Effect of Fluid Flow on Subsea Pipe Line Riser

by

Muhammad Shahmi bin Ahmad Shauki

Dissertation submitted in partial fulfillment of

the requirement for the

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(MECHANICAL ENGINEERING)

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CERTIFICATION OF APPROVAL

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Approved by,

____

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TRONOH, PERAK

DECEMBER 2010

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.

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MUHUMMAD SHAHMI BIN AHMAD SHAUKI

ABSTRACT

The study of the effect of fluid flow on subsea pipe line riser is presented on this report. The main focus of this study is the investigation of vibration that is due to the fluid flow effect externally on subsea pipe line riser. From vibration perspective, the hydrodynamic flow characteristic which is the sea water wave has a remarkable influence to the pipe line riser that may contribute to the high vibration. The effect of the high vibration will eventually ends the life's span of the pipe line riser earlier than expected. The general method as the primary calculation method is applied and verified with existing results in literature review and some references. The ANSYS software is used for simulation of the parametric effects. The results taken from ANSYS software are the actual result. Based on ANSYS simulation, the pipe has deformed into several shapes that may contribute to the high vibration of the pipe. The results obtained from the ANSYS software which is the actual result are then compared and verified with the theoretical result based on calculation made. There are several considerations that have to be taken in order to enhance the reliability of the studies. Based on the project, there are some aspects that should be considered to enhance the studies for future references are stated in this report.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

A pipe riser is a link that connects the platform on the sea surface with the mounting at the wellhead on the sea bed. The depth of the sea can be from several hundred to a couple thousand feet. The riser can be a single rigid pipeline for the drilling riser system, or a bundle of flow lines which are assembled as an integral unit for the production riser system. The riser system can be installed for the tension leg platform (TLP) as in Figure 1.2, and floating production and storage unit (FPSU) as in Figure 1.1.

A constant top tension is applied to avoid the collapse of a riser by its own weight. It also helps to reduce the excess load on the manifold in the deep sea. Buoyant material is strapped around the riser at intervals to provide additional buoyancy and to reduce the required top tension. The additional buoys make the riser floating depending on the applications.

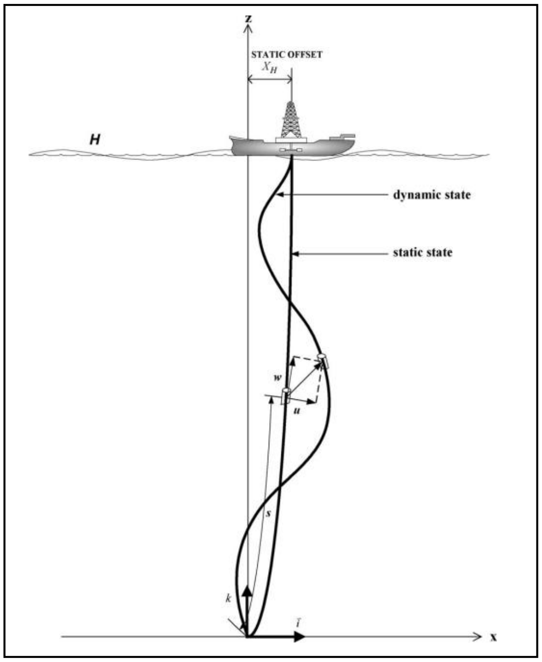


Figure 1.1: Typical riser/pipe configuration. [2].

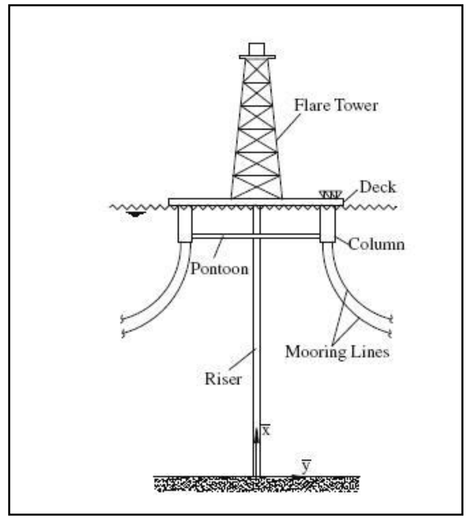


Figure 1.2: An example of a vertical riser connecting to a floating platform [3].

The project is focusing on the effect of the fluid flows (which in this case the sea water wave) on transversely deflected riser. The external fluid dynamic force (sea wave) will exerts periodically against the wall of the link along the riser. The force will transform as vibration of the riser. Eventually, the riser system will fail ahead of its life spend due to the effect of undesirable vibration.

1.2 Problem Statement

As stated before that the study is focusing on the external force of the fluid flow on the subsea pipe line riser. It is the external force by the sea water wave that exerts periodically against the wall of the link along the riser. These forces will eventually vibrating the pipe riser and decreasing its life span.

Here are some questions to guide me for the analysis:

1. Where is the location of the pipe riser and its properties for analysis?
2. How the external forces that exerts by the sea water can affect the pipe line riser vibration?
3. How to develop the calculation study of vibration based on the possible factors given?

1.3 Objectives

Main objectives of this study are:

1. To gain the natural frequencies by applying the vibration equation.
2. To model the corresponding mode shapes based on its corresponding natural frequencies.
3. To simulate the pipe riser deformation based on the mode shapes obtained by ANSYS software.
4. To verify the result by comparing the result taken from ANSYS software (the actual result) with the calculation made (theoretical result).

1.4 Scope of Work

The study will focus more on the effect of the fluid flow current by the sea water on the subsea pipe line riser where it will exerts hydrodynamic force against the wall of the link along the riser. Due to this, the vibration will be excited.

It is assumed that the sea water current is acted from one direction to simplify the calculation. Thus, eliminating the vortex induced vibration and any forces that may contribute to the vibration. The study will also assume that the properties of the system are linear. It is also assumed that the vibration that excited is of harmonic motion and the sea water acts as vibration damper.

The study is based on the pipe line on RESAK platform in the following condition:

- The pipe is from RESAK platform to Onshore Gas Terminal (OGT)
- Length: 135 KM (from RESAK to OGT)
- Product: Gas

The analysis will focus only on the submerged part of the pipe starting from the sea level until the first mounting of the pipe riser on the sea bed.

CHAPTER 2
LITERATURE VIEW

2.1 Introduction

The focus of this project is to study the effect of the sea water fluid flow on subsea pipe line riser where the vibration will take effect. During the author's preliminary research of the topic, I have identified some possible methods to conduct the study of the vibration. These methods are based on some of the journals that I have obtained. Below is the summary of each of the studied journals.

2.1.1 Nonlinear free vibrations of marine risers/pipes transporting fluid (14 July 2004) [2]

The paper is written by Sakdirat Kaewunruen, Julapot Chiravatchradej and Somchai Chucheepsakul. The finite element method is applied to analyze the nonlinear free vibrations of marine pipe riser conveying internal fluid based on the energy approach. The system formulation has been reformed to the eigenvalue problem by using the Lagrange's equation of motion to reach the nonlinear free vibration behaviors. For the nonlinear fundamental frequencies and the corresponding numerically exact mode shapes, they are determined by the modified direct iteration technique incorporating with the inverse iteration. On the other hand, parametric aspects demonstrate the nonlinear effects due to the modulus of elasticity, top tensions, internal flow velocities, and static offsets. Eventually the pipe riser will nonlinearly displace from the static equilibrium configuration due to small perturbation where both ends are modeled as hinged and immovable restrains.

2.1.2 An extraction of the natural frequencies and mode shapes of marine risers by the method of differential transformation (13 July 2009) [3]

This paper is written by Yanfei Chen, Y.H. Chai, Xin Li and Jing Zhou. They used the method of differential transformation which is relatively new technique. It is capable of dealing with eigenvalue problem efficiently. Natural frequencies and mode shapes of marine risers are examined for various boundary conditions. Then, the solutions are compared with numerical and experimental results published in the literature where available.

2.1.3 A finite differences formulation for the linear and nonlinear dynamics of 2D catenary risers (3 January 2008) [4]

This paper is written by Ioannis K. Chatjigeorgiou. Finite differences (FD) method is used although is not popular as the FE methods but it can be equally efficient for solving the dynamic equilibrium problem for catenary shaped slender structures. The difficulties on the use of the FD methods arise mainly from the coupled discretization that is required in time and space which in turn leads to complicated algebraic systems.These problems are properly addressed in the present by extending an existing FD methodology to riser type slender structures with non-zero bending stiffness (Keller Box FD numerical scheme (Hoffman, 1993),).

2.1.4 Dynamic Responses of Marine Risers/Pipes Transporting Fluid Subject to Top End Excitations [7]

This paper is written by Sakdirat Kaewunruen, J. Leklong, Somchai Chucheepsakul. The marine riser is simulated by using two dimensional elements. Energy functional of the marine risers conveying fluids is derived from variational principle. Nonlinear equations of motion influenced by the nonlinear Morison waveform are obtained through Hamilton’s principle. the dynamic responses of marine risers to top end excitation is achieved using the finite element method and Newmark Average Acceleration Method

2.1.5 Dynamic Responses of Marine Risers/Pipes Transporting Fluid Subject to Top End Excitations [8]

This paper is written by A. S. Atadan*, S. M. Calisal, V. J. Modit and Y. Guot. In this paper a relatively general Lagrangian formulation of the problem, applicable to a large class of systems, is presented which accounts for:

1. The tree-dimensional dynamics of the riser and the platform;
2. The internal flow within the riser;
3. The rotary inertia and shear deformation effects (i.e., the riser treated as a Timoshenko beam as against the Eulerian approach often reported in the literature (Brouwers, 1982; Chakrabarti and Frampton, 1982; Chung *et al.*, 1981; Finn, 1972; Hall and Healey, 1980; Irani, 1989; Nordgren, 1982; O'Brien *et al.*, 1987)
4. The geometric nonlinearities.

For detailed literature review, please refer to the Appendixes.

