Stress Analysis of Riser using Finite Element Method (FEM)

By

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CERTIFICATION OF APPROVAL

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Approved by,

____
(Dr Mokhtar Awang)

UNIVERSITI TEKNOLOGI PETRONAS

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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.

NOR NADHIYA SABARUDIN

ABSTRACT

This report basically discusses the preliminary research done and basic understanding of the chosen topic, which is **Stress Analysis of Riser using Finite Element Method**. The objective of the project is to perform static stress analyses for selected load cases on riser. There are two types of load which acting along the riser structure, environmental and functional load. Environmental load is due to wave and current of the sea water whereas functional load is due to temperature and pressure of oil/gas carried by the riser. These loads can cause global buckling and failure to the riser. Thus, the study is about to determine the generated stress along riser due to these loads to ensure that the detailed design of riser safe for operation. Static stress analysis is the core of the riser design. The challenge in this project is to understand the stress generated when load is applied on riser and also to model the real structure of riser itself. Basically, the scopes of study are about effect of environmental and functional load on rigid riser and Finite Element analysis using ANSYS. Several theories have been adapted to complete the study. The theories include One-seventh power law, Morrison Equation and stresses equation. Methodology of this project started with project identification, followed by data gathering and calculation of hydrodynamic forces. After calculation is done, ANSYS is used to conduct modeling. While modeling, steel X65 and two element types are chosen to model the riser. Based on the simulation result, comparison will be done between generated stress from ANSYS and calculated allowable stress. The acceptance criteria for stress analysis based on PTS 20.214, generated stress must less than allowable stress.

ACKNOWLEDGMENT

First and foremost, I give thanks and praise to God for His guidance and blessings throughout the entire course of my training.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Nowadays, with the development of offshore petroleum exploration and exploitation, more and more structures will be constructed and used in deep/shallow seas. The structure includes the topside above sea level and the subsea pipeline. An important pipeline connecting the topside to the subsea pipeline is a "Submarine Riser". Submarine riser is a transporter of crude oil and gas located along the jacket leg. It is use to transport gas and crude oil from the production facilities at topside to the subsea pipeline or vice versa. Because the fact that the environment conditions of seas are more severe, i.e. big winds, high speed currents, high waves and so on, serviced in such an environment, the riser will be subject to enormous environment loadings [1]. Other than that, riser also experienced functional load which come from the fluid carried inside the riser. In order to make sure the effectiveness of transporting the gas and crude oil, riser have to be designed not only fit for purpose but also safe throughout the design life. Hence there is a need to analyze the detailed design of the riser before it can be use in real life. As a reference, J4DP riser at J4 fields has been used for analysis using Finite Element Method (FEM).

PETRONAS Carigali Sdn Bhd (PCSB) is undertaking the development of J4 fields offshore Bintulu, Sarawak. J4 field is located approximately 53km west of the existing D35 oil and gas production facilities (D35 complex). The water depth in the J4 area is 53.6m.

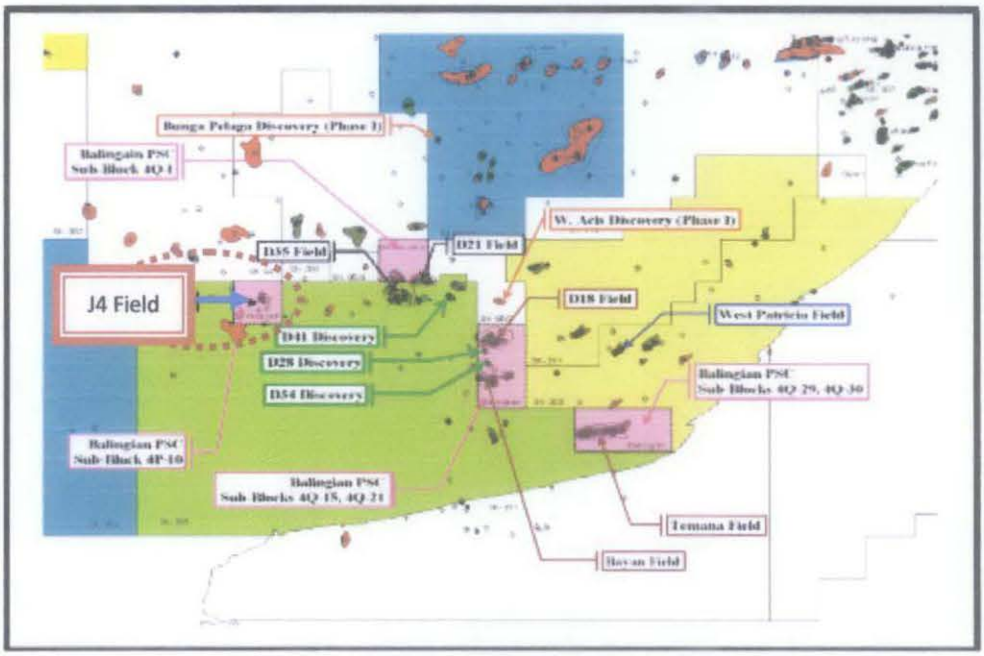


Figure 1.1: J4 Field Location Map

The J4 wellfluid is evacuated to D35 Complex for further processing. 10 inch FWS pipeline has been identified as the optimum size for J4 pipeline from J4DP-A platform to the existing D35 Complex.

The specifications for the riser materials and installation are based on the relevant PETRONAS Technical Standards (PTS) documents, revised where necessary to account for project-specific requirements and conditions.

1.2 PROBLEM STATEMENT

Although submarine riser and pipeline are considered the safest means of transporting crude oil/gas, some failures do occur which result in spillage, loss of revenue and possible impact on Health, Safety and Environment [2]. The submarine riser failure caused by the action of environmental and functional load become a major challenge in submarine riser construction and operation. In order to solve the problems, analysis of the detailed design of submarine riser need to be conducted first, before fabrication and installation of submarine riser begin. The detailed design of submarine riser must be analyzed to ensure that the submarine riser is not only fit for purpose, but also safe throughout the design life (Refer Appendix A). One of the famous methods used for stress analysis on any structure is Finite Element Method (FEM). FEM is used because it can modeled the submarine riser with a capability to analyze each small section of the riser. It is important to analyze each section of the riser because each section will have different amount of forces which acting on it. Expected outcomes from the analysis are hoop and von mises stress. According to PETRONAS Technical Standard (PTS) 20.214, the design of submarine riser is considered safe for operation if the generated hoop and von mises stress are not exceeding the allowable stress.

1.3 OBJECTIVES

The aims of this project are:

- To develop a Finite Element modelling of submarine riser
- To determine the stress distribution along the submarine riser
- To compare the maximum hoop and von mises stress with their allowable stress.

From the comparison stress, decision can be made whether the detailed design of the riser is safe or not for operation.

1.4 SCOPE OF STUDY

This study deals with a real life data. The data includes detailed design of riser, wave and current, functional load and material specification for riser. Detailed design of riser and environmental condition used is based on J4 project which is located at Sarawak offshore. The water depth at J4 field is 53.6m. Thus, the most suitable and economical riser to be use at shallow water is rigid riser. For material selection, Steel Grade API 5LX65 is used rather than Duplex Stainless Steel because Steel API 5LX65 is more economical and at the same time, it can ensure the safety of the riser due to effect of environmental and functional load at offshore. Riser at D35 platform also used the same material which is Steel API 5LX65.

There are numbers of software that can be used to conduct stress analysis such as ABAQUS, AutoPIPE and ANSYS. In this project, author focus on ANSYS software only. In ANSYS, FEM is used to determine the stress distribution along the riser. Results from ANSYS (hoop and von mises stress) are compared to the calculated allowable stress. As long as the stresses below the allowable value, the designed riser is considered safe and the detailed design is accepted.

1.5 THE RELEVANCY OF THE PROJECT

This project is relevant to the oil and gas industry all over the globe because the main concern of each analysis is for safety precaution. The significant of the project is to provide another method for stress analysis, which is using Finite Element Method using ANSYS software. Nowadays, with the development of various software, engineers tend to use ABAQUS and AutoPIPE compared to ANSYS because ANSYS is quite complicated. It required a lot of effort and time to understand the flow of work using ANSYS. The one year time frame would be ample enough to garner all necessary data and collection of any relevant items or results to be kept as a record which perhaps could be enhanced in the future study.

