identification of free spanning pipeline that requires rectification becomes harder. As the presence of free span along the length of pipeline may result in excessive displacement and bending or vibration of the pipeline section, the identification process must be done to avoid the situation from worsen.

Thus, an assessment of free spanning pipeline is crucial in order to ensure the reliability of these pipelines. In current practice, the DNV RP F109 Free Spanning Pipeline serves as a guideline of assessments of free spans subjected to combined wave and current loading. However, numerical method analysis is also believed as a reliable approach to simulate the pipeline reliability. Thus, FEM is adopted as an approach to achieve the objective.

1.3 Scope of Study

The scope of this research paper is to assess the integrity of free spanning pipeline by using FEM. A case study for a gas pipeline in east coast area of Peninsular Malaysia is selected as a verification case study. For obvious reason, like that of complete data availability, the aforementioned pipeline is chosen. The gas pipeline is named Pipeline X throughout this whole research.

The pipelines are drawn using *Computer Aided Three-dimensional Interactive Application V5 P3 (CATIA).* Five different model off various free span length are drawn. The entire range of computer simulation however, is performed using *ANSYS Workbench 14.0.* The untrenched, simply supported pipelines are then subjected to various pressure. The free spanning pipeline simulation will result in the stress distribution of the free span under different pressure.

1.4 Objectives of Study

The primary aim of this research is to perform a computer-based simulation assessment on free spanning pipeline, subjected to five different internal pressure. Free spanning pipelines are modelled and simulated by using Finite Element Modelling (FEM) and later described in this report.

To complement the latter, the second objective is to identify the free span that require monitoring and decision for rectification work. The differences are made based on the result of simulation itself, together with the support of information from DNV RP F109 Free Spanning Pipelines.

1.5 Relevancy & Feasibility

This research suggests a method to address free spanning pipeline assessment for its reliability. The method may provide an insight into the identification of free spans with regards to differing pipeline length, soil characteristics and length of free span. The author then appropriately infers this to deem the project as industrially relevant.

As for the time basis, the author concludes that the project is progressing as planned although there were slight hiccups along the way, the project is completed as scheduled.

CHAPTER 2

LITERATURE REVIEW

This chapter encompasses a comprehensive review of key elements and concepts that is crucial in gaining a sound grasp of this project. These terms can be abstracted from the project theme – Free spanning pipelines, In line oscillation and Cross flow oscillation.

2.1 Free Spanning Pipelines and its Causes

Free spanning pipelines are one of the important criteria during design or operation stage of submarine pipelines. In order to ensure a safe operation of offshore product during installation stage, the free span length shall be first determined and maintained within its allowable length. The many types of free spanning condition is as shown in Figure 2. Various situation of free spanning pipelines are due to the pipeline location itself and the behaviour of current in the water.

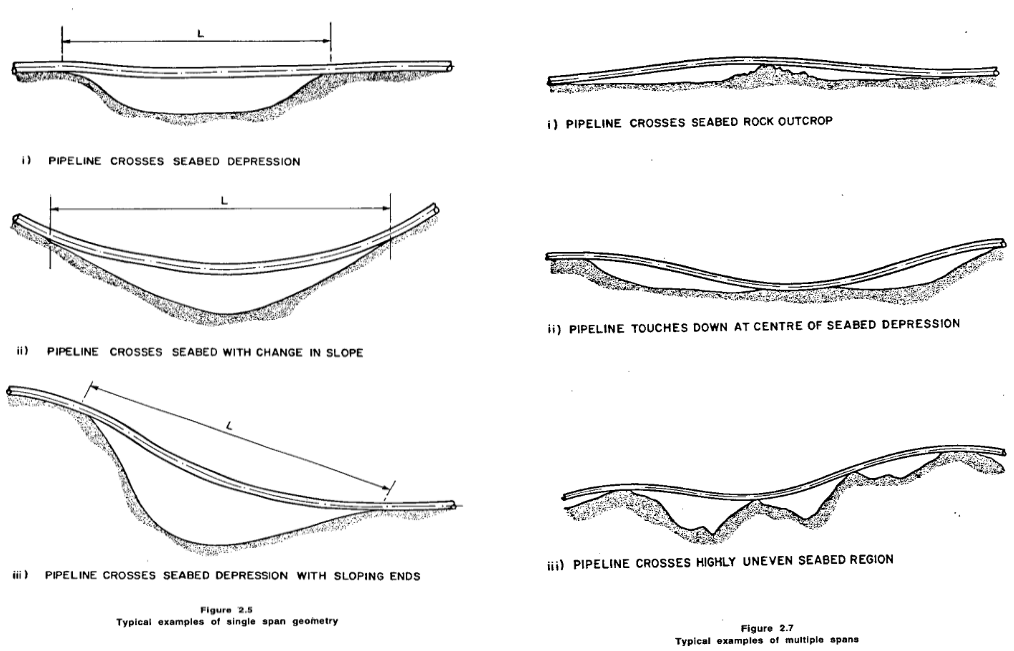


Figure 2: Type of Free Span.

Free spanning can occur when the contact between pipeline and seabed is lost over an appreciable distance on a rough seabed (Guo et al., 2014). A few researches made beforehand by Bakhtiary et al. (2007) and Mehdi et al. (2012) agree that the reasons of the existence of free spans in subsea pipelines are due to the seabed irregularity and by scouring phenomena existing around the installed non-buried pipeline. The aforementioned statement is then supported by an established code that is widely used by pipeline engineers, DNV-RP-F105 Free Spanning Pipelines, as it mentioned that free span can be caused by seabed unevenness, change of seabed topology, artificial support as well as strudel scours.

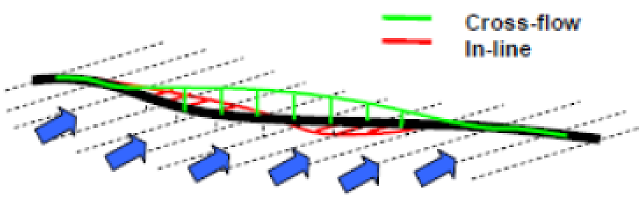


Figure 3: Ideal VIV Model for Free Spanning Pipeline.
From: Koushan, K. (2009) Vortex Induced Vibrations of Free Span Pipelines.

Vortex induced vibration (VIV) that is caused by steady current is recognized to be one of major sources for dynamic loads in free spanning pipelines. As the free span length grows larger that the allowable limit, the free span is most likely to experience VIV (Choi, 2000). Figure 3 shows a typical VIV of free spanning pipeline that illustrates flow and motion that acts on the pipeline. The flow of wave and current around a pipeline free span results in the generation of sheet vortices in the wave. These vortices are shed alternately from the upper and lower part of the pipe resulting in an oscillatory force being exerted on the free span. Resonance may be reached when the frequency of vortex shedding approaches the condition when the frequency of shedding approaches the natural frequency of the pipeline span. Under resonant condition, sustained oscillations can be excited, and the pipeline will oscillate at a frequency (Guo et al., 2014). The resulting vibration may threaten pipeline integrity and this might lead to fatigue failure. Therefore, free spans and fatigue due to vortex induced vibrations (VIV) is an important design aspect in pipeline engineering.

VIV takes place as the flow of current comes in all direction around the pipeline. According to Beckmann et al. (1991), at lower flow velocities, vortex shedding is symmetrical, i.e. vortices are shed simultaneously from both sides of the pipe. While at higher velocities, vortex shedding is asymmetrical, i.e. a vortex is shed from one side of the pipeline followed by a vortex shed from the other side in an alternating pattern. Symmetrical shedding causes the pipeline to vibrate in line with flow direction. While asymmetrical shedding, however, causes two components of vibration. Referring to Figure 2, the two components are in line and cross flow motion. In layman term, the in line motion refers to the motion that is in the direction of the flow while cross flow motion is perpendicular to the flow. The in line motion exists in the similar direction with every vortex, though the cross line motion alternates direction. Inline excitation is at a frequency twice that of cross flow excitation and has a smaller motion amplitude and stress. Guo et al. (2005) studies that in line oscillations are excited at flow velocities lower than critical velocities for cross flow motion. The severe motion in the cross flow direction causes a high degree of potential to be more dangerous than in in line direction. This situation is due to the amplitudes of response in earlier mentioned motion are larger than those associated with in line motion. However, these oscillations occur at much larger velocities than in line oscillations and are not normally governing.