2.2 The Design of Pipe Line Riser

The design of the pipe line is taken from PETRONAS Carigali SDN BHD in Kerteh. As mention before, the analysis is based on RESAK platform's piping specification. The followings are the pipe specifications:

- The pipe is from RESAK platform to Onshore Gas Terminal (OGT)
- Length of the pipe line: 135 KM (from RESAK to OGT)
- Product: Gas
- Pipe riser material: 5LX-65 (duplex stainless steel)
- Maximum and minimum pressure (bar): 99 and 85

For more detailed information of the pipe riser, please refer to Table 2.1 for the riser's specifications. For the riser's engineering design, please refer to Figure 2.1 which shows the cross section view of the riser from the front (diameter), and Figure 2.2 which shows the cross section view of the side of the pipe (length).

Table 2.1: Riser Data

Risers Data						
Riser (L)	**Riser (R)**	**Material**	**OD (mm)**	**WT (mm)**	**ID (mm)**	**Corrosion Allowance (mm)**
L2930		5LX-65	771.0	23.0	665	

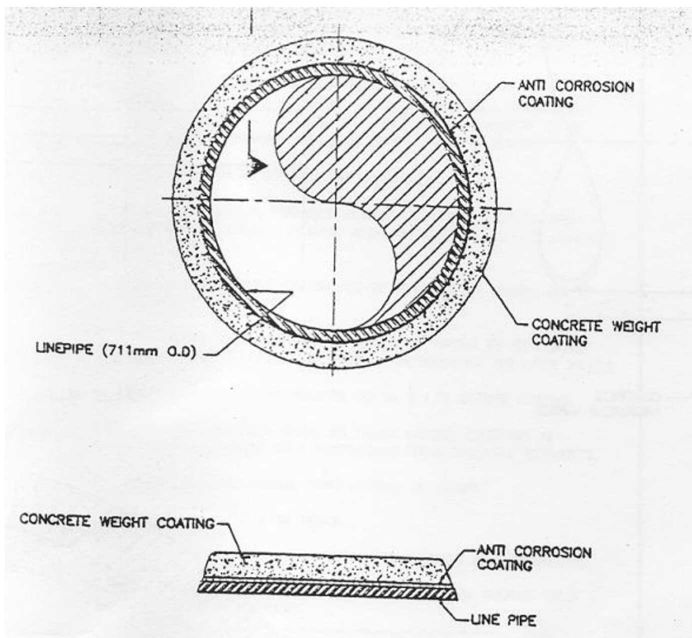


Figure 2.1: Cross section view of the riser

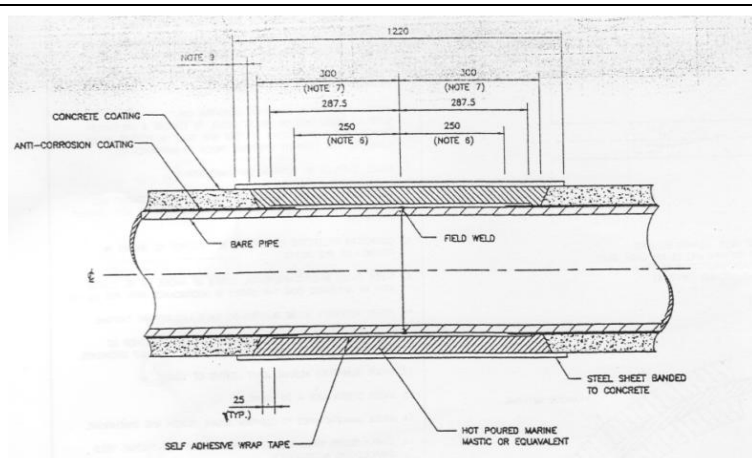


Figure 2.2: Cross section view of the side of the riser

2.3 Vibration Study

2.3.1 Vibration Analysis

The main focus of study in this project is the vibration analysis. Theoretically, vibration system is a dynamic system where the response (output) depends on the excitations (inputs) and the characteristics of the system (for example mass, stiffness, and damping). The input and output are time dependent. Figure 2.3 below shows the vibration system relation.

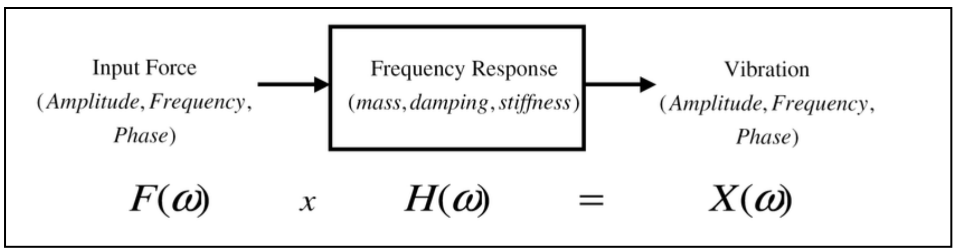


Figure 2.3: The vibration system relation

Vibration analysis of a given system involves determination of the response for the excitation specified with respect to time. The analysis usually involves mathematical modeling, derivation of the governing equations of motion, solution of the equation of equations of motion, and interpretation of the results.

2.3.2 Dynamic Analysis

Dynamic analysis is consisting of mathematical model, derivation of governing equations, solution of the equation and the interpretation of the results. As mentioned before, vibration system is dynamic system which the input and output are time dependent. The response of a vibrating system depends on the initial conditions and external excitations. The fact is that vibration problem is very complicated in life practice. The variables in the mathematical analysis are not totally considered and calculated. This is usually being analyzed using a simple model.

2.3.3 Natural Frequency

All objects have a natural frequency or set of frequencies at which they vibrate. Natural frequency is the frequency at which a mechanical system will vibrate freely once it has been set to a motion. In other words, natural frequency is the number of times a system will oscillate (move back and forth) between its original position and its displaced position, if there is no outside interference (see Figure 2.4) [9]

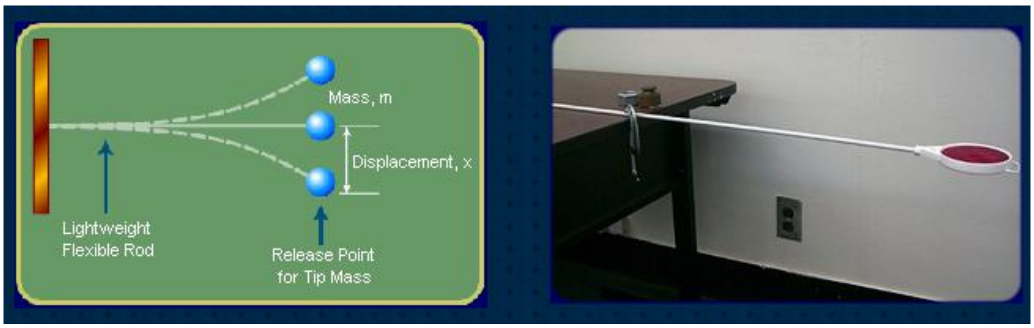


Figure 2.4: Simple beam fixed at one end and having a mass attached to its free end [9]

Based on Figure 2.4, if the beam tip is pulled downward, then released, the beam will oscillate at its natural frequency. If the tip mass (m) weighs much more than the beam to which it is attached, the natural frequency can be calculated using the simple formula [9]

Frequency: $$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$ **Eq. (2.1)**

Natural Frequency: $$\omega_n = \sqrt{\frac{k}{m}}$$ **Eq. (2.2)**

Where; k is the stiffness of the beam

m is the mass of the tip mass

2.3.4 Mode Shape

Mode shape is the expected curvature or displacement of a surface vibrating at a particular mode. The mode shape (see Figure 2.5) is multiplied by a function that varies with time to determine its vibration system. Therefore, mode shape is best describes as the vibration curvature at all points in time but the curvature's magnitude can be changed. The mode shape is dependent on the shape of the surface as well as the boundary conditions of a particular surface [10].

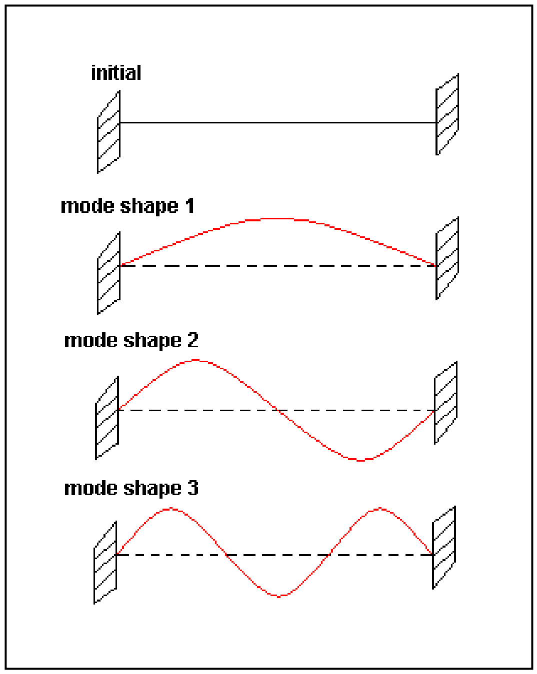


Figure 2.5: The mode shape of a deflected beam [11]

2.3.5 Response

The vibration analysis can be viewed as input/output relation where the force is the input while the vibration is the output. The governing equations of motion of a vibrating system are solved to find the response of the system (see Figure 2.6). There are many techniques available for finding the solution. In addition, the solution of partial differential equations that result for the vibration of continuous systems is far more involved than that of the ordinary differential equation for the discrete systems [12].

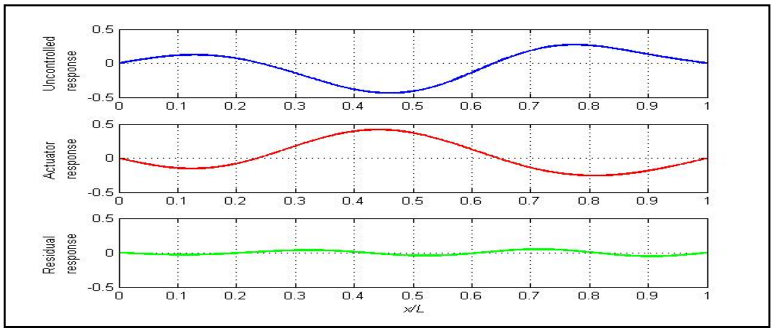


Figure 2.6: Vibration response of a beam [13]

2.4 Continuous System

Continuous system is a system of infinite degree of freedom in which it is not possible to identify discrete masses, damping and spring. For this project, the author considers the continuous distribution of elasticity, mass and damping and assumes that each of the infinite number of elements of the system will be vibrating.