1.6 ABBREVIATIONS AND DEFINATIONS

PCSB	PETRONAS Carigali Sdn Bhd
OPR	Offshore Pipeline and Riser
PTS	PETRONAS Technical Standard
Zone 2	Pipeline Zone 2 is the portion(s) of the pipeline system located at an offshore platform from pig trap down to the riser bottom bend at the seabed, including an extra length of pipe of at least five pipe diameters beyond the bottom bend or fitting.
Zone 1	Pipeline Zone 1 is the remainder of the pipeline system.
MSL	Mean Sea Level
SWL	Still Water Level
SMYS	Specified Minimum Yield Strength
ASME	American Society of Mechanical Engineers
FBE	Fusion Bounded Epoxy
3LPP	3 Layer Polypropylene
FEM	Finite Element Method

CHAPTER 2

LITERATURE REVIEW

2.1 SUBMARINE RISER

The submarine risers have been first used since 1949 in Mohole Project in the US. In general design perspective, the marine riser are considered to carry their own weight and subjected to a static offset for flexible riser [3]. In Malaysia, most of the project conducted by PETRONAS used rigid riser for shallow water. The weight of rigid riser is supported by jacket leg on the clamp. They are also designed to confront the nonlinear hydrodynamic drag forces, internal and external fluid pressures, surface waves and current effect. It is found that although there are a number of investigations related to the stress analysis of the marine riser/pipes, the stress analysis due to environmental load is rarely been discussed.

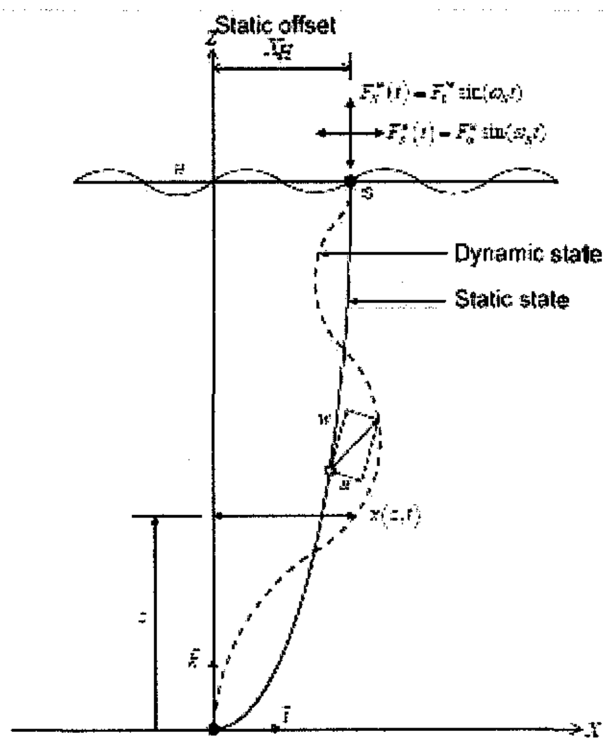


Figure 2.1: Flexible Riser with static offset [3]

Submarine riser is defined as the vertical or nearly-vertical segment of pipe connecting the facilities above water to the subsea pipeline [2]. Submarine riser is an important pipeline in transporting gas and crude oil from the platform to the subsea pipeline or vice versa. There are three types of submarine riser which is rigid riser, flexible riser and hybrid riser (combination of rigid and flexible riser). Flexible riser normally used at Floating Processing Storage and Offloading (FPSO) and Floating Storage and Offloading (FSO) [4] while rigid riser is used at fixed Platform. In this project, only rigid riser will be analyzed using Finite Element Method because J4 field is shallow water and the only suitable riser to be used is rigid riser.

For a rigid riser, resistance to various loads is one of the main concerns because a huge load can cause fatigue/failure to the structure. Different from the onshore riser, submarine riser is hard and costly to be repaired if anything happened. Besides that, submarine riser also is exposed to continuous hydrodynamic forces due to the wave and current. For this reason, riser need to be design so that it will remain stable and safe along the jacket leg under various condition from empty riser during installation phase up to heavy storm during operation period [5].

Hydrodynamics force is determined using Morison's Equation which relates hydraulic drag and inertial forces to local water particle velocity and acceleration. There are several methods can be implemented for riser to resist hydrodynamic forces which is by adding external coatings, correct material selection and increase the riser wall thickness. These method commonly applied together to increase the resistance due to functional and environmental (hydrodynamics) loads.

2.2 THERMAL EXPANSION AND GLOBAL BUCKLING

Thermal expansion and global buckling due to functional load can be analyzed using FEM. The objectives of this analysis is to determine if expansion spool is required to be install between the riser and pipeline. According to *Yong Bai* [6] a spool was designed to absorb the thermal expansion of pipeline containing inlet fluid up to design temperature at the platform end. The analysis was carried out using ABAQUS finite element analysis. In the finite element analysis of pipeline thermal expansion, the structure is modeled from the lowest riser clamp to the submarine pipeline. The analysis includes the followings:

- Thermal expansion
- Maximum hoop and von mises stress.

In the analysis, condition where expansion spool is installed and without expansion spool are analyzed. The pipe end expansion length of pipeline determines the stress distribution in the spool area. Non linear ABAQUS software was used to assess the thermal expansion and potential lateral buckling for pipeline. Other than that, hoop and von mises stress are evaluated too. Figure 2.2 shows effective force distribution along pipeline under the design condition. The pipeline does not buckle even though without expansion spool under the design condition.

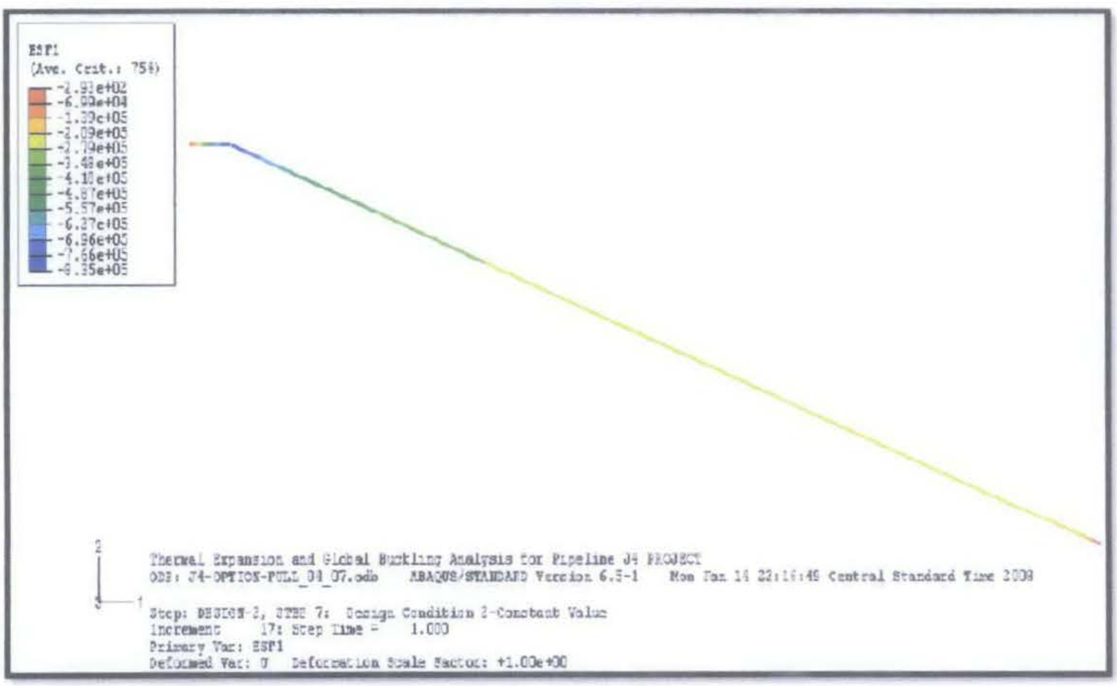


Figure 2.2: Effective Force Distribution in Design Condition [6]

Based on the summary of Table 2.1, all unity checks are below 1.0, therefore, the pipeline system satisfies the design temperature requirement. It can be conclude that, finite element analysis has successfully analyze the system; with or without expansion spool. Global buckling does not occur in this case and the project is more economical without spool.

Table 2.1: Summary of result [6]

Key Parameters and Results	Unit	Calculated Value	Allowable Value	Unity Check
Max. Von Mises stress in Pipeline Zone 1	[MPa]	110.0	430.1	0.26
Max. Von Mises stress in pipeline zone 2, riser and riser base	[MPa]	107.0	300.2	0.36
Max. Hoop stress in pipeline zone 1	[MPa]	81.3	322.6	0.75
Max. Hoop stress in pipeline zone 2	[MPa]	70.8	224.0	0.68

2.3 RISER STRESS ANALYSIS AND EXPANSION OFFSET SIZING

According to Offshore Pipeline and Riser (OPR) Inc., the riser stress analyses were performed to verify the pipe wall thickness and riser design by determining the maximum stress within the riser [7]. The design conditions considered in the riser stress analysis as specified by PTS 20.196 [8] are the functional load, functional load plus 100 year environmental storm conditions and hydrostatic test plus 1-year environmental storm conditions.