A free span failure case recorded at the subsea pipelines in the Cook Inlet in South Alaska experienced fourteen failures due to VIV between 1965 and 1976. While in another case at East China Sea, Ping Hu pipeline failed at two locations during the autumn in 2000 due to VIV (Fyrileiv et al., 2005). These cases are the most distinctive evidences to show how severe free span might affect pipelines. However, the expenses related to seabed correction and free span rectification would incur substantial costs thus making these projects considerable. Therefore it is highly relevant to investigate in depth whether such intervention work is necessary.

2.2 Offshore Pipeline Design Code

DNV RP F109 Free Spanning Pipeline is a recommended practice to account for technical research for free span problems. This guideline also provide design methodology as well as acceptance criteria for fatigue, thus making it possible to select the cost effective methods in design and operational phase. Pipeline deflections and natural frequencies for both in line and cross flow motion can be determined for the effective span length calculation by using the guideline. According to Elsayed et al. (2012), DNV suggested three approaches for assessment; dynamic lateral stability analysis, generalized lateral stability method and the absolute lateral static stability method. Any of these approaches are highly recommended to be used according to environmental and pipeline condition. Figure 4 shows a flow chart for the design checks for a free span according to this code. In current practice, pipeline engineers obey to this flow chart in order to assist free spanning severity on offshore pipelines.

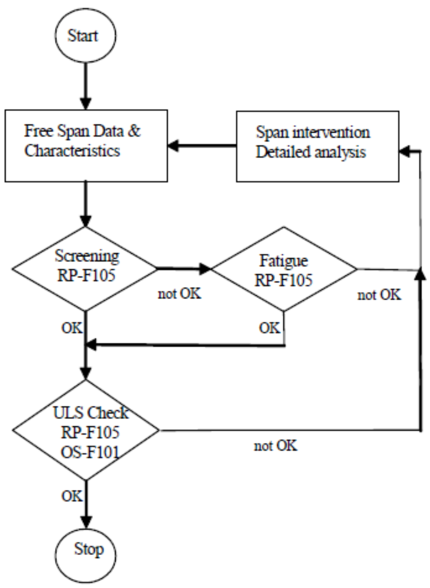


Figure 4: Free Span Assessment Flowchart based on DNV RPF109 Free Spanning Pipelines

2.3 Assessment of Free Spanning Pipelines

The number of free spans in a pipeline varies from none to hundreds and could reach thousands depending on the pipeline's length, seabed and ocean condition. The existence of such amount of free span on offshore pipeline requires close monitoring by pipeline engineers especially to the free spans that has exceeded the maximum allowable free span length calculated. FEM is foreseen to be a reliable tool to assist such assessment. Generally, FEM adopts the idea of dividing a large body into small parts. These small parts are called element, and are connected at predefined points called nodes. In this research, free span is the element and the pipeline is labelled as the large body.

A research done by Elsayed et al. (2012), adopted finite element model approach for the checking of free spanning condition in subsea pipelines subjected to hydrodynamic forces resulting from wave and currents with pipe soil interaction. FEM modelling was basically simulated using finite element package, ANSYS. The simulation allowed friction forces as well as soil stiffness to be involved in the analysis. The pipeline is modelled as a rigid structure while the seabed is considered as a flat non-deformable area. ANSYS contact elements have been used to model the contact between the two. Meanwhile, the seabed soil stiffness is used to state the contact stiffness between seabed and pipeline. Apart from that, a number of elements used for the modelling of the pipe-soil interaction and contact between pipeline and seabed. The pipeline stress is then calculated using Von Mises Stresses equation, following the recommendation by DNV RP F109 Free Spanning Pipelines.

In another research done, it is concluded that a number of parameters contributes to the vortex shedding induced response of the pipe. Namely, pipe soil interaction, turbulence in current and wave flow, seabed vicinity, pipeline sagging, flow inside the pipeline and also dynamic coupling between adjacent free span. Various investigations handled beforehand regarding each parameter in order to understand free spanning pipeline in depth. These parameters are handful in estimating the pipeline fatigue life. The quality of estimation of pipeline design life for a specific free span at a specific location greatly depend on the quality input, specifically the analysis tool itself. Many research programmes aimed in predicting the VIV response correctly (Yttervik et al. 2003). In an investigation by Ytterrvik et al. (2003), the fatigue life design estimation focuses on the VIV of free span by using the current speed and direction. The findings implies that as the free span length is reduced, the flow speed that is required to create VIV increases but the number of occurrences of VIV (for a given distribution of flow speed) decreases. Simultaneously, when VIV is created, the stresses that occur, also increases.

Therefore, it is difficult to estimate the fatigue life early since free span length changes with current condition. The researchers then concluded that a detailed analyses, using a pipeline model is necessary to clearly define the fatigue life of a free spanning pipeline.

A related research by Fyriliev et al. (2003), assessed long free spanning pipelines for its VIV induced fatigue condition. By fully using the design methodology of DNV RP F109 Free Spanning Pipelines, VIV is identified as a displacement controlled load due to its probability of span length change with the vibration amplitude. The code applies response models to predict the amplitude of vibration due to vortex shedding. Thus a comparison between the response model and FATFREE software is done to identify the best method to estimate its fatigue life. However, the computational procedure is revealed to be not very sensitive.

Very irregular seabed condition results in large number of free spans. The measurement for the severity of free span is by the length to the diameter ratio (L/D). Current practice for free span design is relevant for L/D ratios up to approximately 120 (Nielsen et al., 2002). For the spans below this value, the stiffness of pipeline is significant to the beam effect. And as for free spans that has L/D ratio much larger than 200 are dominated by cable effect which contributes significantly to the stiffness.

DNV RP F109 proved that research made by Nielsen et al. (2002) is correct and the method used is highly reliable. On the other hand, the response classification of L/D ratio according to DNV RPF109 is as shown in Table 1.

Table 1: Free Span Response Classification

L/D	Response description
L/D < 30	**Very little dynamic amplification** Normally not required to perform comprehensive fatigue design check. Insignificant dynamic response from environmental loads expected and unlikely to experience VIV.

30 < L/D < 100	**Response dominated by beam behaviour** Typical span length for operating conditions. Natural frequencies sensitive to boundary conditions (and effective axial force)
100 < L/D < 200	**Response dominated by combined beam and cable behaviour** Relevant for free spans at uneven seabed in temporary conditions. Natural frequencies sensitive to boundary conditions, effective axial force (including initial deflection, geometric stiffness) and pipe “feed in”.
L/D > 200	**Response dominated by cable behaviour** Relevant for small diameter pipes in temporary conditions. Natural frequencies governed by deflected shape and effective axial force.

Table 2 summarized the literature review as discussed in the earlier part of this section. In a nutshell, DNV RP F109 Assessment of Free Spanning Pipeline shall be the first reference to be used in assessing free spans. While Nielsen et al, (2002) agreed to the response classification as written by DNV RP F109. This shows that free span carries different characteristics according to its length. Meanwhile, Elsayed et al, (2012) used the same tool as the author that is FEM and proven that the simulation values are within the target value. The result received is then compared with hand computation and shows a positive remark. In another research conducted by Choi (2000), it is concluded that axial load of pipeline affects the natural frequency and allowable span length at the same time.

It is also mentioned that the free span analysis may be based on approximate response expressions or a refined FEM approach depending on the free span classification and response type (DNV RP F109, 2006). Thus, it is safe to say that FEM is believed to be a reliable approach as DNV RP F109 also suggests the usage of this method.

Table 2: Summary of Literature Review

No	Author	Title	Methodology	Result
1.	Det Norske Veritas	DNV RP F109 Assessment of Free Spanning Pipelines	Estimating the magnitude of IL & CF oscillations	Recommended practice by pipeline engineers
2.	Nielsen et al.	VIV Response of Long Free Spanning Pipelines	Model Test – setting up model by adding support. Observe the effect of free span length under VIV.	a)Short span – beam dominated behavior b)Intermediate spans – semi-cable behavior c)Long spans – cable dominated behavior
3.	Elsayed et al.	A Finite Element Model for Subsea Pipeline Stability and Free Span Screening	a)FEM simulation by using ANSYS b)Result comparison with pipeline lateral displacement calculation using Von Mises Stress equation	a)Computed displacement by using ANSYS are within target values b)Proposed approach is a reliable tool
4.	Choi, H.S.	Free Spanning Analysis of Offshore Pipelines	Closed form solution considering beam-column equation considering tension and compression forces	a)Axial load of pipeline affects the natural frequency and allowable span length at the same time. b)Beam column equation are used to find natural frequency

				of pipeline.