2.5 Method of Solving Continuous System

There are a number of methods for solving the continuous system model. These are the exact solution that consists of Newtonian method or energy method, and the approximate method which consists of Rayleigh methods and finite element method. These methods have different approach on solving the continuous system.

2.5.1 Exact Solution (the General method or Newtonian method)

Exact solutions are possible only in relatively few simple cases of continuous systems. The general method developed by considering the free body diagram (FBD) of the respective system (see Figure 2.7, page 12).

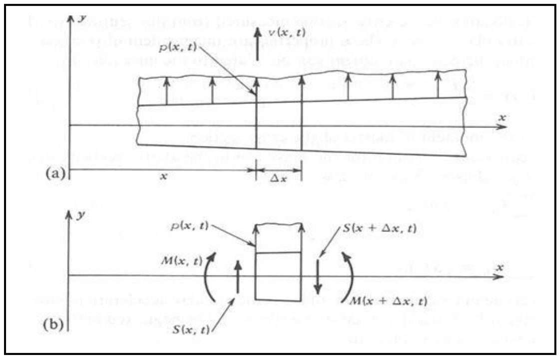


Figure 2.7: Structural dynamics of a beam

Based on the FBD, it yields two equations:

1. Force equation of motion
2. The moment equation of motion

By applying the partial differential method for the above equation, both equations can be joined together to form the equation of motion:

$$EA\frac{\partial^2 u(x,t)}{\partial x^2} + f(x,t) = \rho A\frac{\partial^2 u(x,t)}{\partial t^2} \qquad \textbf{Eq. (2.3)}$$

This equation will be elaborated further using Euler-Bernoulli theory of bending beam which participate the relation of the bending moment and deflection. This will yield the equation of force vibration of a non-uniform and uniform beam. The equation of motion:

$$EA\frac{\partial^2 u(x,t)}{\partial x^2} + \rho A\frac{\partial^2 u(x,t)}{\partial t^2} = f(x,t) \qquad \textbf{Eq. (2.4)}$$

This method uses the application of boundary condition in order to find the unique solution (mode shape) as the equation of motion above involving the higher-order derivative with respect to time and displacement. The natural frequency of the beam:

$$\omega = \beta^2\sqrt{\frac{EI}{\rho A}} = (\beta l)^2\sqrt{\frac{EI}{\rho A l^4}} \qquad \textbf{Eq. (2.5)}$$

The total free vibration response of the beam can be found by superposing the normal modes as:

$$w(x,t) = \sum_{i=1}^{\infty} W_i(x)(A_i \cos \omega_i t + B_i \sin \omega_i t) \qquad \textbf{Eq. (2.6)}$$

2.5.2 Approximate Solution (the Rayleigh methods and finite element method)

The approximate methods can be classified into two categories. The first category is based on the expansion of the solution in the form of a finite series consisting of known functions multiplied by unknown function. The second category of methods is based on a simple lumping of system properties. All the approximate methods basically convert a problem described by partial differential equations into a problem described by a set of ordinary differential equations. There are two classes of methods that are based on series expansions: Rayleigh –Ritz methods and weighted residual methods.

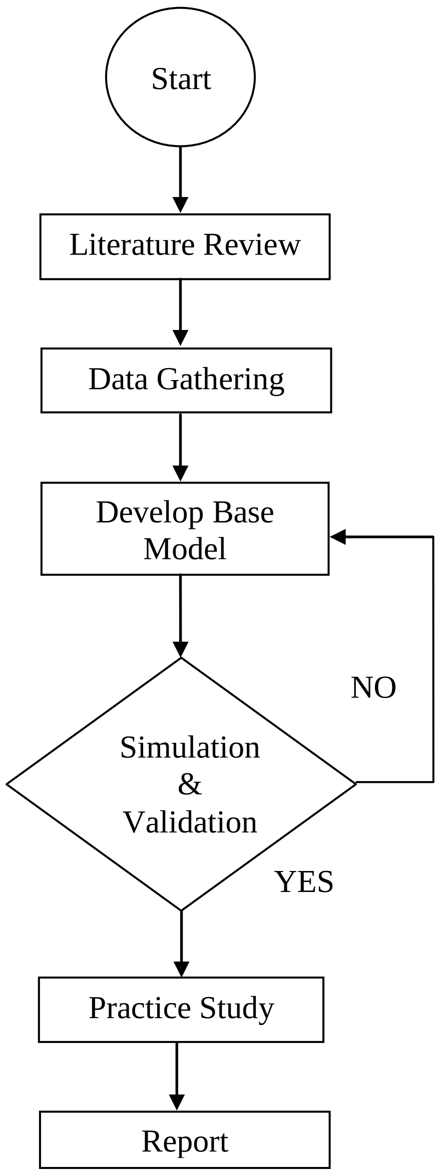
2.6 Method Used in the Project

For solving the project, the author has chosen to implement the general method as the primary calculation method. The project will be conducted relatively in a simple way based on some assumptions that have been made. The dynamic analysis for the pipe riser structure will be based on the analysis on the beam structure. Besides that, the general method will be more accurate compared to the approximate solution as the general method uses the exact solution rather than the approximation.

However, the approximation method will be used as the comparison and to validate the result taken from the exact solution method such as the Rayleigh method.

CHAPTER 3

METHODOLOGY



- Preview or analysis problem
- Fundamental studies from journals and references

- Identify suitable solving methods for the project
- Develop methodology for solving project
- Conducting calculation analysis

- Apply computer based calculation
- Simulation analysis in Ansys

- Report on the analysis of harmonic response on subsea pipe line riser
- Recommendation on operation and safety requirements

Figure 3.1: The methodology of the FYP

At the preliminary phase, the complete standard design of the subsea pipeline riser with full dimension has to be considered. Therefore, the author has to search on recognizing and developing the design of the pipe line riser. By having the actual dimension of the subsea pipe line riser, it will help to make the dynamic analysis to more reliable and logic.

After finishing the preliminary stage which is the designing phase, a study on the fundamental of dynamic analysis on the continuous system provides the information of its behavior and response (displacement) under the longitudinal and transverse vibrational forces. The study also provides the natural frequency and its mode shapes depending on the type of the vibration. However, these are theoretical parts that are not being done practically in the real life situation as the knowledge can be obtained from books and any references from class. Therefore, to make the project research more reliable, a thorough study will be conducted on previous papers and journals which are related to dynamic analysis of the system. By gathering the papers and journals, it will help the author to gain more ideas and method which is very helpful to select the best method of vibration analysis eventually.

A suitable solving method of this project is identified after the literature review and data gathering phase are completed. The next step is to develop the methodology for solving the project. The suitable method on calculating the natural frequency and its mode shape of the dynamic analysis of the continuous system will be specified and executed. Meanwhile, the parameters of the structure of the system will be acknowledged which will be used in the calculation phase. Assumptions are also to be considered to ease the calculation analysis.

Subsequently, to gain the values and equations of the natural frequency, displacement and mode shape of the pipe line riser, the analytical analysis will be conducted. As mentioned before, the scope of the analytical analysis is the effect of the fluid flow (the sea water current) on subsea pipe line riser. If the calculations are successfully done, all the date will be collected and related graphs will be plotted. This is where ANSYS software is used to validate all the values and relations found. If the values are coherent with the values given by the software, then the values are proven. But if its not, the calculation process have to be calculated again. At the end of the project, the report will be compiled where recommendation and safety measures will be included.

3.1 Project Milestone

In implementing the study, a specific time line is prepared for completion of the FYP that is mainly based on the FYP guidelines for students and supervisor requirements and academic schedule. Figure 3.2 below shows the project milestone that has been completed during FYP 1. The author managed to complete the activities within the weeks given.

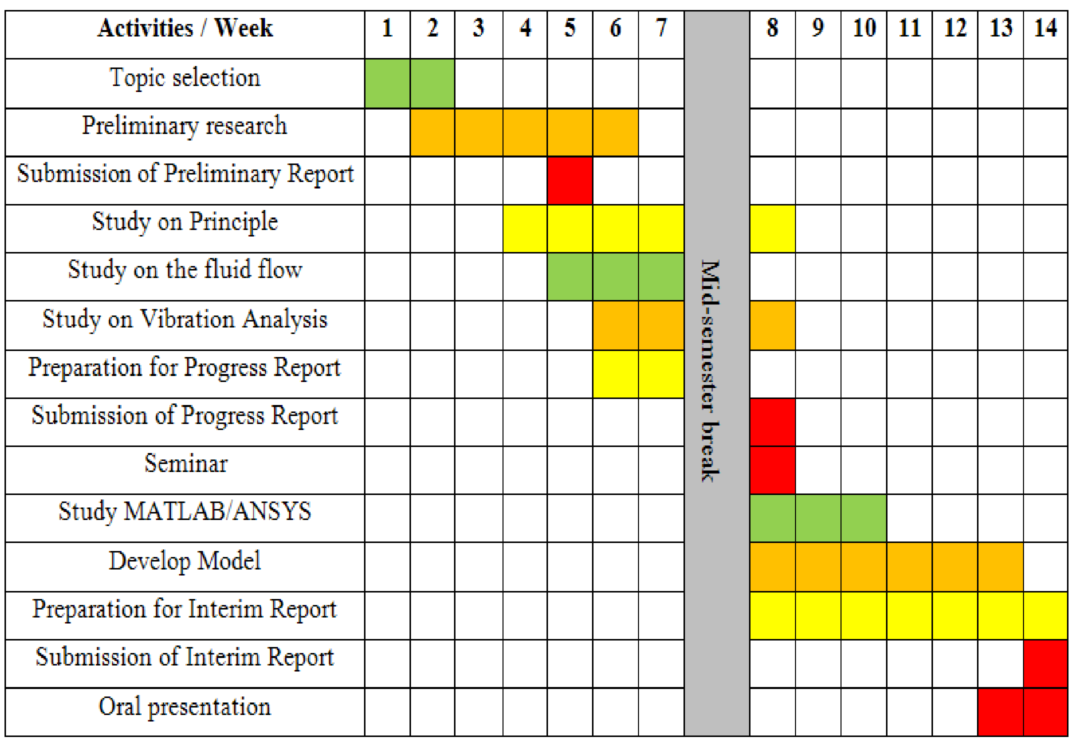


Figure 3.2: Gantt chart for FYP 1

As for FYP 2, it is basically the continuation of the FYP 1. The main focus of FYP 2 is the analysis of the project based on the research done during FYP 1. During FYP 2, the progress was quite slow. It was due to the lack knowledge in using ANSYS and MATLAB software. However, the author managed to overcome it with the help of some references via journals, books and the internet. Figure 3.3 shows the project milestone that has been completed during FYP 2.