From the stress analysis and expansion offset sizing, the design should have the minimum length of expansion offset to accommodate the end expansion of the pipeline. The maximum stress induced in the riser and the expansion offset/pipeline is, in all cases, less than maximum allowable stress.

2.4 COMMON WAVE THEORIES

According to Chakrabati [9], it is assumed that the waves are two dimensional in the XY plane, that the ocean floor is flat of undisturbed depth, *d* from the Still Water Level (SWL), and that the waves are progressive in the positive X direction. The progressive wave is defined in Figure 2.3 in which the various symbols used to characterize the wave are given. A wave train is generally defined by its height, *H*, period, *T* and water depth, *d*.

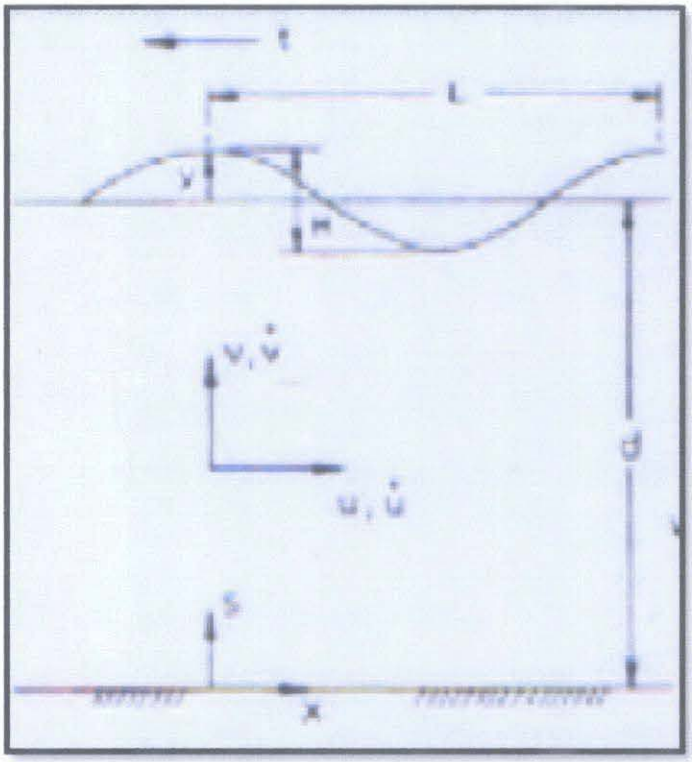


Figure 2.3: Definition sketch for a progressive wave train [9]

Wave forces on offshore structures are calculated in three ways:

- Morison equation
- Froude – Krylov theory
- Diffraction theory

The Morison equation was developed by Morison and his colleagues in describing the horizontal wave forces acting on a vertical pile which extends from the bottom through the free surface. Morison et al. [9] propose that the force exerted by unbroken surface waves on a vertical cylindrical pile which extends from the bottom through the free surface (Figure 2.4 and Figure 2.5) is composed of two components, inertia and drag.

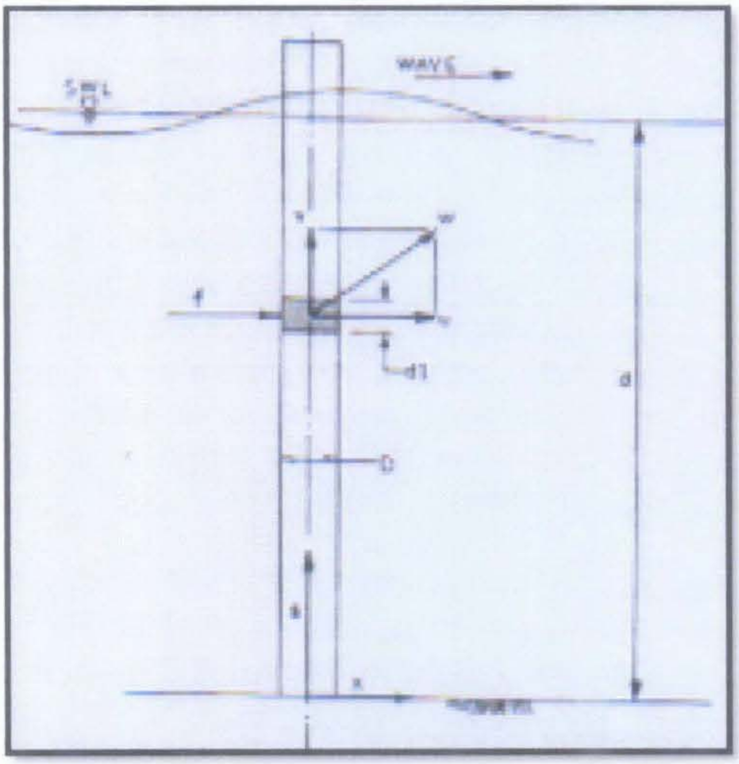


Figure 2.4: Definitions sketch for wave forces on small diameter cylinder (riser) [9]

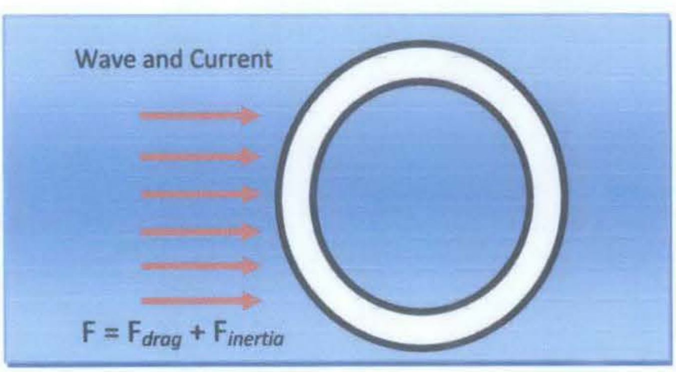


Figure 2.5: From top view of the riser [10]

2.4.1 Drag Force

The principal cause of the drag force component is the presence of a wake region on the "downstream" side of the cylinder. The wake is a region of low pressure compared to the pressure on the "upstream" side and thus a pressure differential is created by the wake between the upstream and downstream of the cylinder at a given instant of time. The pressure differential causes a force to be exerted in the direction of the instantaneous water particle velocity. In a steady flow downstream side is a fixed and the drag force is proportional to the square of the water particle velocity. In an oscillatory flow, the absolute value of the water particle velocity is inserted to insure that the drag force is in the same direction of velocity.

$$F_D = C_D\,(1/2)\,\rho V^2 D \qquad (2.1)$$

Combining the inertia and drag components of force, the Morison equation is written as

$$f = F_D + F_i = C_D\,(1/2)\,\rho V^2 D + (\pi/4)\,\rho D^2 C_M (\delta u/\delta t) \qquad (2.2)$$

F	=	Combine drag and inertia force
F_D	=	Drag force
F_i	=	Inertia force
u	=	Instantaneous velocity
C_M	=	Inertia coefficient
D	=	Outside diameter of a riser
$\delta u/\delta t$	=	Horizontal acceleration of water

Basically, the inertia force is in the same direction as drag force. Thus, summation of these two forces is equal to hydrodynamic force.

2.5 ANALYSIS USING MEASURED CURRENT DATA

If in-situ current measurements are available, then these can be used to determine the distribution of velocity incident upon the riser. For riser and other vertical structures, several current meters should be used and distributed throughout the full depth. A full depth velocity profile can then be fitted to the resulting measured data points.

For engineering design purposes, the "one-seventh power law" is commonly used to determine a velocity profile from a single measured current value [11]. The one-seventh power law is given by the following expression:

$$u = u_1\left(\frac{y}{y_1}\right)^{1/7} \tag{2.3}$$

Where,

u = velocity at given high, y, above the seabed

u_1 = known velocity from current meter

y_1 = height of current meter above seabed

The steps involved using one seventh power law will be explain more at the methodology part.

Figure 2.6 illustrate the use of the law, showing general velocity profile can be determined from a single known velocity at a known height above the seabed. This latter point is particularly relevant in the case of riser design, where the velocity profile over the entire water depth may be required. To be reasonably reliable, current meter measurements should at least be available at near-bottom, mid depth and near surface positions. These will be explained more at methodology part.

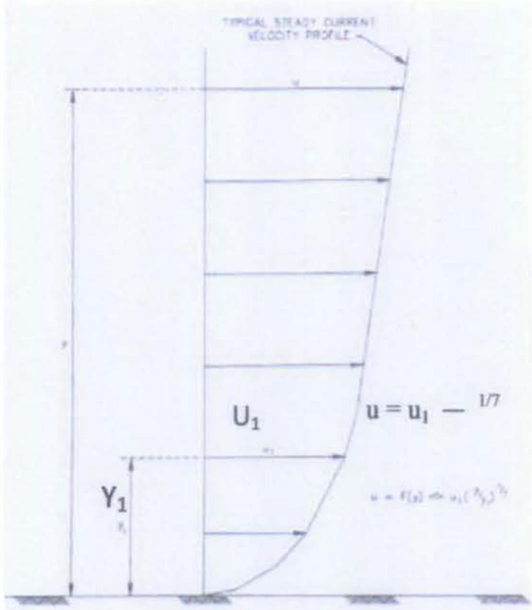


Figure 2.6: "One-seventh power law" definition sketch [11]

2.6 FINITE ELEMENT METHOD (FEM)

The FEM is based on the idea of building a complicated object with simple blocks, or dividing a complicated object into small and manageable pieces. Application of this simple idea can be found everywhere in everyday life, as well as in engineering (e.g., building and approximation of the area of a circle).