CHAPTER 3

METHODOLOY

This section elaborates a discussion on the means used in performing the research, from how information was grasped till how the project was structured and executed.

3.1 Research Tool

Internet resources. In the early stage of this research, a sound study on the key component such as the causes of free spanning pipelines is conducted. Simultaneously, sourcing for literature prevalent to free spanning pipeline is carried out. The access to UTP's online subscribed resources via OpenAthens other than material from Google Scholar is maximally used in order to perform a concise study

Computer Aided Design (CAD) and Simulation. Two software are used in this research. The software namely *Computer Aided Three-dimensional Interactive Application V5 P3 (CATIA)* played a crucial role in modelling pipeline model while *ANSYS Workbench 14.0* is primarily used for simulation of free spanning pipeline as a while.

Conversing with lecturers and seniors. Some parts of the research was performed via word of mouth, consultation with lecturers and chatter with post graduate students in order to make up for the short coming of the small number of relevant documented materials made available.

3.2 Research Methodology

The research is broken down into three major sections. The first part kick off as a preparatory stage which provides great emphasis on data collection and familiarization of literature review, alongside with *ANSYS Workbench 14.0* software training.

At the initiation phase, all stresses and loads towards the pipeline is identified since these factors influence the failure of a free spanning pipeline. Concurrently, the natural frequency of the free spanning pipeline will also be determined. Then, the natural frequency will deduce to the maximum allowable free span value of the pipeline. From the value, all free spans that exceed the allowable limit will be identified. Five different span length are selected and then further tested.

The free spanning pipelines modelled using finite element modelling allow various range of analysis. Finite element modelling involves variety model shapes and material behaviour. Thus, ANSYS allow its users to simulate the critical area and deforming surfaces. Free spanning pipeline modelling includes several stages before the analysis can be executed. The stages involved are as stated in Figure 5.

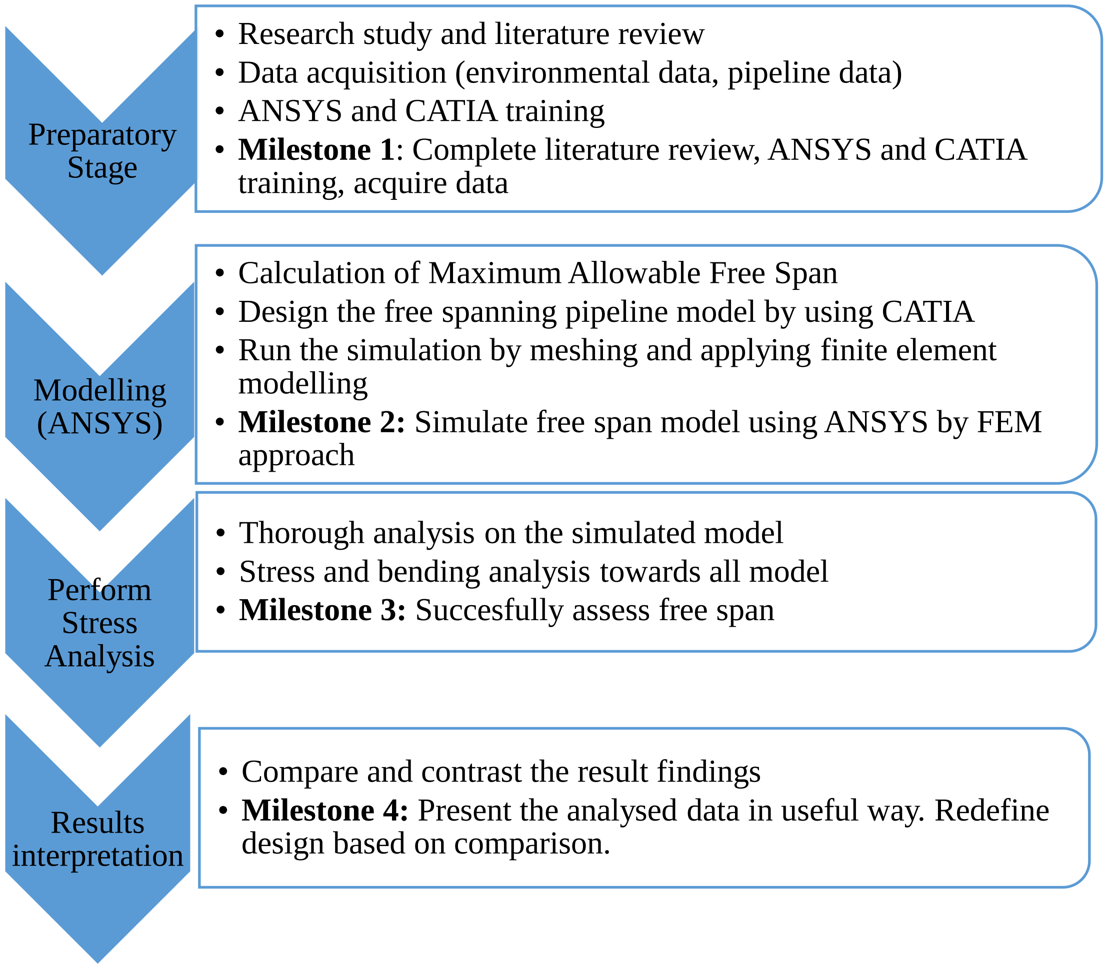
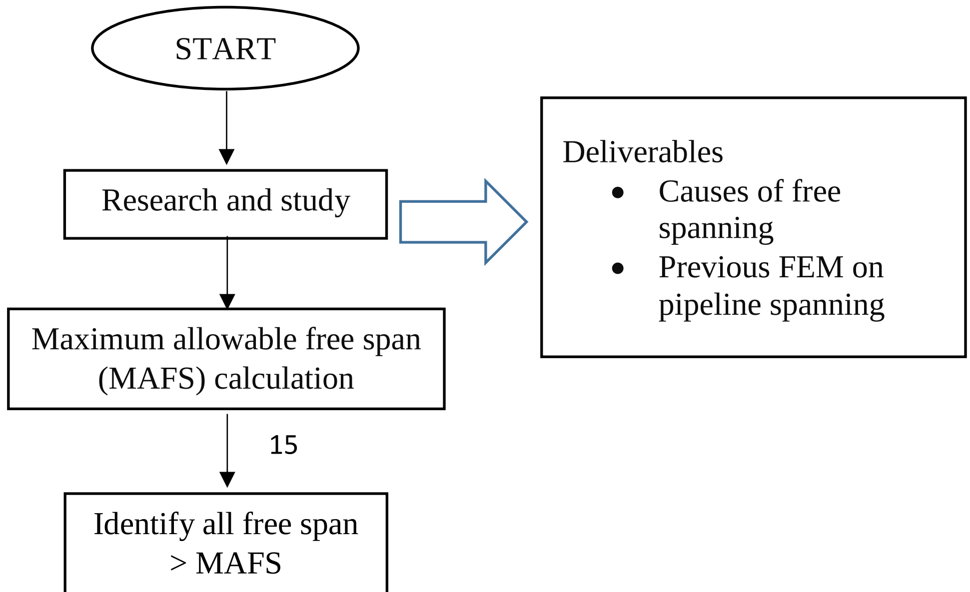


Figure 5: Generic Project Methodology/ Flow with Key Milestones

3.3 Research Flow

Figure 6 depicts the flow of this research according to the author planning.



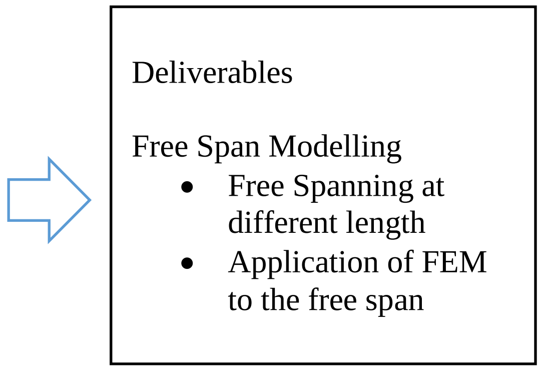


Figure 6: Flow chart of research

3.3.1 Gathering Pipeline Properties

A gas lift pipeline is adopted to be the subject for this research. Throughout this report, the pipeline is named Pipeline X. Located in the east coast area of Peninsular Malaysia, Pipeline X is used as a verification case study. Table 3 shows the pipeline data.