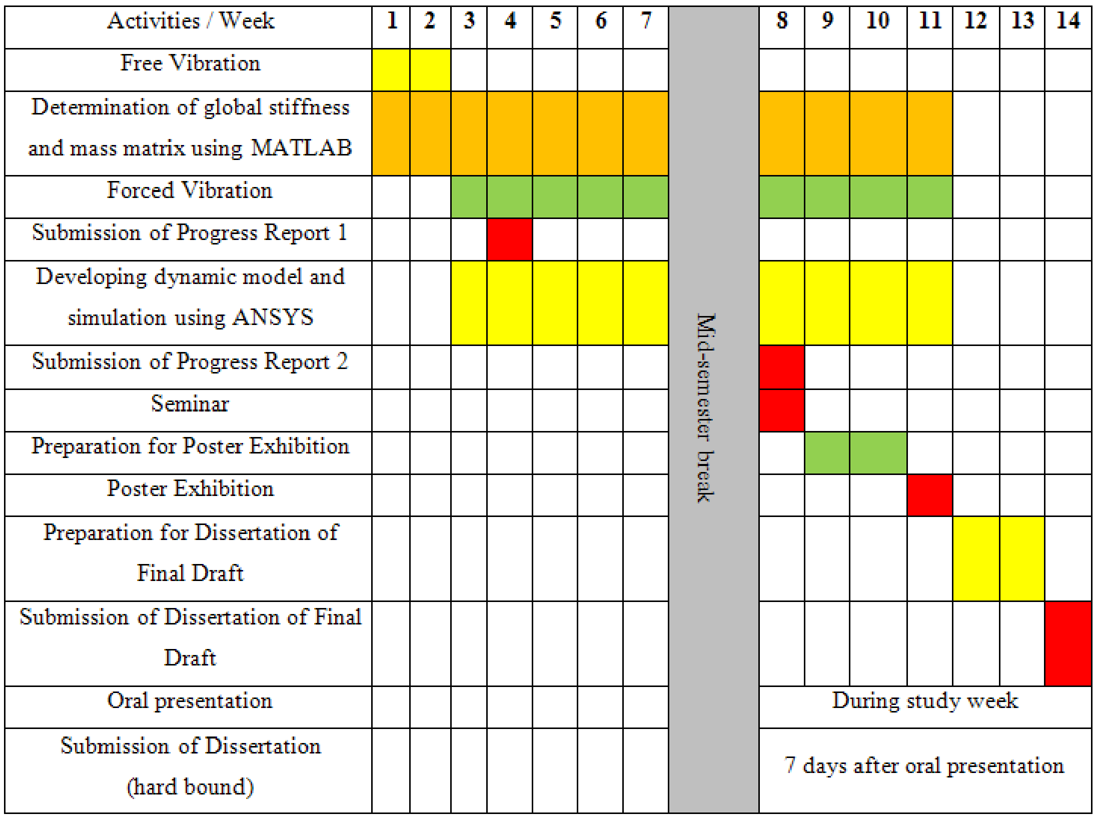


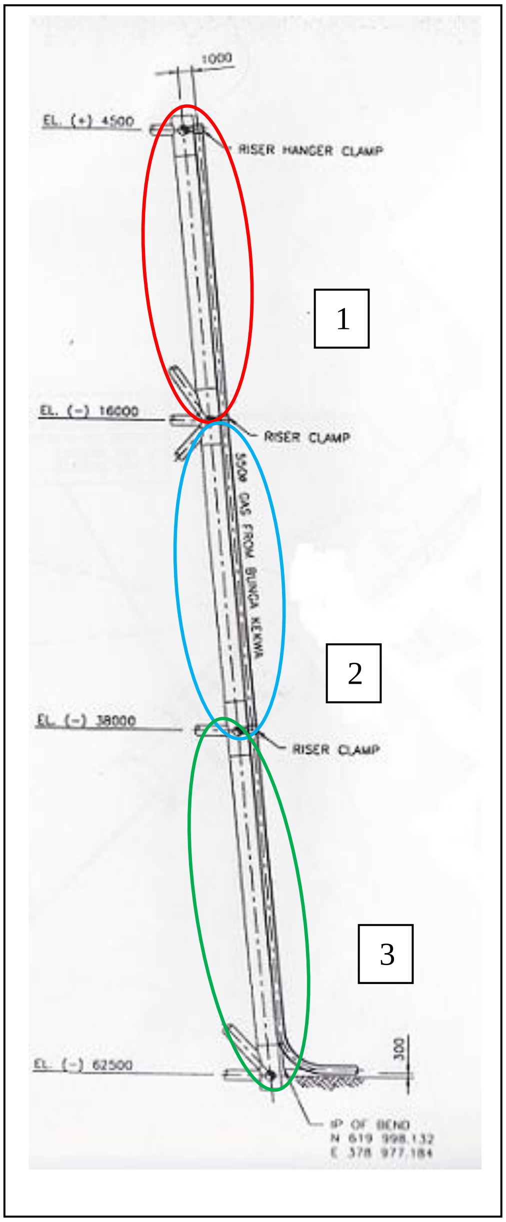
Figure 3.3: Gantt chart for FYP 2

3.2 Tools Required

The tools that will be used for the project are EXCEL for graphs and charts, MATLAB for solving complex equation and ANSYS for simulation.

3.3 Exact Solution for Fixed Beam

To solve the project, the author used the general method or the Newtonian method. The riser pipe will be assumed as fixed beam.



As shown in Figure 3.4, this is the design of the pipe riser. The pipe riser is positioned beside the platform's leg. There are 3 colors of circle which indicate the segment or the boundary condition of the analysis. To start the analysis, the red color circle at the top of the pipe riser will be investigated first which means that all the analysis calculation will be conducted for the first segment of the pipe riser. The other two segments are having similar properties as the first segment except only for their length. Therefore, the analysis calculation for the first segment can be used for those two segments only changing the length parameter.

Figure 3.4: The pipe line riser

3.3.1 Vibration Analysis

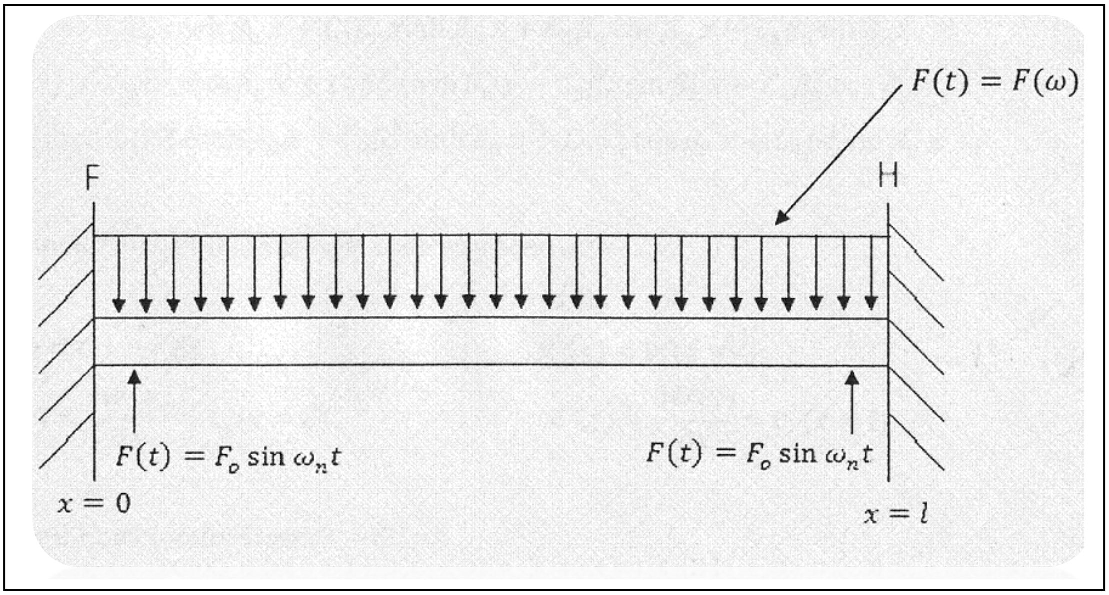


Figure 3.5: Distributed load on beam FH

Where ω is the frequency, in radians per second, and for loading case as the above (Figure 3.5), the differential equation of motion is as follow;

$$EI\frac{\partial^4 w}{\partial x^4} + m\frac{\partial^2 y}{\partial t^2} = q \sin \omega_f \mathrm{t}$$ **Eq. (3.1)**