2.6.1 FEM in structural analysis

- Discretize the structure into elements with nodes
- Describe the behavior of the physical quantities on each element
- Connect the elements at the nodes to form an approximate system of equations for the whole structure
- Solve the system of equations involving unknown quantities at the nodes (e.g., displacements)
- Calculate desired quantities (e.g., strain and stress) at selected elements

The advantages of using FEM:

1. Can handle complex loading

    - Nodal load (point loads)
    - Element load (pressure, thermal, inertial forces)

2. Can handle a wide variety of engineering problems

    - Solid mechanics
    - Dynamics
    - Heat problems
    - Fluids
    - Electrostatic problems

2.7 RISER DESIGN

Basically, the design of riser is similar to the subsea pipeline. It is a hollow pipe which coated according to its location. Based on the J4DP riser design, the coated are as follows:

- Riser above Splash Zone : 0.5mm glass flake polyster
- Splash Zone : 12.7mm Neoprene over 0.5mm FBE
- Riser Submerged : 3.5mm 3LPP

Corrosion coating which normally used is Fusion Bounded Epoxy (FBE) and 3 Layer Polypropylene [12]. FBE is a high performance anti-corrosion coating that provides excellent protection for small and large diameter pipelines with moderate operating temperatures [13]. It also provides long term corrosion protection, good mechanical and chemical protection, chemical resistance and soil stress resistance.

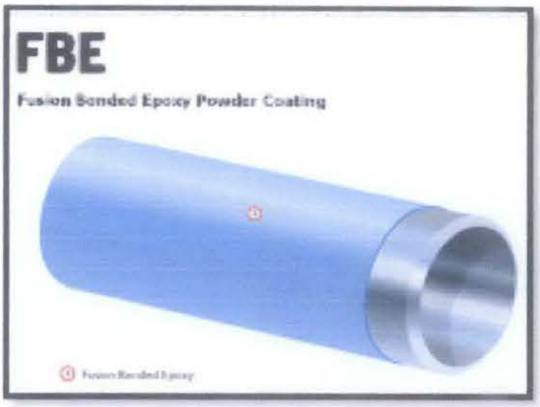


Figure 2.7: Fusion Bounded Epoxy (FBE) [13]

3LPP System is a multilayer coating composed of three functional components consists of a high performance FBE followed by a copolymer adhesive and an outer layer of polypropylene which provides the toughest, most durable pipe coating solution. It gives long term corrosion resistance, High temperature performance, resistance to moisture penetration and mechanical damage.

Figure 2.8: 3LPP [13]

Neoprene is used as impact resistant, e.g. boat impact. As the fabrication of riser consists of several layers of coating, it can provide full protection against corrosive environment and give impact resistance. As stated above, at splash zone, the coating is thicker compared to the other location because it is most corrosive environment which can caused corrosion happened very fast and by adding neoprene, it can protect the riser from various impact as the splash zone is located around the Mean Sea Level (MSL).

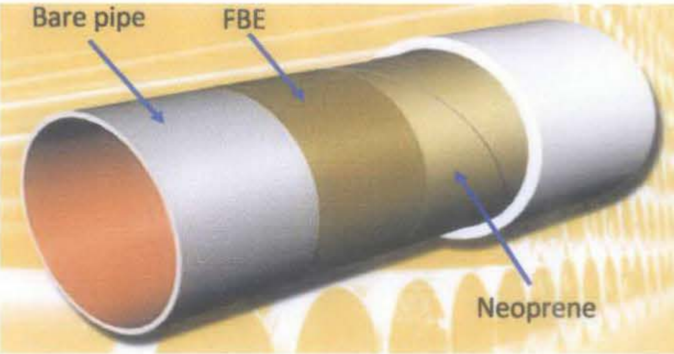


Figure 2.9: Example of insulation material coating [14]

A riser has to be stable and safe along the jacket leg. The wall thickness plays an important role while designing the riser. If it is too thin, it can caused rupture under the action of high internal pressure. On the other hand, if it is very thick, it will be difficult to install and expensive to construct. Normally, designers will design the riser based on the environmental condition and by referring to the related codes. The environment load is important because wave and current load give huge effect to the structure of riser.

While designing, good material selection for the riser makes it possible to sustain load due to external pressure and temperature. However, wave, current, internal pressure and temperature still affect the stability of the designed riser. In some cases where the pipeline thermal expansion gives an effect on riser, it is controlled by installation of expansion absorbing mechanism. Good material selection can reduce cost while fabrication.

The first step in design against high internal pressure and temperature is to determine how large the design- internal pressure and temperature ought to be followed by checking the worst case scenario for wave and current effect.

2.8 MODELLING THEORY

Generally, a riser resting along the jacket leg is exposed to environmental forced due to the actions of waves and currents. As a transporter, crude oil and gas carried by riser also induced load, known as functional load. Normally, functional load are due to temperature and pressure from the crude oil which flow inside the riser. The following subsections describe the forces acting on riser which are relevant to the study.

2.8.1 Temperature

Crude oil's temperature is based on the reservoir's temperature. When crude oil flow inside the riser from the platform to the subsea pipeline, the temperature will decrease. But for the modeling purposes, the maximum temperature was used and it applied constantly along the riser. The maximum internal temperature is at design condition, $90^{o}C$ while the external pressure is based on the seawater temperature, $24^{o}C$. When the temperature is high, riser might experience thermal expansion which can also caused displacement of the riser.

2.8.2 Pressure

Internal pressure from the contained fluid is the most important loading a riser has to carry. Maximum internal pressure used is 13.8 MPa. If the generated stress in the pipe wall is too large, the pipeline will yield circumferentially, and continued yielding will lead to thinning of the pipe wall and ultimately to rupture [15]. While the usage of higher-grade steel or thicker wall pipe would protect the riser against the external hydrostatic pressure. The external hydrostatic pressure from seawater varies according to the water depth. It can be calculated using equation:

$$P_{external} = \rho . g . h \quad (2.4)$$

Where,

ρ = seawater density, 1025 kg/m^3

g = gravity, 9.81 m/s^2

h = water depth

Since water is much heavier than air, this pressure increases as we venture into the water. For constant density and gravity acceleration, this relation reduces to Equation 2.4, as expected. It changes with the vertical, but remains constant in other directions." [16]

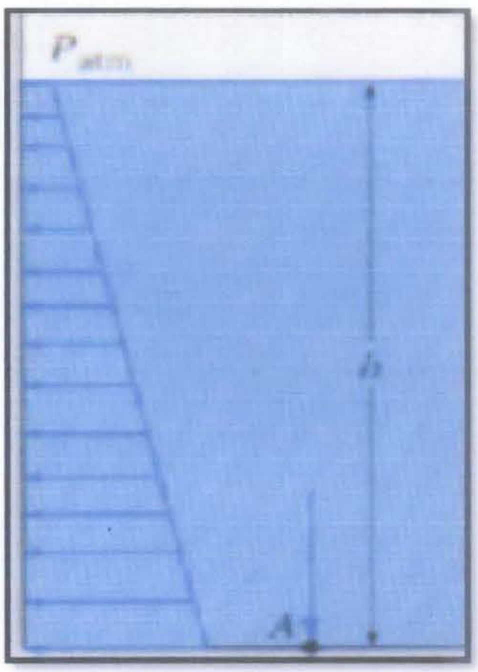


Figure 2.10: Pressure distribution [16]

Based on the equation above, the highest pressure is at the seabed and the lowest pressure is at MSL. Riser experienced hoop stress due to these pressures. (Pressure distribution can be found at Appendix)

2.8.3 Hydrodynamic Loads

Hydrodynamic loads are flow induced loads caused by the relative motions of the pipe & surrounding liquids. When determining the hydrodynamic loads, the relative liquid particle velocities and accelerations calculations must take into account contributions from waves, currents and pipe motions. The hydrodynamic loads acting on a riser are:

- Drag forces - In phase with the relative water particle velocity acting normal to the pipe axis.
- Inertia forces – Are in phase with the relative water particle acceleration acting normal to the pipe axis

2.8.4 Load Combinations

The worst combinations of simultaneously acting loads must be considered. The simultaneous occurrence of loads related to the same environmental or functional phenomenon, i.e. the coincidence of extreme winds, waves & storm tide, must be evaluated during the pipeline design process. Combination of various unrelated extreme loads or exceptional functional loads need not be considered. For wind, wave & current loads interaction, it is permitted to consider their relative directions and to add the components perpendicular to the pipeline system or a section thereof. Hence, the submarine part of a riser shall be designed for the most critical of the following load conditions:

- Functional loads acting alone
- Functional loads plus simultaneously acting design environmental loads.