Table 3: Pipeline Operating Data

Description	Unit	Pipeline X
Outside Diameter	mm	168.3

Length	km	7.1
Pipeline Wall Thickness	mm	9.5
Service	Gas lift	
Design Pressure	MPa	13.8
Operating Pressure	MPa	7.7
Design Temperature	°C	60
Operating Temperature	°C	37

3.3.2 Calculation of Maximum Allowable Free Span (MAFS)

One of the key drivers in this research is a proper definition of free span length limit which will then be used in the simulation. The maximum allowable free span length is calculated in order to draft a limit before undergoing the latest underwater inspection report. The following are the steps used to calculate the maximum allowable span length for Pipeline X.

Step 1: The design current is determined (100 year near bottom perpendicular to the pipeline)

Step 2: The effective unit mass of the pipeline is calculated.

Step 3: Reynolds Number is calculated.

Step 4: Stability parameter is calculated.

Step 5: The reduced velocity for in-line motion is determined based on stability parameter calculated.

Step 6: The reduced velocity for cross flow motion is determined based on Reynolds Number calculated.

Step 7: Based on the terrain and conditions involved, the type of free span end conditions is determined and the end condition constant is calculated.

Step 8: The critical span length for both in line and cross flow motion is calculated.

It is noted that table 4,5 and 6 contains the relevant information that aided the calculation while calculation for critical length is shown afterwards.

Table 4: Pipeline Data

Description	Symbol	Unit	Value
Pipe Outer Diameter	d_0	mm	168.3
Wall Thickness	t	mm	8
Pipe Material Grade	-	-	API 5L X52

Corrosion Coating Material	-	-	CTE
Corrosion Coating Thickness	t_c	mm	5
Corrosion Coating Density	ρ_c	kg/m^3	1400
Concrete Coating Thickness	t_{cc}	mm	25.4
Concrete Coating Density	ρ_c	kg/m^3	3044
Product Density	ρ_{pr}	kg/m^3	50

Table 5: Environmental Data

Description	Symbol	Unit	Pipeline X
Seawater Density	ρ_{sw}	kg/m^3	1025
Minimum Water Depth	d	m	74.2
Seawater Ambient Temperature	T_{amb}	deg	25
Current velocity	U_c	m/s	0.53
Current angle to pipe axis	Θ_c	deg	90

Table 6: Other data

Description	Symbol	Unit	Pipeline X
Young's Modulus	E	MPa	207000
Seawater Kinematic Viscosity	ν	m^2/s	9.6E-07
Constant for fixed-pinned ends	C_e	-	15.4

Calculation for Maximum Allowable Span Length for Pipeline X.

Step 1: Effective Mass, M_e

$M_e = M_p + M_c + M_a$

M_p= unit mass of pipe including coatings (kg/m)

M_c= unit mass of content (kg/m)

M_a= added unit mass (kg/m)

$w_P = 0.02464\ t(d_0\text{-}t)$

w_p = unit mass of steel pipe (kg/m)

t = pipe wall thickness (mm)

d_0 = outer diameter (mm)

w_{cc} = unit mass of concrete coating (kg/m)

w_{pc} = unit mass of pipe coating (kg/m)

$w_P = 0.02464\ (8)(168.3\text{-}8) = 31.6$ kg/m

$w_{cc} = 0.02464\ (25.4)\ (193.7\text{-}25.4) = 105.33$ kg/m

$w_{pc} = 0.02464\ (5)\ (198.7\text{-}5) = 23.86$ kg/m

$M_p = (31.6+105.33+23.86)$ kg/m = 160.79 kg/m

$M_c = \frac{\pi\ (d_i)^2}{4}(\rho_{sw}) = \frac{\pi\ (0.1523m)^2}{4}(1025kg/m^3)$ = 18.67 kg/m

$M_a = \frac{\pi\ (d_0)^2}{4}(\rho_{pr}) = \frac{\pi\ (0.1683m)^2}{4}(50kg/m^3)$ = 1.11 kg/m

$M_e = (160.79+18.67+1.11)$kg/m = 180.57 kg/m

Step 2: Stability Parameter, K_s

$$K_S = \frac{2\ M_e\delta}{(\rho_{sw})(d_o{}^2)}$$

δ = total modal damping ratio (take 0.125)

$K_s = \frac{(2)(182.59)(0.125)}{(1025)0.1683)^2} = 1.56$

Step 3: Reynolds Number, Re

$Re = \frac{u_c D}{v_k}$

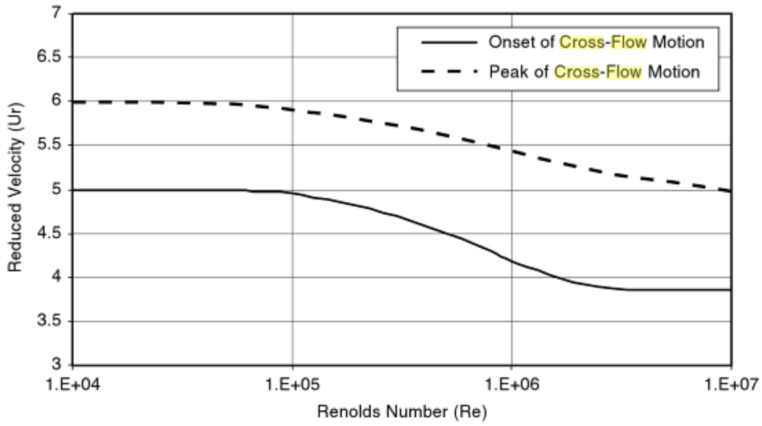
V_k = kinematic viscosity of fluid (9.6 x 10^{-7} m^2/s for seawater)

$Re = \frac{(0.53)(0.1683)}{9.6\times10^{-7}} = 9.2915 \times 10^4$

Step 4: Reduced Velocity (from DNV 1981, Appendix A, Figure A.5)

For in-line motion, graph in Figure 7 is used.

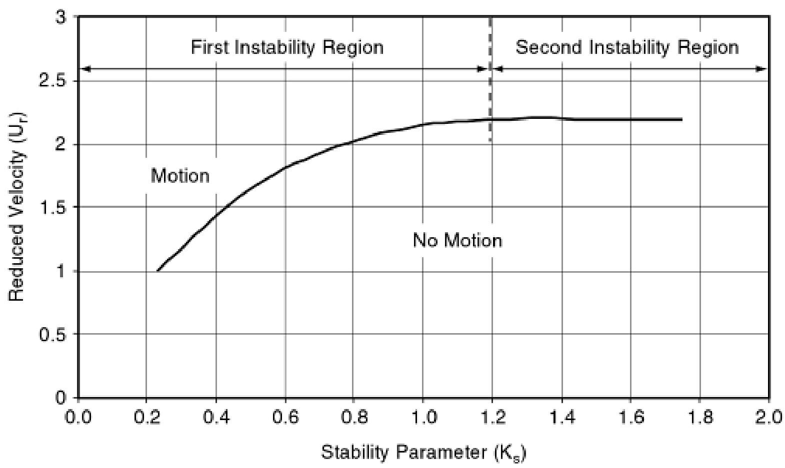
Figure 7: Reduced Velocity vs Reynolds Number



Since K_s=1.56, V_r=2.2 m/s

While for cross-flow motion, graph in Figure 8 is used.

Figure 8: Reduced Velocity vs Stability Parameter



Since Re=9.292×10^4, V_r= 4.94 m/s

Step 5: Critical span length

$$L_c = \sqrt{\frac{c_e\, v_r d_o \sqrt{\frac{EI}{M_e}}}{u_c}}$$

$$I = \frac{\pi}{64}\,({d_o}^4 - {d_i}^4) = \frac{\pi}{64}\,(0.168^4 - 0.152^4) = 1.29 \times 10^{-5}\text{m}^4$$

$$L_c = \sqrt{\frac{(2.45)(2.2)(0.1683)\sqrt{\frac{(2.07\times10^{11})(1.29\times10^{-5})}{180.57}}}{0.53}} = 14\text{m}$$

From the calculation, it is concluded that the maximum allowable free span length of Pipeline X is 14 m. Thus, 14 m is the critical length for the free span of this pipeline. Screening process are conducted to the latest underwater inspection report of this pipeline. Based on the latest underwater inspection report of Pipeline X, a total of 36 free span that exceeded 14 m was found. From the values, the author narrowed down to five span lengths to be drawn and simulated by using aforementioned software, *CATIA* and *ANSYS*. The five span lengths are 36 m, 25 m, 20m, 14 m and 10 m.