Assuming that y = Y sin ω_ft , where Y is the function of x. **Eq. (3.2)**

Substituting Eq. (3.2) into Eq. (3.1), obtaining the ordinary differential equation:

$$\frac{\partial^4 y}{\partial x^4} + \beta^4 Y = \frac{q}{EI}$$ **Eq. (3.3)**

Where;

$$\beta^4 = \frac{m{\omega_f}^2}{EI}$$ **Eq. (3.4)**

The general equation of the first beam is;

$$W(x) = C_1 sinh\beta_n x + \ C_2 cosh\beta_n x + C_3 sin\beta_n x + \ C_4 cos\beta_n x$$

$$W'^{(x)} = C_1\beta_n cosh\beta_n x + \ C_{2\beta_n} sinh\beta_n x + C_3\beta_n cos\beta_n x - \ C_4\beta_n sin\beta_n x$$

$$W''^{(x)} = C_1{\beta_n}^2 sinh\beta_n x + \ C_2{\beta_n}^2 cosh\beta_n x - C_3{\beta_n}^2 sin\beta_n x - \ C_4{\beta_n}^2 cos\beta_n x$$

$$W'''^{(x)} = C_1{\beta_n}^3 cosh\beta_n x + \ C_2{\beta_n}^3 sinh\beta_n x - C_3{\beta_n}^3 cos\beta_n x + \ C_4{\beta_n}^3 sin\beta_n x$$

The boundary condition at both ends was been set:

At F;

$W(x) = 0$; (x = 0)

$W(x) = \dfrac{\partial W(x)}{\partial x} = 0; (x = 0)$

At H;

$W(x) = 0$; (x = l)

$W'(x) = \dfrac{\partial W(x)}{\partial x} = 0; (x = l)$

General Equation for Beam is FH:

$$W(x = 0) = \ C_2 + \ C_4$$

$$W'(x = 0) = C_1\beta_n + \ C_3\beta_n$$

$$W(x = l) = C_1 sinh\beta_n l + \ C_2 cosh\beta_n l + C_3 sin\beta_n l + \ C_4 cos\beta_n l$$

$$W'(x = l) = C_1\beta_n cosh\beta_n l + \ C_2\beta_n sinh\beta_n l + C_3\beta_n cos\beta_n l - \ C_4\beta_n sin\beta_n l$$

Converting equation into matrix form:

$$\begin{bmatrix} 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ sinh\beta_n l & cosh\beta_n l & sin\beta_n l & cos\beta_n l \\ cosh\beta_n l & sinh\beta_n l & cos\beta_n l & sin\beta_n l \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

To find the root β_n, the determinant of the matrix equation must be zero, 0. So, solving the matrix equation:

$$\Rightarrow$$

$$0\begin{bmatrix} 0 & 1 & 0 \\ \cosh\beta_n l & \sin\beta_n l & \cos\beta_n l \\ \sinh\beta_n l & \cos\beta_n l & -\sin\beta_n l \end{bmatrix} - 1\begin{bmatrix} 1 & 1 & 0 \\ \sinh\beta_n l & \sin\beta_n l & \cos\beta_n l \\ \cosh\beta_n l & \cos\beta_n l & -\sin\beta_n l \end{bmatrix} +$$

$$0\begin{bmatrix} 1 & 0 & 0 \\ \sinh\beta_n l & \cosh\beta_n l & \cos\beta_n l \\ \cosh\beta_n l & \sinh\beta_n l & -\sin\beta_n l \end{bmatrix} - 1\begin{bmatrix} 1 & 0 & 1 \\ \sinh\beta_n l & \cosh\beta_n l & \sin\beta_n l \\ \cosh\beta_n l & \sinh\beta_n l & \cos\beta_n l \end{bmatrix} = 0$$

$$\Rightarrow$$

$$0 - 1\left[1\begin{bmatrix} \sin\beta_n l & \cos\beta_n l \\ \cos\beta_n l & -\sin\beta_n l \end{bmatrix} - 1\begin{bmatrix} \sinh\beta_n l & \cos\beta_n l \\ \cosh\beta_n l & -\sin\beta_n l \end{bmatrix} + 0\begin{bmatrix} \sinh\beta_n l & \sin\beta_n l \\ \cosh\beta_n l & \cos\beta_n l \end{bmatrix}\right] +$$

$$0 - 1[1\begin{bmatrix} \cosh\beta_n l & \sin\beta_n l \\ \sinh\beta_n l & \cos\beta_n l \end{bmatrix} - 0\begin{bmatrix} \sinh\beta_n l & \sin\beta_n l \\ \cosh\beta_n l & \cos\beta_n l \end{bmatrix} + 1\begin{bmatrix} \sinh\beta_n l & \cosh\beta_n l \\ \cosh\beta_n l & \sinh\beta_n l \end{bmatrix} = 0$$

$$\Rightarrow$$

$$-1[1(-\sin^2\beta_n l - \cos^2\beta_n l) - 1(-\sin\beta_n l \sinh\beta_n l - \cos\beta_n l \cosh\beta_n l) + 0] -$$

$$1[1(\cos\beta_n l \cosh\beta_n l - \sin\beta_n l \sinh\beta_n l) - 0 + 1(\sinh^2\beta_n l - \cosh^2\beta_n l)] = 0$$

$$\Rightarrow$$

$$\sin^2\beta_n l + \cos^2\beta_n l - \sin\beta_n l \sinh\beta_n l - \cos\beta_n l \cosh\beta_n l - \cos\beta_n l \cosh\beta_n l +$$

$$\sin\beta_n l \sinh\beta_n l - \sinh^2\beta_n l + \cosh^2\beta_n l = 0$$

Then;

$$1 - 2(cos\beta_n l cosh\beta_n l) + 1 = 0$$

$$2 - 2(cos\beta_n l cosh\beta_n l) = 0$$

$$1 - cos\beta_n l cosh\beta_n l = 0$$

$$cos\beta_n l cosh\beta_n l - 1 = 0$$ **Eq. (3.5)**

Using Eq. (3.5) to find the roots, $\beta_n l$:

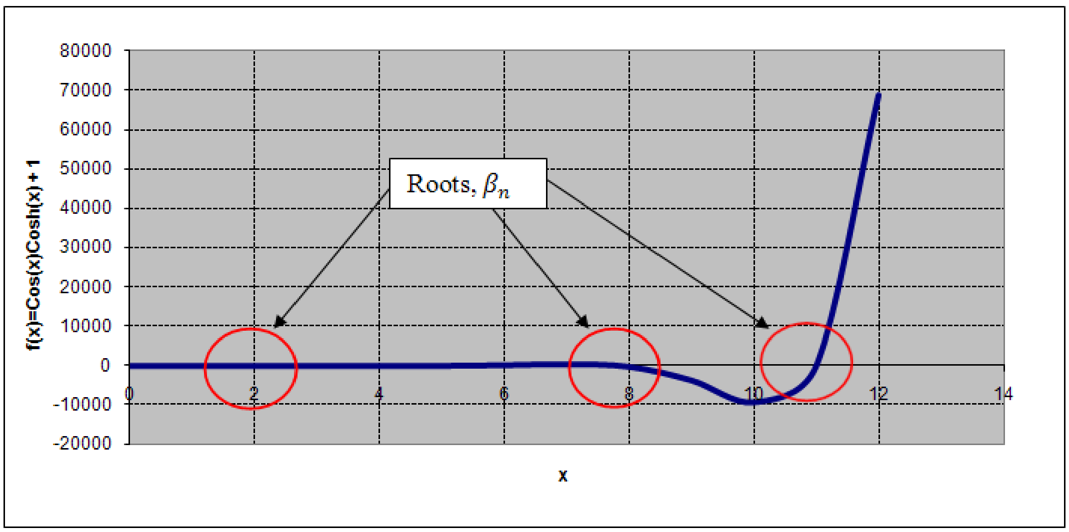


Figure 3.6: The roots, β_n

Roots, β_n:

$\beta_n l$ = 4.233

$\beta_n l$ = 172.451

$\beta_n l$ = 4826.073

Therefore;

β_n= 0.3680

β_n= 14.996

β_n= 419.66

The equation to find the natural frequency is:

$$\omega_n = (\beta_n l)^2 \sqrt{\frac{EI}{\rho A l^2}}$$ **Eq. (3.6)**

Therefore, by using the value of β_n that have obtained, the value of ω_n for part FH is:

- Modulus of elasticity, E = 200 GPA
- Area moment of inertia, I = 0.01735
- Density of the stainless steel pipe, ρ = 7800 kg/m^3
- The length of pipe, l = 11.5 m
- The area of the pipe, A = 0.00883 m^2

As mentioned before, the formula is for fixed supported beam. The calculation of finding the natural frequency is a crucial part because this where the formula given is altered to suits the pipe calculation criteria. This is true and can be modified because it deals with the pipe matter and not beam. As a result, the natural frequencies are:

- The first natural frequency, ω_1 = 11054.65 rad/s
- The second natural frequency, ω_2 = 18356358.65 rad/s
- The third natural frequency, ω_3 = 1.438E10rad/s

From the natural frequencies, the values can be taken to obtain the mode shape of each of the natural frequency. Figure 3.7 below shows the mode shape of ω_1