2.9 ALLOWABLE STRESSES

While designing and conducting analysis of the riser [17], two types of stress should be checked in riser design which is Hoop stress and Von Misses stress. Hoop stress can be calculated by using a simplified formula, usually known as Barlow's formula [3]. Barlow's formula, however, is not the most accurate formula to calculate pipeline wall stress. It overestimates the maximum hoop stress. But most pipeline codes specify that Barlow's formula be used in riser/pipeline design. Hoop stress is induced into the riser by pressure effect.

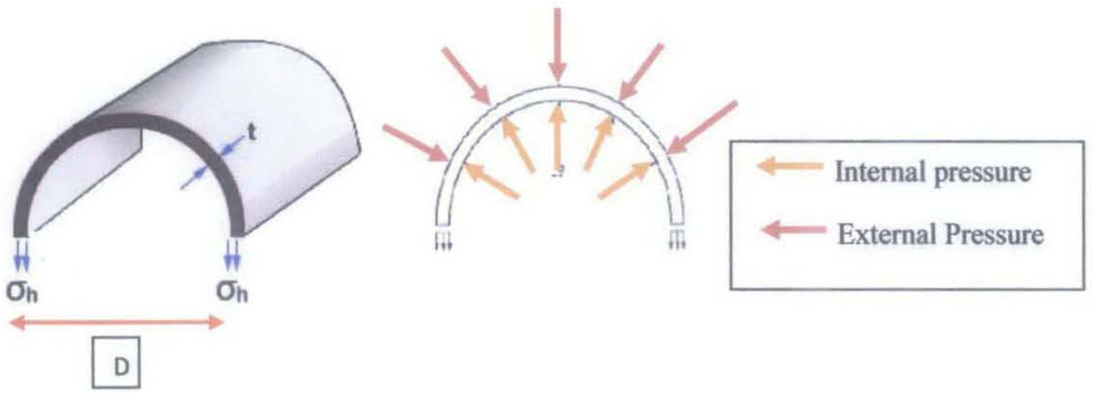


Figure 2.11: Hoop stress and direction of pressure [3]

The Barlow's formula:

$$\sigma_h = (P_i - P_e)\, D / 2t \qquad (2.5)$$

Where σ_h = Hoop Stress

P_i = Internal Pressure

P_e = External Pressure

D = Outside Diameter

t = Nominal Wall Thickness

The Von Mises stress can be considered as an equivalent stress. Based on PTS 20.214, maximum Von Mises stress in a riser is calculated using:

$$2\,\sigma_v^2 = \sigma_h^2 + \sigma_L^2 - \sigma_h\sigma_L + 3\sigma_s^2 \qquad (2.6)$$

Where σ_V = Von Mises,

σ_h = hoop stress (due to pressure)

σ_L = longitudinal stress (due to pressure, thermal expansion and bending)

σ_s = shear stress

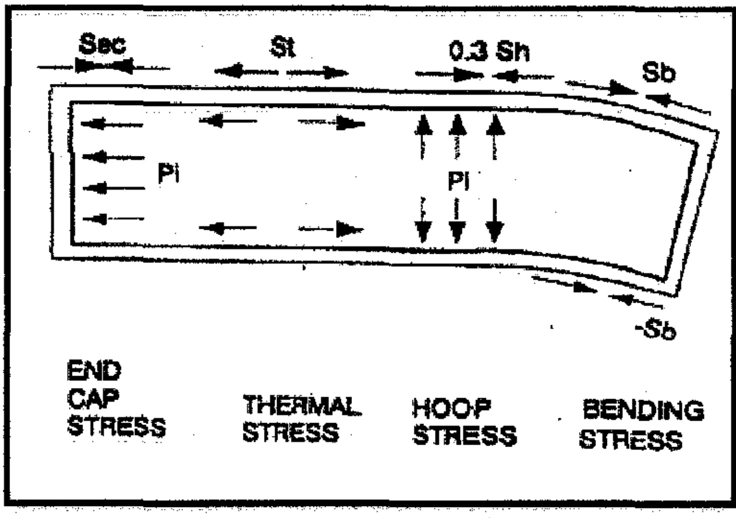


Figure 2.12: Equivalent Stress [3]

Basically, the shear stress, σ_s is neglected for riser because the riser is in vertical position. Water flow perpendicular to the riser and make it zero shear stress. A force which causes axial stresses in a riser section also lengthens or shortens the section. Hoop stresses, σ_h are induced into the pipeline by pressure effects, results in tension stress. Another effect that can induce axial stress is temperature. If the temperature of the riser is increased and free to expand in all directions, it will expand both circumferentially and axially. Circumferential expansion is usually completely unconstrained, but longitudinal expansion is constrained by seabed friction and attachments. Bending stresses are caused by the bending moment when the riser is bent under the action of transverse load. The sum of bending stress and axial stress is known as longitudinal stress, σ_L.

$$\sigma_L = 0.3\sigma_h + \sigma_b + \sigma_t + \sigma_{en} \quad (2.7)$$

Where σ_b = bending stress

σ_t = thermal stress

σ_{en} = end cap stress

Maximum Von Misses stress occurs at the inside wall of the compressive side of bending moment. Negative value bending moment and without "end-capped" tensile stress should be used in axial stress calculation

In this project, author use PTS 20.214 as a reference to study the acceptance criteria for load applied and stress. The value for each loads acting on riser has to be determined first. Variety value of load will be evaluated based on different condition and the aim of this project is to analyze the stresses and make sure the amount for each stresses is within the range based on PTS.