3.3.3 Modelling and Simulation Approach

For the purpose of this research, *Computer Aided Three-dimensional Interactive Application (CATIA)* is used to draw the pipeline model according to desired dimension. *CATIA* is a relevant design software that is universally used as it facilitates collaborative engineering disciplines especially in shape design, mechanical and system engineering. Five model off the same pipeline size and criteria with different span lengths are drawn. The models are of 36 m, 25 m, 20m, 14 m and 10 m in length. Figure 9 depicts a sample of free spanning pipeline of 10 m drawn using *CATIA*.

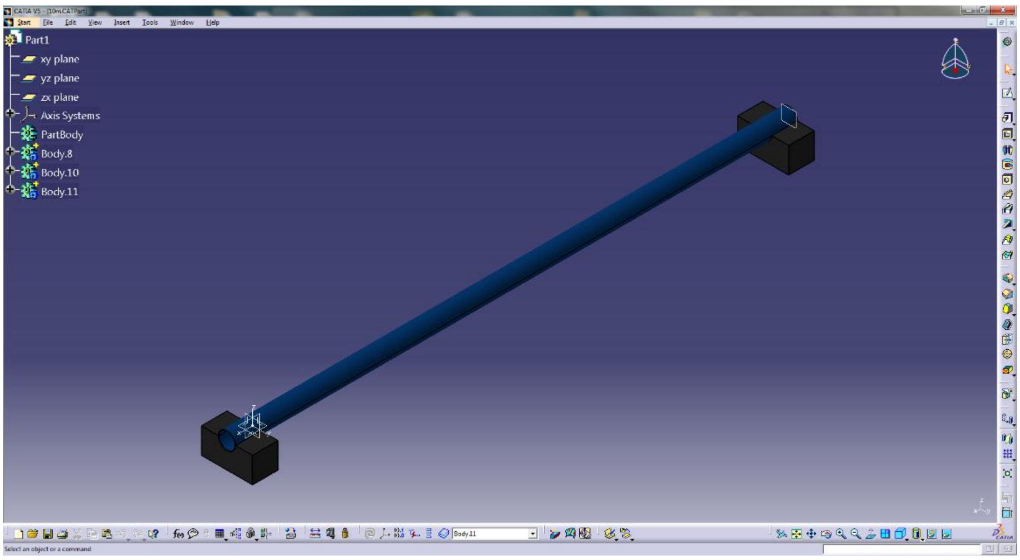


Figure 9: Free Spanning Pipeline in CATIA

While *ANSYS Workbench 14.0* is used extensively for the finite element modelling simulation. In *ANSYS*, the static structural module is used herein. Figure 10 shows the imported drawing that is ready to be simulated in *ANSYS*.

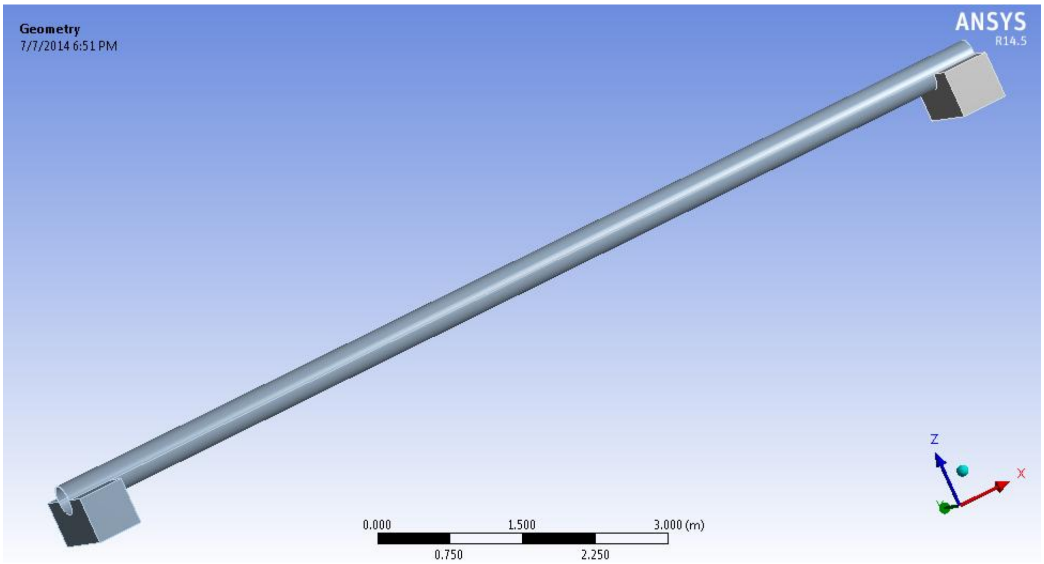


Figure 10: Free Spanning Pipeline in ANSYS

Sequentially, meshing module is used. This aims in aiding result evaluation and accuracy of finite element solution. Finer mesh produced better result. Thus, the author applied fine meshing to all models. Figure 11 shows a sample of fine meshing product.

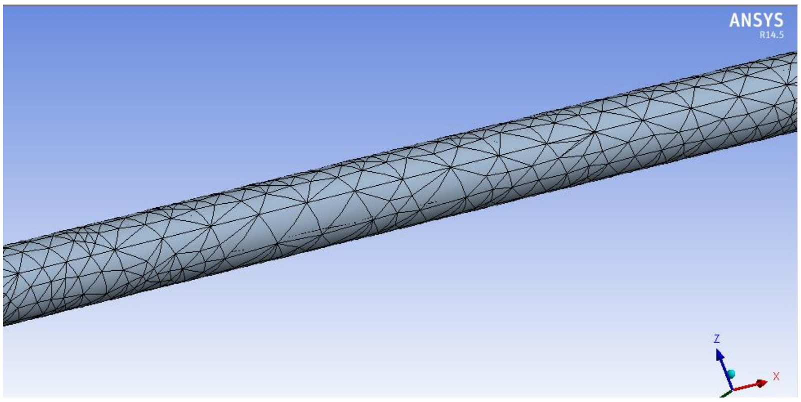


Figure 11: Fine meshing

For the simulation to be performed, several loads are applied on to the pipeline. The environmental load applied is standard earth gravity that is 9.81 m/s^2. The boundary condition of these pipeline is made fixed-fixed end at the edge of the pipe. The support functions to show the connection to other pipeline so the model is fixed in moment, displacement and shear at the edge. And lastly, the internal loading is applied to represent the internal pressure subjected to pipeline. The magnitude of load is set up by building up the internal pressure from 5 MPa, 7.7 MPa, 9.5 MPa, 13.8 MPa and 15 MPa. It is noted that <u>7.7 MPa is the operating pressure</u> for Pipeline X while <u>13.8 MPa is the design pressure</u>. Five simulations are carried out to five different span length namely <u>36 m, 25 m, 20m, 14 m and 10 m</u> to verify the effect of different loads to respective span length.

3.3.4 Simulation Expected Outcome

The expected results to be produced from the finite element modelling are the stresses when the pipeline is subjected to building up internal pressure, which is 5 MPa, 7.7 MPa, 9.5 MPa, 13.8 MPa and 15 MPa. As these pressure are acted upon five span length, which is 36 m, 25 m, 20m, 14 m and 10 m, the stresses as a result of internal pressure towards various span length are expected.

In an elastic body that is subject to a system of loads in 3 dimensions, a complex 3 dimensional system of stresses is developed. That is, at any point within the body there are stresses acting in different directions, and the direction and magnitude of stresses changes from point to point. The Von Mises criterion is a formula for calculating whether the stress combination at a given point will cause failure.

$$\sigma_e = (\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2])^{\frac{1}{2}}$$

Von mises stress was used in the research since it allows any arbiter three-dimensional stress state to be represented as a single positive stress value. Von Mises or equivalent stress is used to check whether the pipeline model would withstand the given load condition. It is expected that the pipeline model will fail, if the maximum value of Von Mises stress induced in the material is more than strength of the pipeline itself.