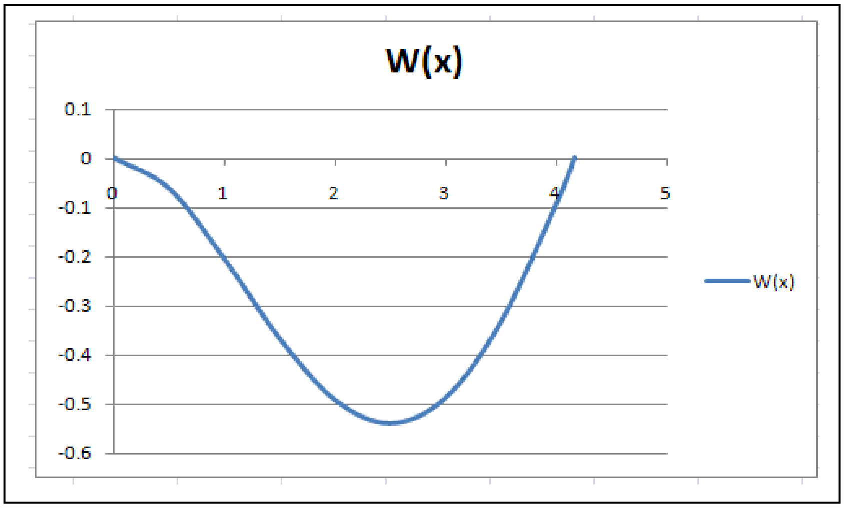


Figure 3.7: Mode shape 1 of ω_1

Figure 3.8 below shows the mode shape of ω_2

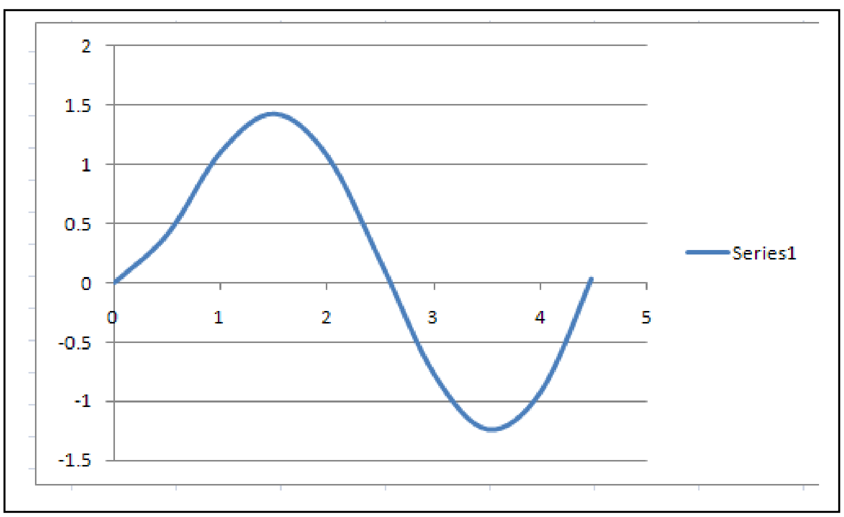


Figure 3.8: Mode shape 2 of ω_2

Figure 3.9 below shows the mode shape of ω_3

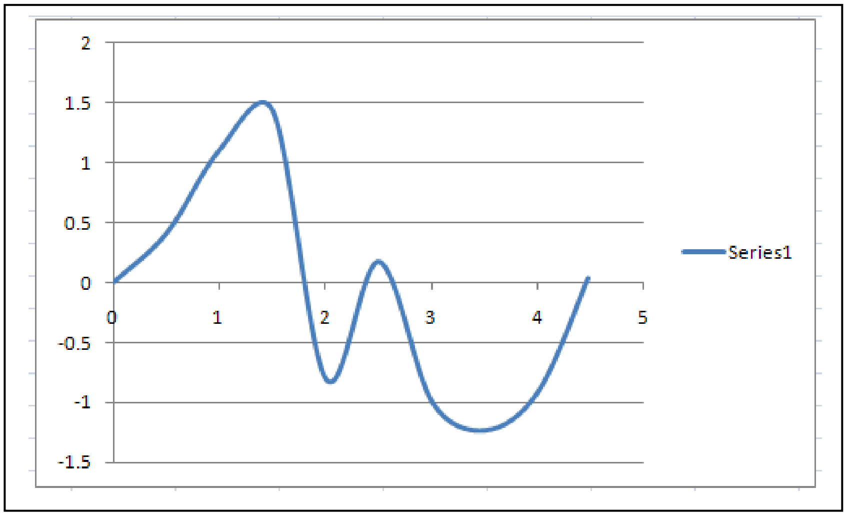


Figure 3.9: Mode shape 3, ω_3

The mode shapes obtained are the expected result from the calculation. These mode shapes represent the deflection of the pipe when the force is acted on the pipe.

However, for mode shape of ω_3**,** the shape is actually not the correct one. This is due to some error and lack of knowledge of the author. The red line indicates the expected mode shape of ω_3 is shown below in Figure 3.10

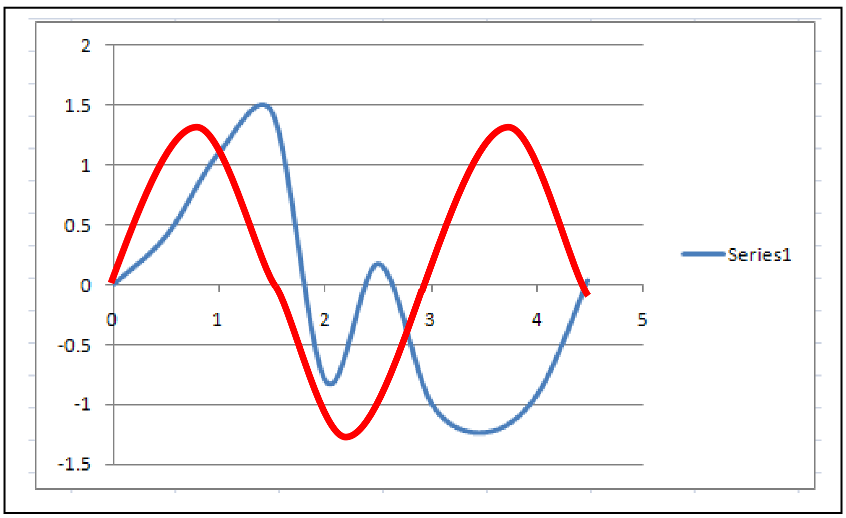


Figure 3.10: The actual mode shape 3, ω_3

3.4 Hydrodynamic Force

Based on the assumption, the flow of the current is in a steady state where the force is acting in the in-line direction [15].

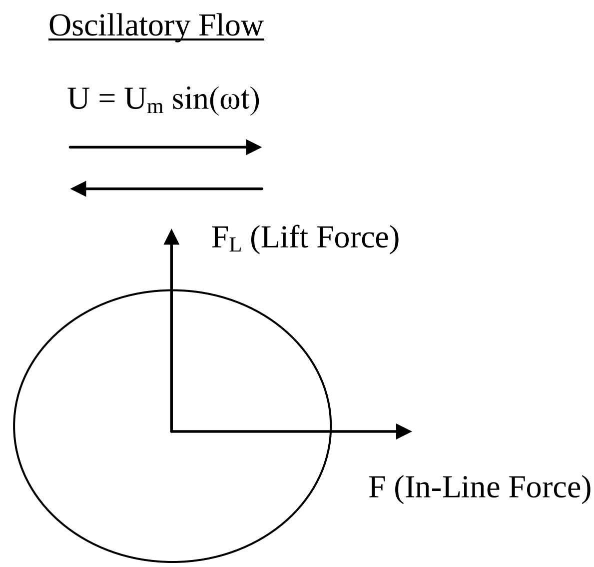


Figure 3.11: Definition sketch

Total in-line force: $$F = \frac{1}{2} \rho C_D D U \, |U| + m' \mathring{U} + \rho V \mathring{U}$$ **Eq. (3.7)**

Where; $\mathring{U}$ = hydrodynamic-mass force

$\rho V \mathring{U}$ = Froude-Krylov force

m' = hydrodynamic mass

V = volume of cylinder

3.4.1 The application of hydrodynamic force

A cylinder or the pipe is held stationary and the fluid moves with a velocity U in the negative direction of the x-axis (see Figure 3.11, page 26); the velocity potential is given by:

$$Ø = U \left(r + \frac{r_o}{r}\right) \cos\theta \qquad \textbf{Eq. (3.8)}$$

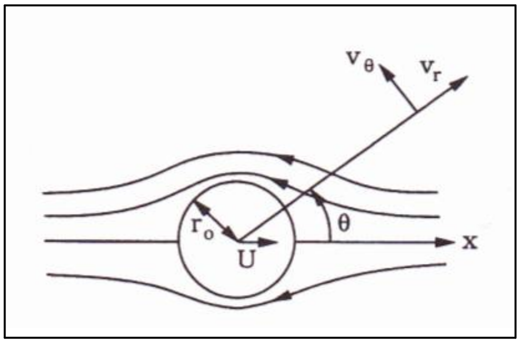


Figure 3.12: Potential flow around an accelerated cylinder, moving with velocity U in opposite direction

The velocity will move in positive direction if we superimposed the whole system, thus the cylinder will move forward with velocity U and the fluid will be at rest at infinity (see Figure 3.12 above).

Therefore, Ø is given by:

$$Ø = U \frac{r_o}{r} \cos\theta \qquad \textbf{Eq. (3.9)}$$

The velocity components υ_r and υ_θ as follows:

$$v_\theta = -\frac{1}{r}\frac{\partial \phi}{\partial \theta} = U\frac{r_0^2}{r^2}\sin\theta \qquad \textbf{Eq. (3.10)}$$

$$v_r = -\frac{\partial \phi}{\partial r} = U\frac{r_0^2}{r^2}\cos\theta \qquad \textbf{Eq. (3.11)}$$

Employing the general Bernoulli equation:

$$\frac{p}{\rho} + \frac{1}{2}\upsilon^2 - \frac{\partial \phi}{\partial t} = \text{constant}$$ **Eq. (3.12)**

in which υ is the speed;

$$\upsilon^2 = \upsilon_r^{\,2} + \upsilon_\theta^{\,2}$$ **Eq. (3.13)**

On the cylinder surface υ^2 will be

$$\upsilon^2 = U^2 (\sin^2\theta + \cos^2\theta) = U^2$$ **Eq. (3.14)**

Therefore the pressure on the cylinder surface from Eq. 4.12 can be written as

$$\frac{p}{\rho} = \frac{\partial \phi}{\partial t} + \text{constant}$$ **Eq. (3.15)**

With the dropping the constant, the pressure on the cylinder surface may be written as

$$p = \rho \frac{\partial \phi}{\partial t} = \rho \frac{\partial}{\partial t}\left(U \frac{r_0^2}{r_0} \cos\theta \right) = \rho r_0 \cos\theta \frac{\partial U}{\partial t}$$ **Eq. (3.15)**

Or

$$p = \rho\, r_o\, a \cos\theta$$ **Eq. (3.16)**

Where;

a = acceleration, $a = \frac{\partial U}{\partial t}$

The resultant force can be calculated by integrating the pressure around the cylinder

$$P = -\int_0^{2\pi} p \cos\theta (r_0 \, d\theta)$$ **Eq. (3.17)**

The vertical component of the force will be automatically zero due to symmetry. So the resultant force sill be

$$P = -a\rho r_0^2 \int_0^{2\pi} \cos^2\theta \; d\theta$$

or

$$P = -\rho r_o^2 a \pi \qquad \textbf{Eq. (3.18)}$$

The force required to accelerate to a cylinder with an acceleration, a in otherwise still fluid should be given by

$$F = ma + \rho r_o^2 a \pi = (m + m') a \qquad \textbf{Eq. (3.19)}$$

The hydrodynamic mass of a circular cylinder will be given by

$$m' = \rho r_o^2 \pi = \rho C_m A \qquad \textbf{Eq. (3.20)}$$

Where;

A = cross-sectional area of the body

C_m = hydrodynamic-mass coefficient (cylinder = 1)

As the height of the wave is fluctuating, estimation has to be done to locate the force acting on the pipe [15]. Based on some considerations, the wave is acting almost on the middle of the pipe (see Figure 3.13).