CHAPTER 3

METHODOLOGY

3.1 PROJECT FLOW PROCESS

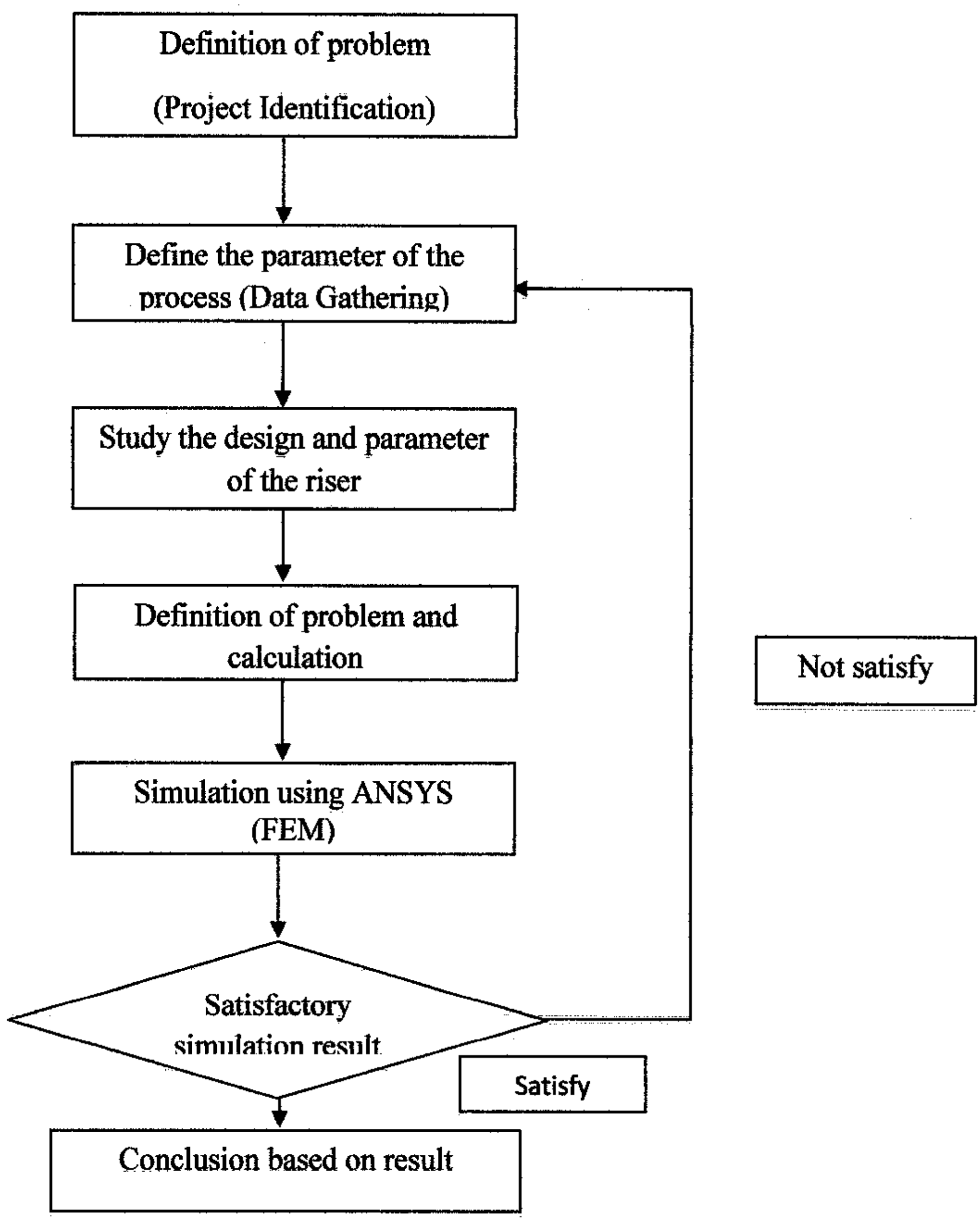


Figure 3.1: Project Flow Process

3.2 PROJECT IDENTIFICATION

For this project, a real life submarine riser project had been identified and it is J4DP riser project. PETRONAS Carigali Sdn. Bhd. (PCSB) has planned to build a new J4DP riser to connect the subsea pipeline to the D35R riser. Sarawak J4 field is located approximately 53km west of the existing D35 oil and gas production facilities (D35 complex).

The technical and structural work is performed by PCSB's Development Division (DD) themselves. The personnel involved are from Facilities Engineering Department (DFE), Supply Chain Management Department (DSCM) and Corporate Health, Safety and Environment Department (DHSE) under PCSB.

The PCSB's Sarawak Operations (PCSB-SKO) will be assisting the project team for the entire work. The work consists the scope of:

- Detailed engineering design
- Procurement
- Construction
- Commissioning

The crude oil riser at J4DP-A platform shall be designed in accordance with PTS 20.214 and its which specifies the ASME B31.4 and B31.8 code in order to comply with the requirement of the Petroleum (Safety Measures) Act, 1984.

3.3 DATA GATHERING

Figure 3.2 shows the detailed design of the J4DP riser which connected to submarine riser and D35R riser. At splash zone area, riser is coated with several layer of coating material for corrosion protection and impact resistance, which will be considered while modelling using ANSYS.

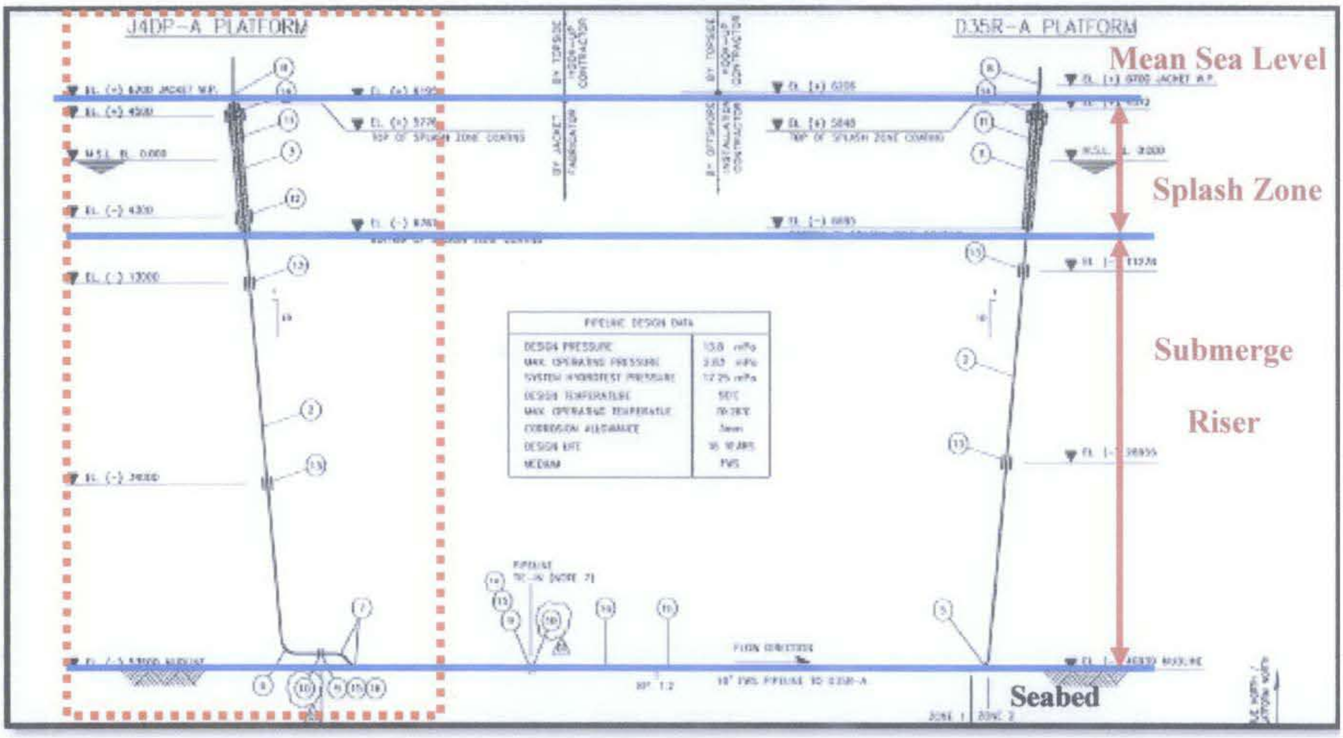


Figure 3.2: Location of riser at J4 field [18]

Below are the data for riser stress analysis. The most important element in riser/pipeline mechanical design is the determination of the wall thickness [15]. Wall thickness is a function of the pipeline's maximum allowable operating pressure and the yield strength of the steel pipe used. It is important because without correct wall thickness, riser cannot sustain various loads which acted on it. If overloading, the wall can crack and continue applied load on it can cause fracture. Based on PTS 20.214, the recommended wall thickness for riser is 11.41mm but in real life the wall thickness will be designed as 12.7 mm. Designed wall thickness must be greater than recommended wall thickness for safety during real operation.

3.3.1 Riser Design Parameter

The designed riser for J4 field as below:

Table 3.1: Design parameter for the riser

Parameter	Units	Dimension
Wall Thickness	mm	12.7
Outer Diameter	mm	273.1
Corrosion Allowance	mm	3
Riser Length	m	53
Riser Bottom Bend at Platform (bend angle)	Degree (^{o})	84.9
Riser Bottom Bend at Platform (bend radius)	mm	1250
Design Service Life	years	16

3.3.2 Pressure and Temperature

The pressure and temperature of crude oil carried along the riser is based on the "Design Condition"

Table 3.2: Pressure and Temperature

Parameter	Units	Value
Design Pressure	MPa	13.8
Design Temperature	^{o}C	90
Maximum Operating Pressure	MPa	2.83
Maximum Operating Temperature	^{o}C	70.26
Hydrotest Temperature	^{o}C	30
Hydrotest Pressure	MPa	17.25

3.3.3 Wave and Current

In order to calculate hydrodynamic force, two important data (wave data and current speed data) must exist.

Table 3.3: Wave Data

	Unit	1-year	100-year
Maximum Wave Height, H_{max}	m	8.0	10.4
Associated Period, T_{ass}	s	9.0	9.7

Table 3.4: Current Speed Data

Elevation, y_1		Velocity, u_1 (m/s)	
Description	Height above Seabed (m)	1-year	100-year
Surface	1 x Depth	0.72	1.21
Mid-Depth	0.5 x Depth	0.65	1.1
Near Bed	0.01 x Depth	0.37	0.63

3.4 CALCULATE HYDRODYNAMIC FORCE

The steps involved to calculate hydrodynamic force:

i. Velocity for 265 nodes has been calculated using **"One-seventh power law"**, refer equation 2.3. Information from Table 3.4 is used (reference current speed, u_1 at three different heights, y_1). Each node has different velocity. The velocity distribution represent by the graph, Figure 3.3. It is clearly show that the velocity is higher at MSL and getting lower when it is closed to seabed. Maximum velocity is 1.21 m/s at MSL whereas minimum velocity is zero at seabed. (refer Appendix for the result of velocity distribution at each nodes)