CHAPTER 4
RESULT AND DISCUSSION

The results of this research that is included in this section gives high emphasis on the interpretation and discussion of the response of free spanning pipeline towards the internal pressure applied on it. Note that all simulation pictures may look similar, but each of it is off different span length.

4.1 Simulated Free Spanning Pipeline, 36 m

The pictures shown below are the simulated free spanning pipeline, length 36 m. This span length is the longest identified from the underwater inspection report.

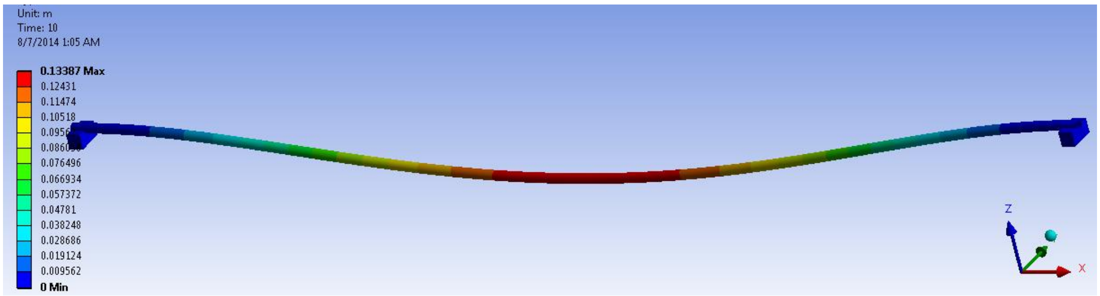


Figure 12: Equivalent Stress at 36 meter

Table 7 shows the simulated maximum equivalent stress of the 36 m free spanning pipeline after 5 MPa, 7.7 MPa, 9.5 MPa, 13.8 MPa and 15 MPa internal pressure are applied. The values taken are the maximum stresses of all simulation.

Table 7: Simulated Stress Distribution for 36 m Free Spanning Pipeline

Pressure (MPa)	Stress (MPa)
5.00E+06	1.39E+07
7.70E+06	1.77E+07
9.50E+06	2.04E+07
1.38E+07	2.70E+07
1.50E+07	2.90E+07

While Figure 13 depicts the stress distribution of 36 m free spanning pipeline. It is identified that as the pressure building up, the stresses increases together. As this span length is the longest, it is noted that as the highest pressure is applied, the stress shoots up to 29 MPa.

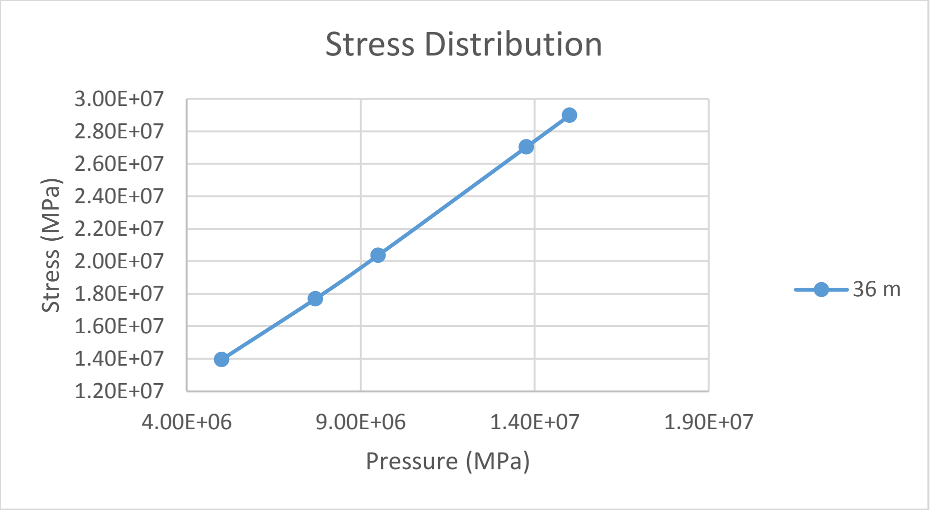


Figure 13: Stress Distribution for 36 m Free Spanning Pipeline

4.2 Simulated Free Spanning Pipeline, 25 meter.

The pictures shown below are the simulated free spanning pipeline, length 25 m.

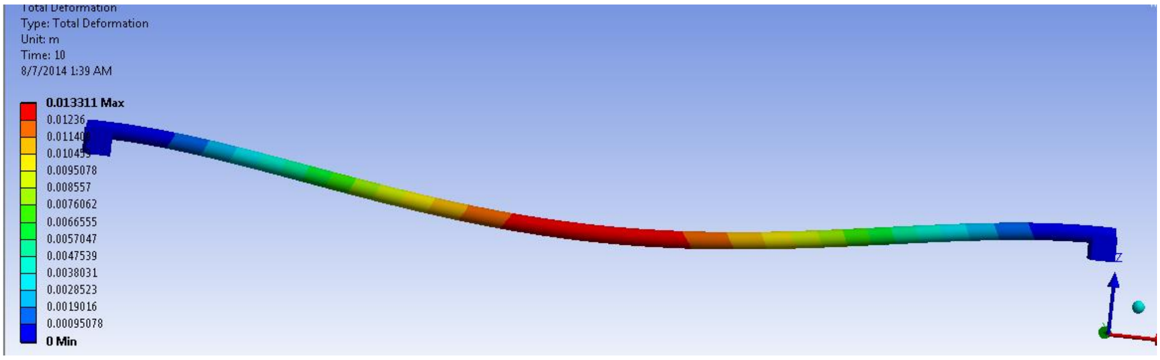


Figure 14: Equivalent Stress at 25 meter

Table 8 displays the simulated equivalent stress of the 25 m free spanning pipeline after 5 MPa, 7.7 MPa, 9.5 MPa, 13.8 MPa and 15 MPa internal pressure are applied.

Table 8: Simulated Stress Distribution for 25 m Free Spanning Pipeline

Pressure (MPa)	Stress (MPa)
5.00E+06	1.17E+07
7.70E+06	1.51E+07
9.50E+06	1.74E+07
1.38E+07	2.07E+07
1.50E+07	2.18E+07

While Figure 15 depicts the stress distribution of 25 m free spanning pipeline. The same observation made in this free span. It is identified that as the pressure building up, the stresses increases as well.

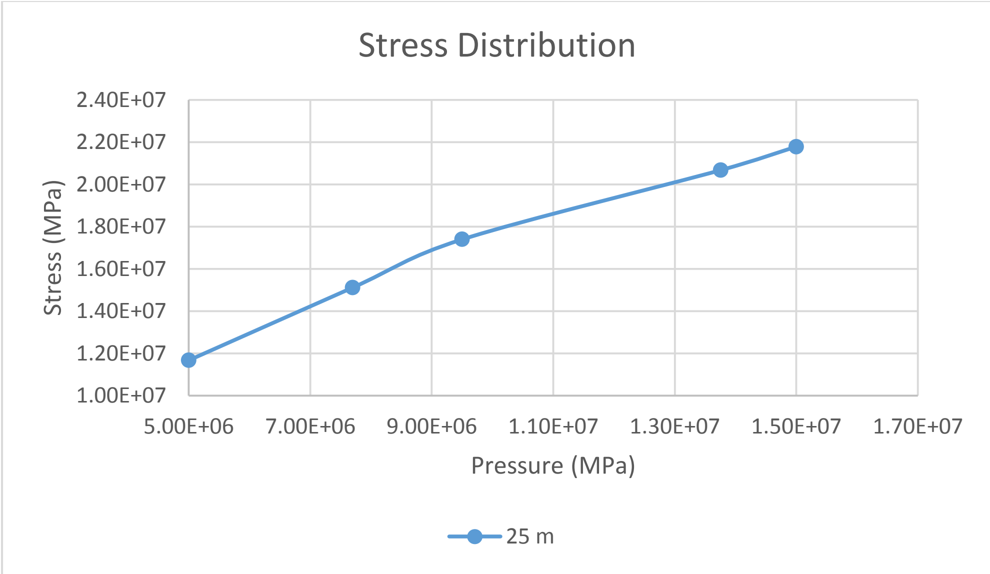


Figure 15: Stress Distribution for 25 m Free Spanning Pipeline

4.3 Simulated Free Spanning Pipeline, 20 m

The pictures shown below are the simulated free spanning pipeline, length 20 m.