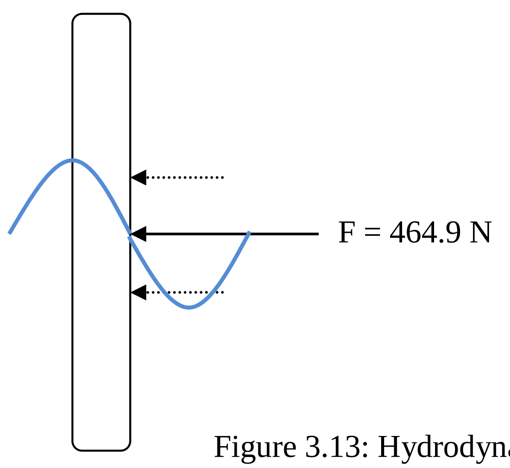


Figure 3.13: Hydrodynamic Force

From the calculation, the value of the hydrodynamic force is 464.9 N. The force will be used for next calculation and simulation by ANSYS.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 ANSYS Analysis Simulation

For FYP 2, the author has started to design and simulate the pipe for its natural frequency and corresponding mode shape. To implement that, Figure 4.1 is the pipe design by CATIA.

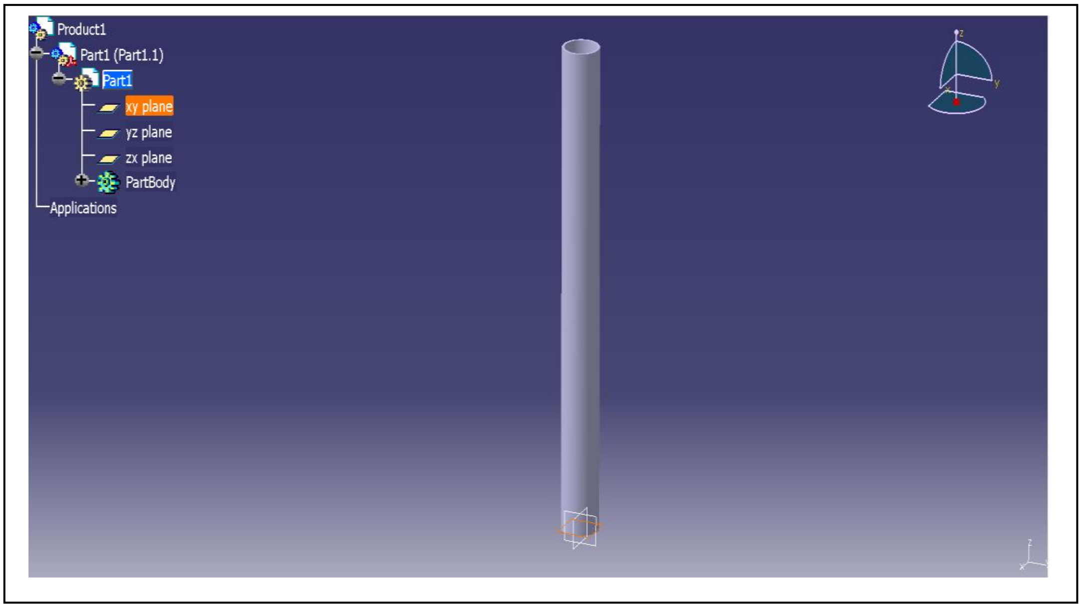


Figure 4.1: The pipe design by CATIA

The pipe model is built by the specification that has been given by Petronas Carigali in Kerteh, Terengganu. These are the pipe profile:

- Outside Diameter, OD: 771 mm
- Inside Diameter, ID: 665 mm
- The length of the pipe: 11500 mm

From CATIA, the drawing is then transferred to ANSYS for engineering analysis. The initial condition of the pipe will be set based on the pipe specification given by the Petronas Carigali. Below is the initial analysis of the pipe in Figure 4. 2.

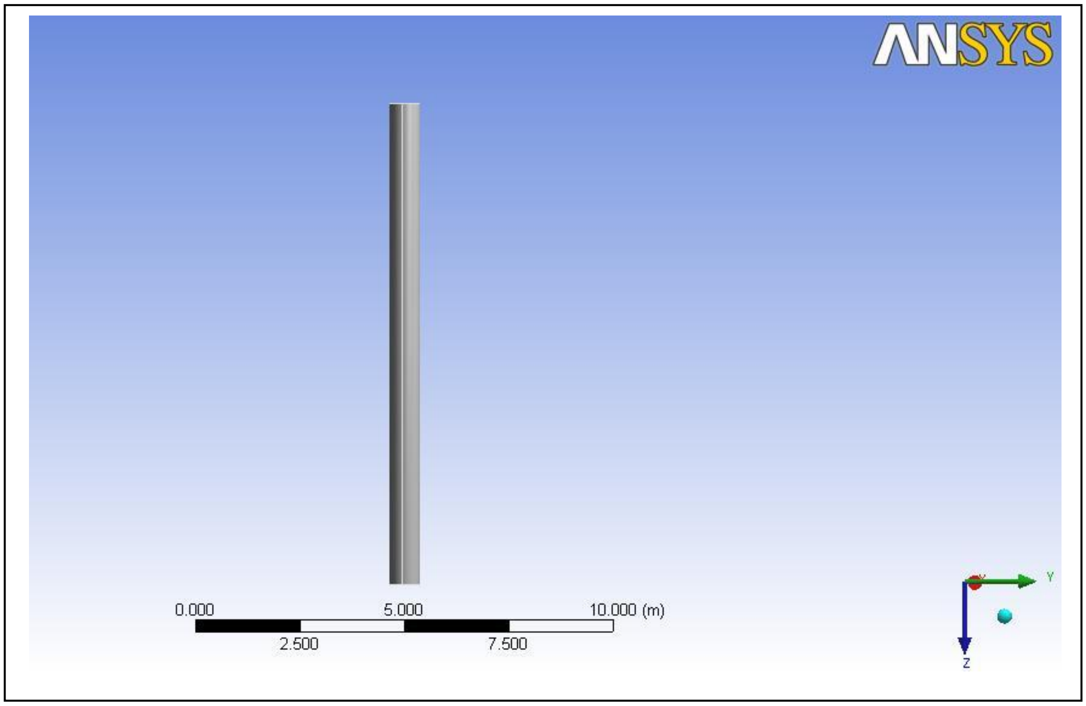


Figure 4. 2: The pipe analysis by ANSYS

The pipe specifications are listed below:

- A stainless steel pipe
- Modulus of elasticity, E = 200 GPA
- Area moment of inertia, I = 0.01735
- Density of the pipe, ρ = 7800 kg/m^3
- The length of pipe, l = 11.5 m
- The area of the pipe, A = 0.00883 m^2

The pipe is then transferred into the model mode where some of the details of the pipe have to be set such as the pipe's elasticity and density. The value is valid and the simulation is carried. Figure 4.3 below shows the first deformation of the pipe.

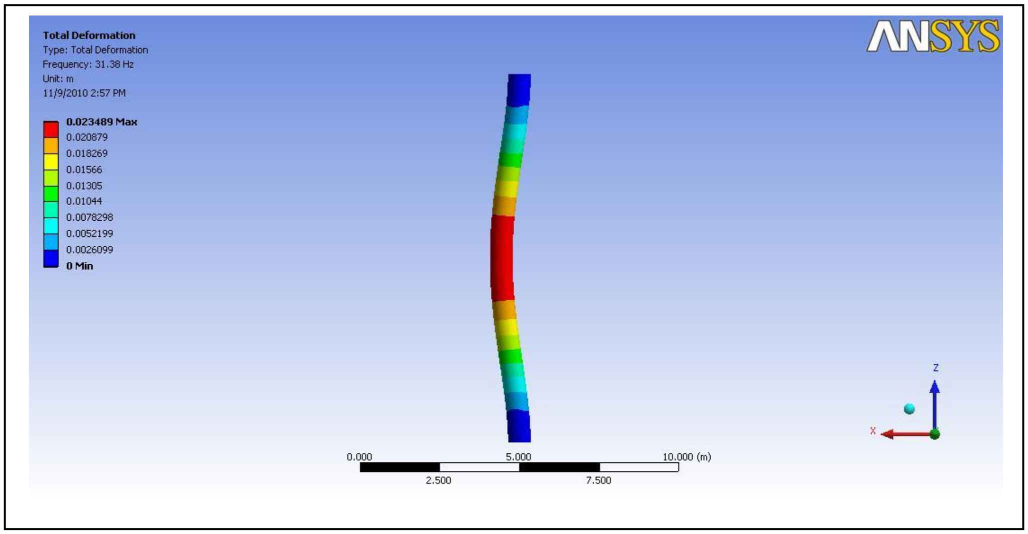


Figure 4.3: The first deformation of the pipe

The deformation occurrence of the pipe is true and as expected the same as in the mode shape obtained earlier (from Figure 3.7, page 24). Figure 4.4 below shows the second deformation of the pipe.