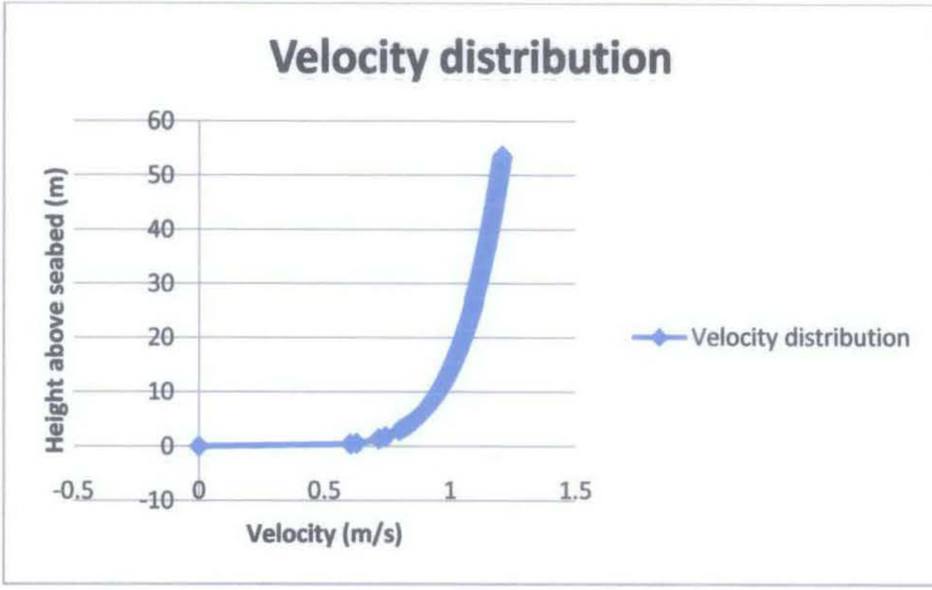


Figure 3.3: Velocity distribution

ii. From the velocity result, it has been input to the "Wave Load Calculator" to calculate the hydrodynamic force at each node, Figure 3.4. Results represented by the calculator are drag force and inertia force.

iii. Summation of these two forces will be the total hydrodynamic force at each node.

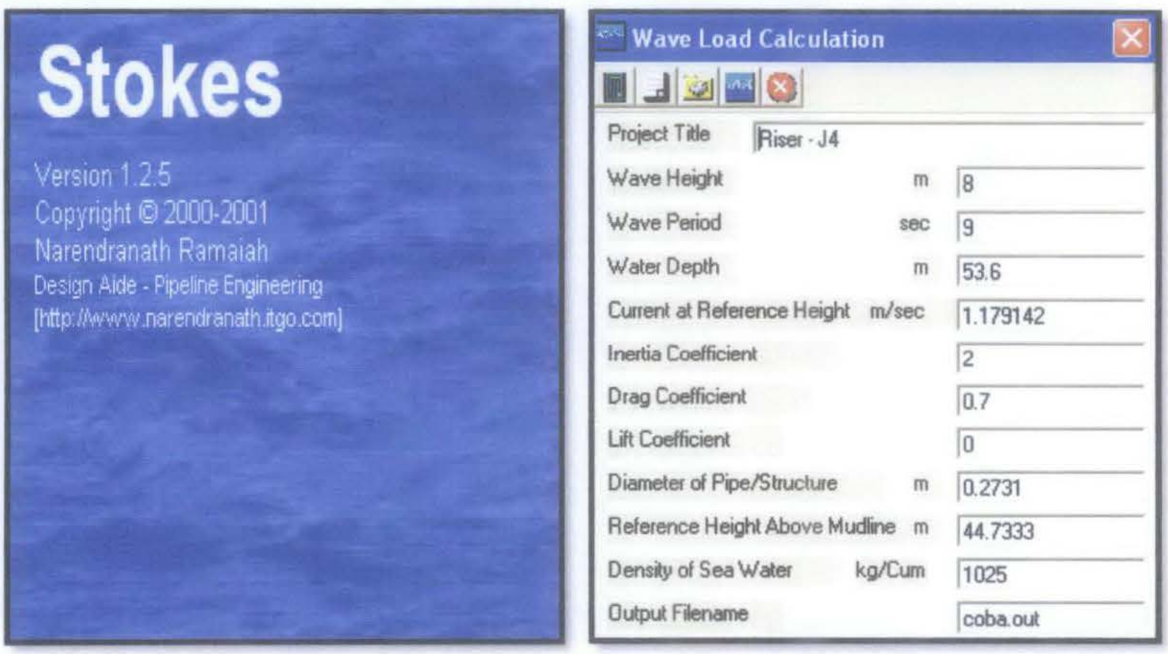
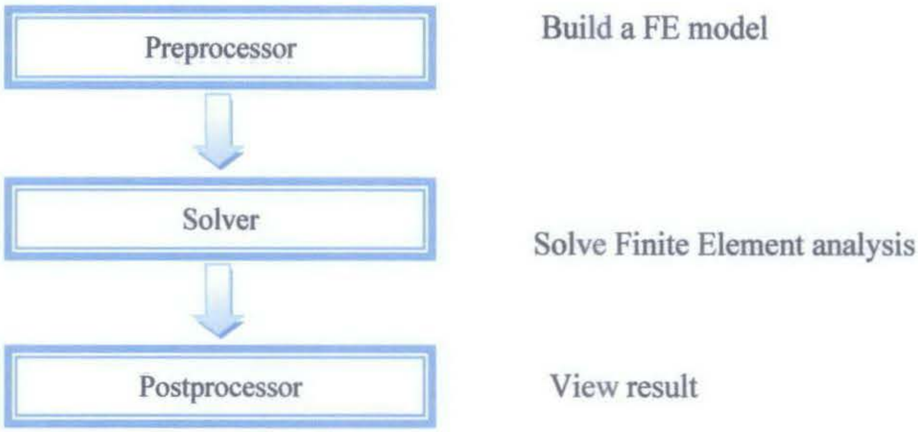


Figure 3.4: Wave Load Calculator

3.5 FINITE ELEMENT MODELLING

FEM performed by using ANSYS. Modeling is done after the data gathering is completed. Below is typical FEM Procedure by ANSYS Software.



3.5.1 Preprocesser

3.5.1.1 Analysis types

In this project, the author uses static stress analysis because the analysis done for rigid riser only. Rigid riser is clamped along the jacket leg.

3.5.1.2 Element types and Real constants

There are two element types used for the modeling; PIPE 16 and PIPE 60. PIPE 16 is used to develop straight line while PIPE 60 for curve. PIPE16 and PIPE 60 are chosen because both are uniaxial element with tension-compression, torsion, and bending capabilities [20]. The element has six degrees of freedom at two nodes: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. Different from PIPE16, PIPE60 is especially to make a curve or elbow. PIPE60 is important in the modeling of riser because the riser design contain goose neck.

The reason why author use PIPE16 is because it is easy to models the riser. Author just has to key in the data such as the wall thickness and outer diameter of the riser and then ANSYS will automatically creates a hollow pipe. Compared to other element types such as Shell 63, it required several steps of work, such as draw the pipe with certain diameter, define wall thickness, meshing and etc. which required a lot of contribution.

Figure 3.5 is an example of rigid riser with their element types.

Command: ***Preprocessor – Element Type - Add/Edit/Delete – Define Element Types***

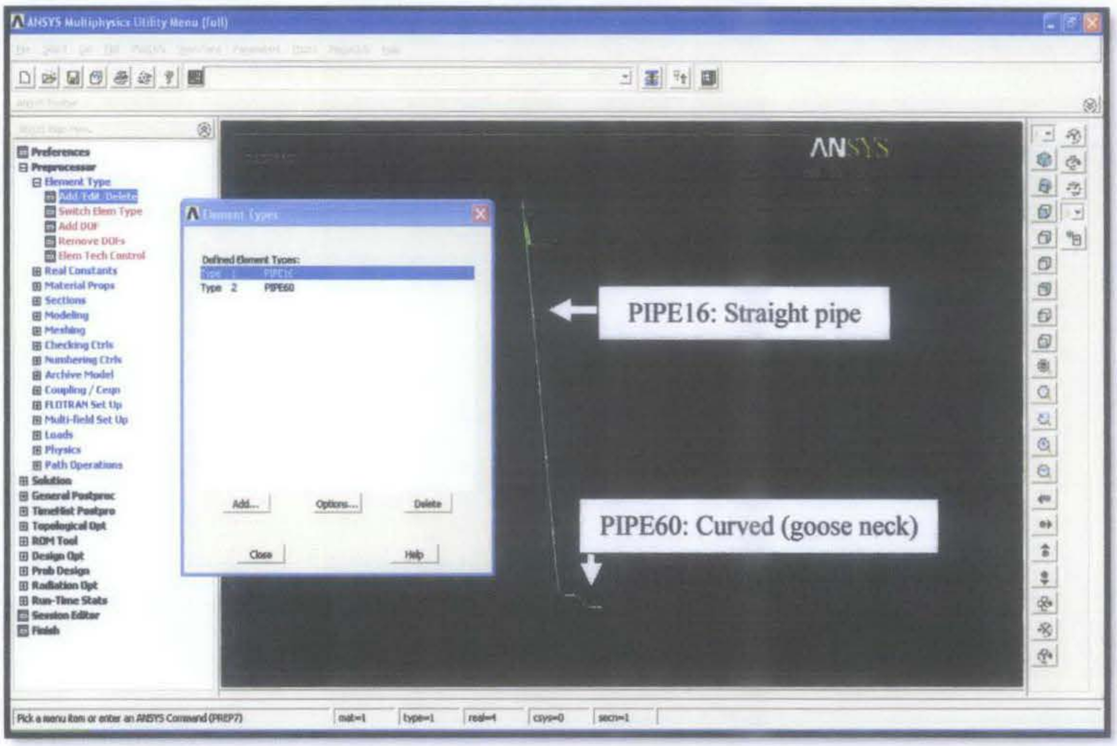


Figure 3.5: Selection of Pipe 16 and Pipe 60 on ANSYS

To set real constant, riser was divided into four sections, each with different set of real constant. The real constants are different in term of the location of each section and the coating used. Refer Figure 3.2 for the location of each section on riser and Table 3.5 represent sets of real constant used.