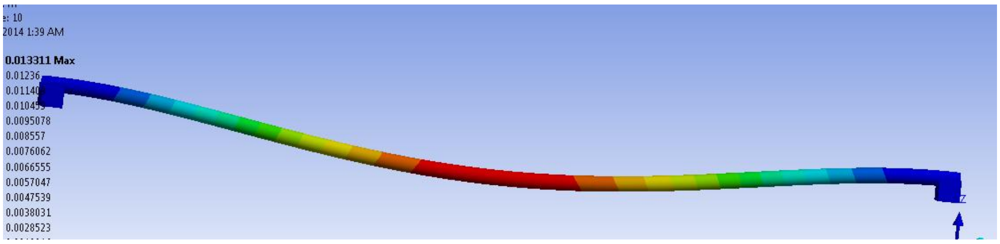


Figure 16: Equivalent at 20 meter

Table 9 shows the simulated equivalent stress of the 20 m free spanning pipeline after 5 MPa, 7.7 MPa, 9.5 MPa, 13.8 MPa and 15 MPa internal pressure are applied. Similarly to previous observation, as the pressure built up, the stress increases.

Table 9: Simulated Stress Distribution for 20 m Free Spanning Pipeline

Pressure (MPa)	Stress (MPa)
5.00E+06	9.85E+06
7.70E+06	1.15E+07
9.50E+06	1.36E+07
1.38E+07	1.70E+07
1.50E+07	1.82E+07

While Figure 17 depicts the stress distribution of 20 m free spanning pipeline. The same observation made in this free span. It is identified that as the pressure building up, the stresses increases too.

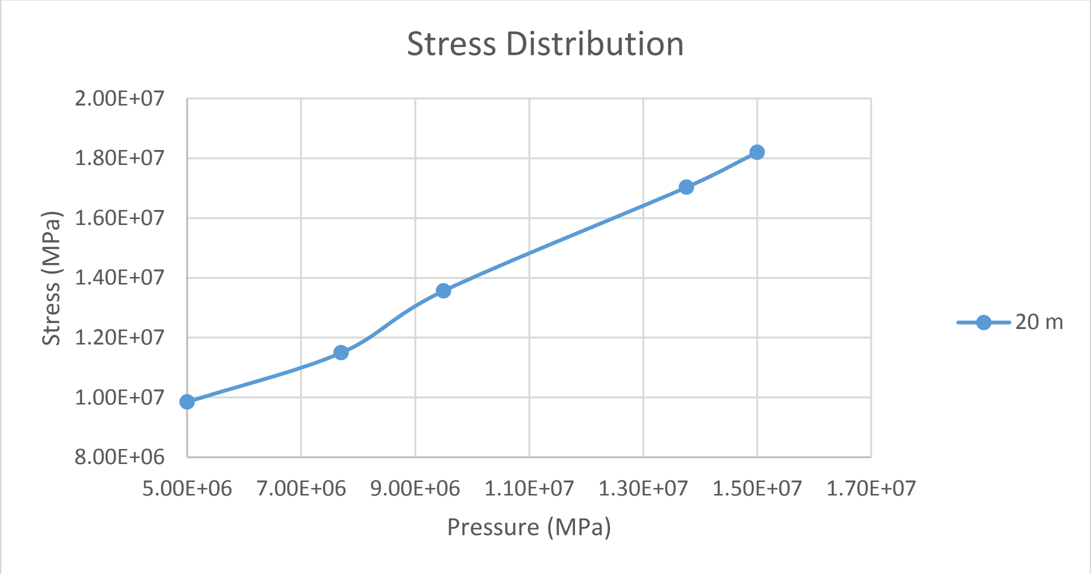


Figure 17: Stress Distribution for 20 m Free Spanning Pipeline

4.4 Simulated Free Spanning Pipeline, 14 meter

The pictures shown below are the simulated free spanning pipeline, length 14 m. Note that this is the critical span length as calculated in the earlier part of this report.

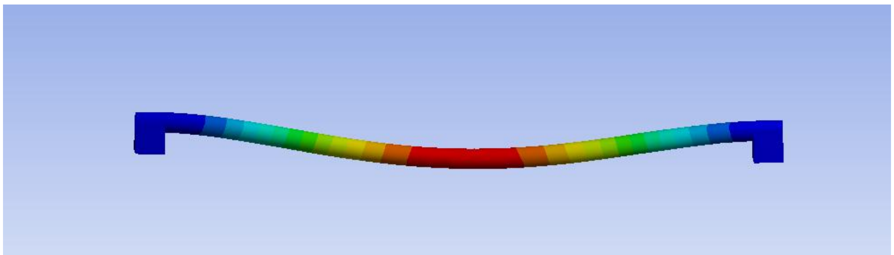


Figure 18: Equivalent Stress at 14 meter

Table 10 shows the simulated equivalent stress of the 14 m free spanning pipeline after 5 MPa, 7.7 MPa, 9.5 MPa, 13.8 MPa and 15 MPa internal pressure are applied.

Table 10: Simulated Stress Distribution for 14 m Free Spanning Pipeline

Pressure (MPa)	Stress (MPa)
5.00E+06	6.18E+06
7.70E+06	8.95E+06
9.50E+06	1.10E+07
1.38E+07	1.59E+07
1.50E+07	1.75E+07

While Figure 19 depicts the stress distribution of 14 m free spanning pipeline. The same observation made in this free span. It is identified that as the pressure building up, the stresses increases too.

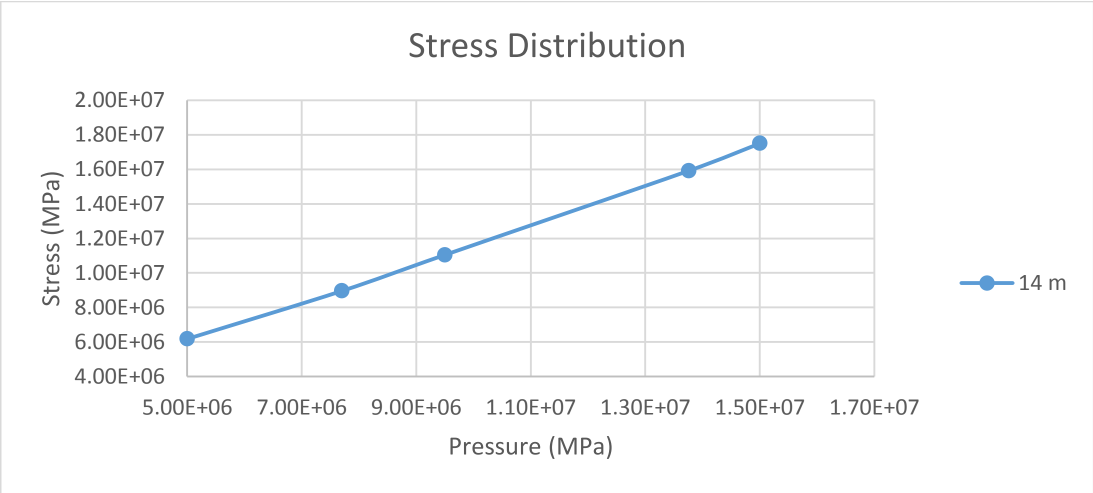


Figure 19: Stress Distribution for 14 m Free Spanning Pipeline

4.5 Simulated Free Spanning Pipeline, 10 meter

The pictures shown below are the simulated free spanning pipeline, length 10 m. This is

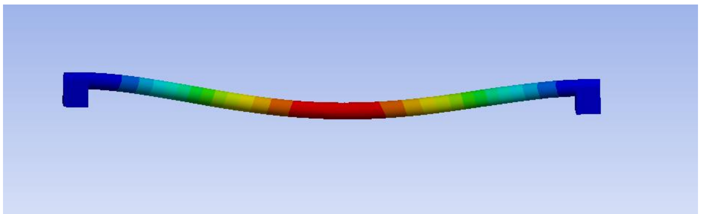


Figure 20: Equivalent Stress at 10 meter

Table 11 shows the simulated equivalent stress of the 10 m free spanning pipeline after 5 MPa, 7.7 MPa, 9.5 MPa, 13.8 MPa and 15 MPa internal pressure are applied.