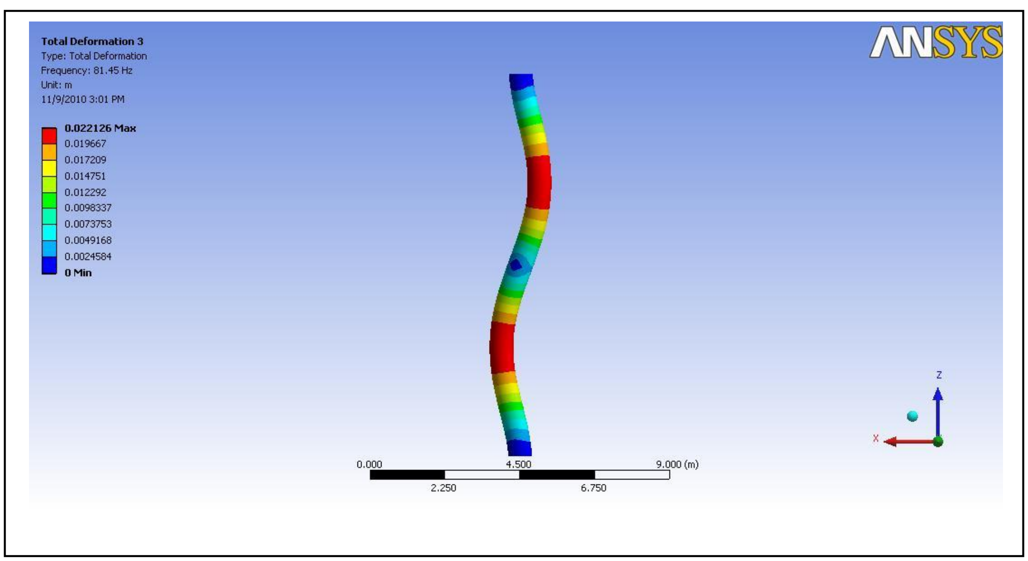


Figure 4.4: The second deformation of the pipe

The deformation occurrence of the pipe is true and as expected the same as in the mode shape obtained earlier (from Figure 3.8, page 24). Figure 4.5 below shows the third deformation of the pipe.

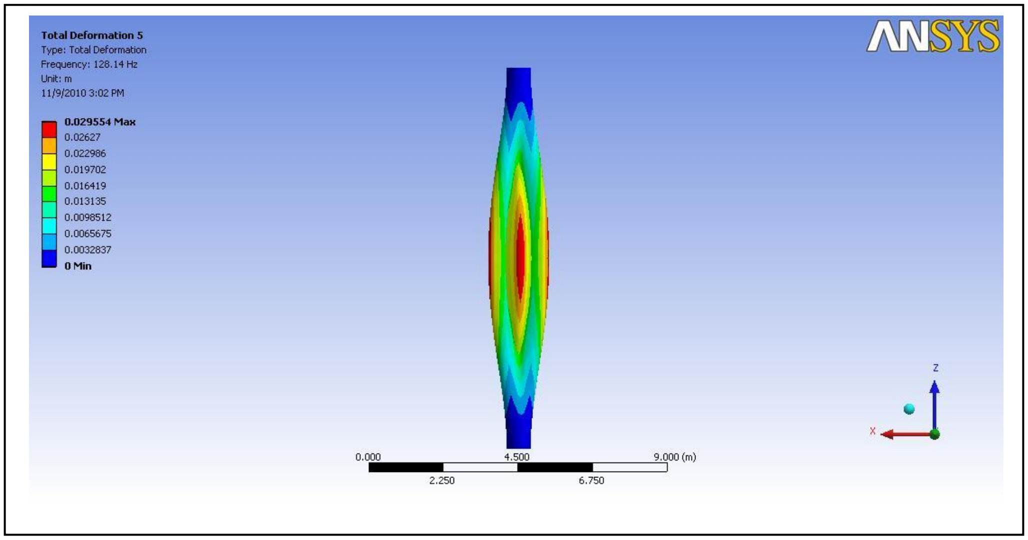


Figure 4.5: The third deformation of the pipe

The deformation occurrence of the pipe for the third deformation is invalid and is not the same as expected in the mode shape obtained earlier (from Figure 3.9, page 25). Figure 4.6 below shows the fourth deformation of the pipe.

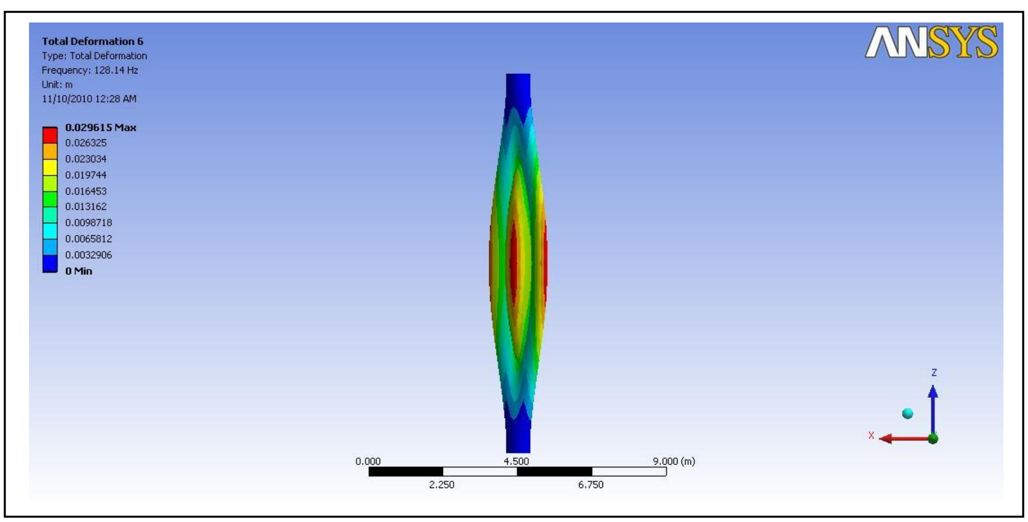


Figure 4.6: The fourth deformation of the pipe

The result of the pipe for the fourth deformation is invalid and it is the same as the third deformation. However, the results obtained from the third and fourth deformation maybe valid for further investigation that involves a more complex calculation.

From these deformation figures, the mode shapes and the natural frequency that have been obtained based on the time line is shown below in Figure 4.7

Figure 4.7: The mode shape and natural frequency of the pipe

The natural frequency for the first deformation of pipe is 31.38 Hz while for the second deformation is 81.45 Hz. The frequency for both third and fourth deformation of the pipe is the same which is 128.14 Hz. From the result; these values are expected to increase based on the theory calculation (please see page 23)

The ANSYS has shown that the probability of the pipe to deform is for the first and second deformation while the rest is for higher level of calculation. These deformations calculated using ANSYS are based on real life or actual condition. Therefore the results are valid and can be taken as reference for future investigation.

CHAPTER 5
CONCLUSION

5.1 Conclusion

The study of the effect of fluid flow on subsea pipe line riser is presented on this report. The main focus of this study is the investigation of vibration that is due to the fluid flow effect externally on subsea pipe line riser. The fluid flow which is the wave is one of the vital components of force that may contribute to the high vibration.

The general method as the primary calculation method is verified with existing results in literature review and some references. The ANSYS is used to demonstrate the parametric effects.

The hydrodynamic flow characteristic has a remarkable influence to the riser that contributes to the high vibration of the pipe. This will eventually ends the pipe's life span earlier that expected. Based on the results obtained by ANSYS simulation which is the actual result, the pipe has deformed into several shapes namely mode shape one, two, three and four. The mode shape of one and two are concurring with the theoretical result but not for the mode shape of three and four. An advance study has to be made to investigate the mode shape of three and four.

5.2 Recommendation

Based on the project, there are some aspects that should be considered to enhance the studies for future reference. These aspects are the design phase and, the regulation and standards for subsea production system.

5.2.1 The Design Phase

For the design phase of a pipe riser, the key issues that have to be considered are [17]:

- Top tension factor determination
- The pipe sizing
- Stroke analysis
- Tensioning system sizing
- Riser component sizing
- Preliminary VIV assessment
- Interference Analysis
- Fatigue Analysis

The detailed design phase includes more detailed strength and fatigue analysis, analysis of centralizer spacing, and riser running and installation analysis. The design of the riser system is an iterative process and these are [16]:

1. Review all aspects of the system operation and identify all conditions to be considered in the design. Also, the selection whether a single or dual casing is to be used. Select riser stack-up arrangement
2. Select initial wall thickness sizes, material and other relevant design factor such as corrosion allowance and dimensional tolerances
3. Perform static analyses to confirm stack-up and define tension requirements
4. Perform extreme, VIV and fatigue response analysis
5. Perform interference assessment
6. If the results from points 3, 4, 5, or 6 generate the requirement for design changes, update the system design and redo all relevant analysis

7. Finalize design of specialist components such as keel joints. Typically initial design of the specialist components is incorporated into the global at the start of the design process, with these initial designs selected based on previous experience. These designs can then be updated in the various design stages. It may also be necessary to undertake local FE analysis to verify the component design and to generate stress concentration factors
8. Perform installation analysis
9. Complete all design reports

In all stages of the design, consideration should be given to the requirement to perform sensitivity studies on key parameters.

5.2.2 Regulation and Standards for Subsea Production Systems [16]

The first step in designing a subsea production system is to determine the regulatory rules applying to the specific situation. Every oil-producing nation has a set of regulations governing the exploration and extraction of its natural resources

The option of standards such as American Petroleum Institute, API and International Standard Organization, ISO in developing and operating the field which a subsea development is to be designed according to is the choice of the operator. The operator is obliged to follow the applicable country's regulations. For the security investment, the developer will demand the designs and constructions of development classified by an independent third party classification society. The society will then reviews and verify the design and construction to ensure compliance with the predefined regulations, standards, rules, and guidelines.

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APPENDIX

LITERATURE REVIEW