Table 11: Simulated Stress Distribution for 10 m Free Spanning Pipeline.

Pressure (MPa)	Stress (MPa)
5.00E+06	5.36E+06
7.70E+06	7.09E+06
9.50E+06	8.58E+06
1.38E+07	1.14E+07
1.50E+07	1.40E+07

While Figure 21 depicts the stress distribution of 10 m free spanning pipeline. The same observation made in this free span. It is identified that as the pressure building up, the stresses increases too.

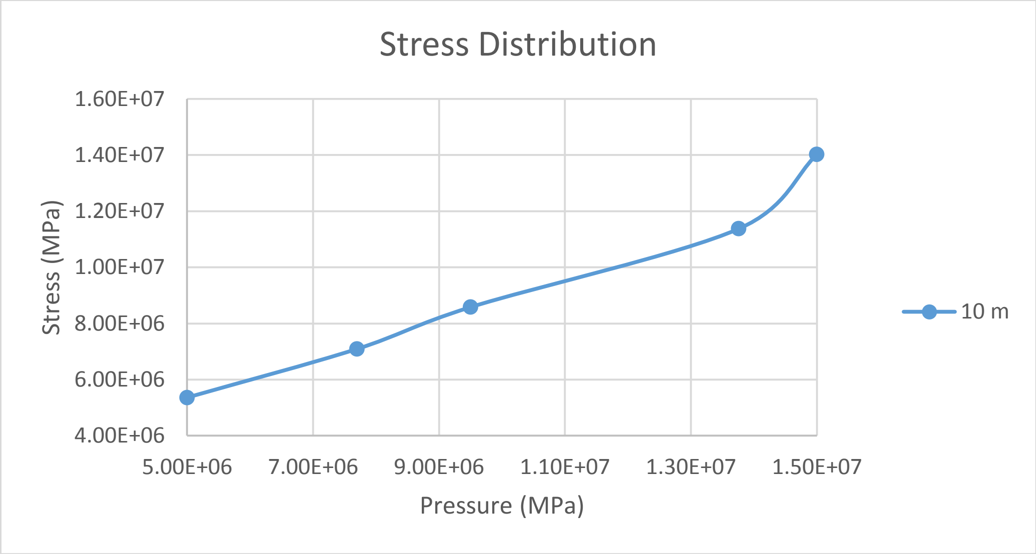


Figure 21: Stress Distribution for 10 m Free Spanning Pipeline

4.6 Discussion

Figure 22 depicts the graph of pressure versus stress distribution for all free spanning pipeline namely 10 m, 14 m, 20 m, 25 m and 36 m. From five simulation for pressure 5 MPa, 7.7 MPa, 9.5 MPa, 13.8 MPa and 15 MPa the highest resulted stress are selected and this graph is plotted. Note that the first line on the graph stated OP which is Maximum Allowable Operating Pressure (MAOP) that is 7.7 MPa while the second line indicates the limit of stresses shall be within, that is below 13.8 MPa, which is the design pressure.

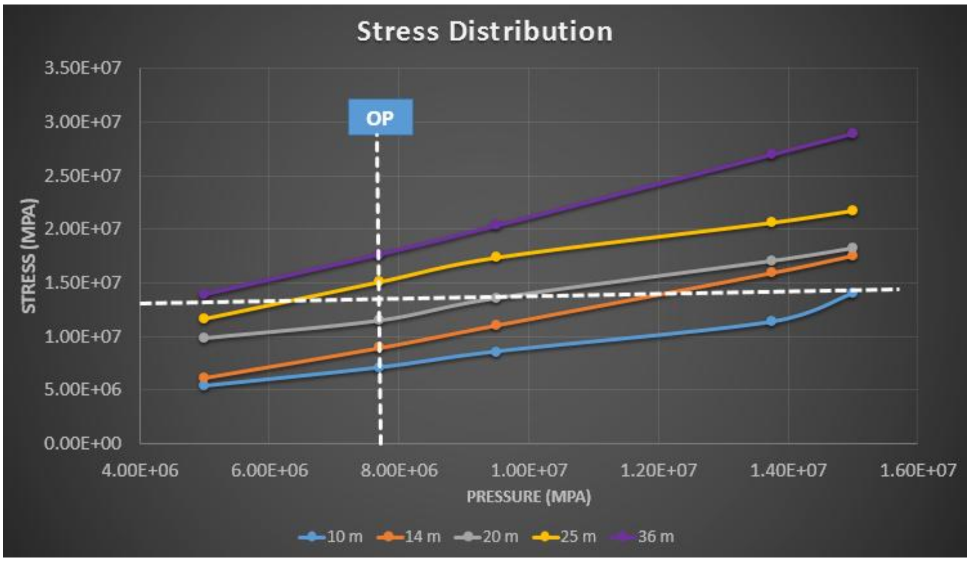


Figure 22: Pressure vs. Stress for all span length

Based on the graph, it is observed that similar trend is shown by the stress resulted by built up pressure for all five span length. The stresses increases when increasing loads are applied. The highlight of this observation would be to the stresses when operating and design pressure is experimented.

When the MAOP which is 7.7 MPa is applied, it is observed that 25 m and 36 m span length has exceeded the design pressure of this pipeline. As the pressure built up to 9.5 MPa, the same behaviour is shown. Then, the design pressure is applied. It is grasped that the critical span length had experienced the stress beyond the design pressure of the pipeline. The same stresses are observed from 25 m and 36 m span length.

To strengthen the aforementioned observation, the author adopted response classification of free spanning pipelines from DNV RP F105 Free Spanning Pipeline. Table 12 shows the response classification for free span is Pipeline X.

Table 12: Response Description based on DNV RP F109

Category	Span Length/ Pipe Outer Diameter (L/D)	L/0.1987 m	Response Description
1	L/D < 30	L < 6 m	Very little dynamic amplification • Normally not required for fatigue check • Unlikely to experience VIV
2	30 < L/D < 100	6 m ≤ L < 20 m	Response dominated by beam behaviour • Typical span length for operating condition
3	100 < L/D < 200	20 m ≤ L < 40 m	Response dominated by combined beam and cable behaviour
4	L/D > 200	L ≥ 40 m	Response dominated by cable behaviour • Vigorous pipeline movement.

It is observed that critical span length of this pipeline is categorized in category 2. While 25 m and 36 m are both in category 3. As described by DNV RP F109, span length in category 2 is typical span length for operating condition. The free span response is dominated by beam behaviour. It is concluded that the free span in this category does not require any further checking. Even though 14 m is the critical span length for Pipeline X, it can still be considered safe for this pipeline. Using 14 m to be the limit for free span rectification will be too stringent as well.

For span length in category 3, which is 25 m and 36 m, the free span response are dominated by combined beam and cable behaviour. These free spans are experiencing VIV and most likely to experience obvious movement. Thus, it is advisable for the free span in this category to undergo close monitoring and fatigue check before decision for rectification to be made.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

In this research, the author presented extensive FEM simulation to aid free spanning pipeline assessment. Computer-based simulation by using ANSYS had aided in the FEM simulation for five span length model at different pressure. ANSYS simulated the pipeline and later produced the equivalent Von Mises stress of the defective pipeline.

The analysis aforementioned in the results and discussion session investigates the stress distribution as a result from internal pressure applied. From the result, it is observed that stress distribution of free spanning pipeline increases with the building up pressure. The results for each model is then compared with DNV RP F109 Free Spanning Pipeline. From the comparison, it is concluded that the free span in category 3 require close monitoring and fatigue check before decision for rectification is made. As free span could affect the integrity of the system, and perhaps even worse, may cause pipeline break, proper monitoring on free span in category 3 must be done.

Rectifying all available may incur substantial cost. Thus, finite element method is well suited to assist in free span assessment as it affects relatively low cost and proven impactful.

5.2 Suggested Future Works

a) Simulation for fatigue check: Among the important steps before making decision whether a pipeline require rectification or not, is fatigue check. Fatigue check involves checking for pipeline cracking and when this checking is completed, decision for rectification could be made.

b) Incorporating other parameter influencing free spanning pipeline: Other parameters and condition that involves in the occurrence of free spanning pipeline includes hydrodynamic loading, VIV, pipeline stiffening and many others. Since FEM is proven as a reliable tool, it is best to include other parameter for a more accurate result in the future.

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