Table 3.5: Set of real constant

Set	Element Type	Location	Description
1	Pipe 16	Above Splash Zone	0.5mm glass flake polyester (ρ=1400kg/m^3)
2	Pipe 60	Goose neck	3.5mm 3LPP (ρ=900kg/m^3); radius curvature = 5D
3	Pipe 16	Splash Zone	12.7 mm neoprene over 0.5mm FBE (ρ=1440kg/m^3)
4	Pipe 16	Submerge	3.5mm 3LPP (ρ=900kg/m^3)

Command: ***Preprocessor – Real Constants – Add/Edit/Delete – Add – Choose Element Type***

3.5.1.3 Material Properties

In ANSYS, modeling is done using Steel API 5LX65. Steel API 5LX65 is selected because it can be used safely in the sea environment and can sustain internal and external load. It can be approved by referring to the generated stress via stress analysis. In industry, Steel API 5LX65 is used because it is cheaper compare to Duplex Stainless Steel [20]. Below are Steel API 5LX65 material properties.

Table 3.6: Riser Material Properties

Parameter	Units	Pipe Size
Steel Nominal Diameter	in	10
Steel Density	kg/m^3	7850
Young's Modulus (E)	GPa	207
Poisson's Ration (v)	-	0.3
Coefficient of Expansion	$10^{-6}\,{}^{o}C^{-1}$	11.7
Thermal Conductivity	W/mK	45.3
Structural Damping	-	0.126

Coefficient		
Specified Minimum Yield Stress (SMYS)	MPa	448
Grade	-	API 5LX65

To define the material properties of Steel API 5LX65, data such as density of steel, Poisson ratio, thermal expansion and etc. need to be filled at the "Material Model":

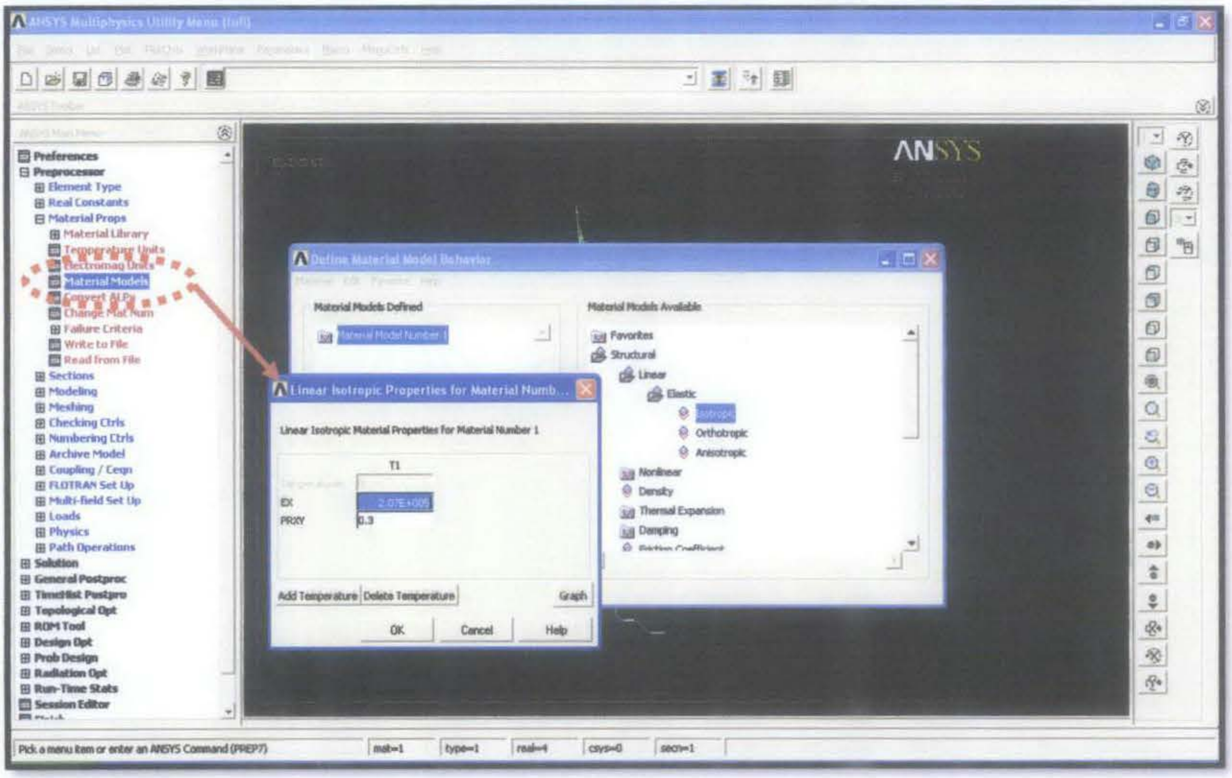


Figure 3.6: Material Model

3.5.1.4 Create nodes

After define all data such as element type, real constant and material properties of riser, then only node can be made. The element input data include two or three nodes which can be represented by node I, J and K. But basically, to create a straight pipe, only node I and J are required. Node I and J is connected by element type PIPE16 with a specific real constant. It same goes to PIPE 60. But, PIPE 60 requires three nodes (node I, J and K) to build a curve. Author has made a total of 265 nodes for the riser's model. Nodes are established at important locations such as at MSL and riser clamps [7]. The length between two nodes is 273.1mm which is similar to the outside diameter of the riser. (Refer Appendix for the list of the nodes)

3.5.1.5 Boundary conditions

Boundary conditions can be specified in ANSYS at any of the nodes to restrain either translation or rotation of a particular node in any of the three global (or local) co-ordinate directions. This feature is used to simulate riser clamps and supports. Boundary condition is applied at node number 10, 45, 79 and 157.

Table 3.7: Boundary Condition

Node	Type of clamp	Constraint
10	Hanger Flange	x,y = 0
45, 79, 157	Sliding	x = 0

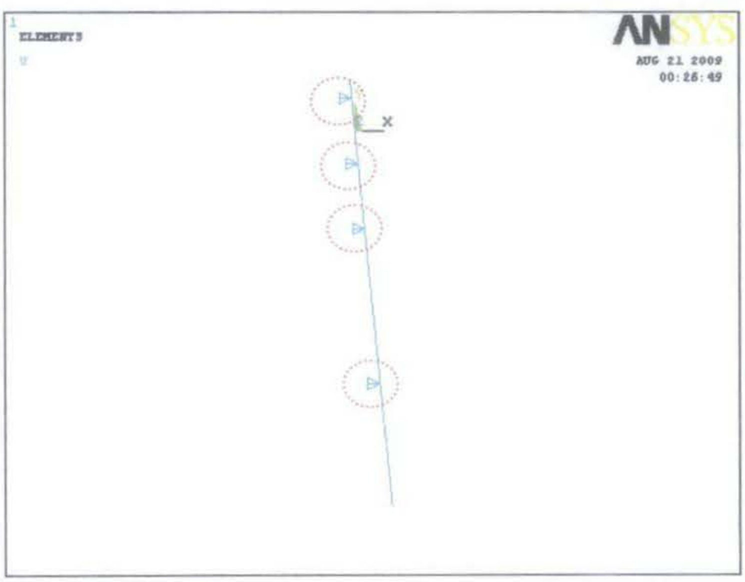


Figure 3.7: An example of boundary conditions

3.5.1.6 Hydrodynamic force and functional loads

Body loads (temperatures for structural elements, heat generation rates for thermal elements, etc.) may be input in a nodal format or an element format. Hydrodynamic force is applied at each node while the internal temperature and pressure is applied constantly along the riser. External pressure varies as stated in section 2.8.2. (Refer Appendix for the list of hydrodynamic force at each node).

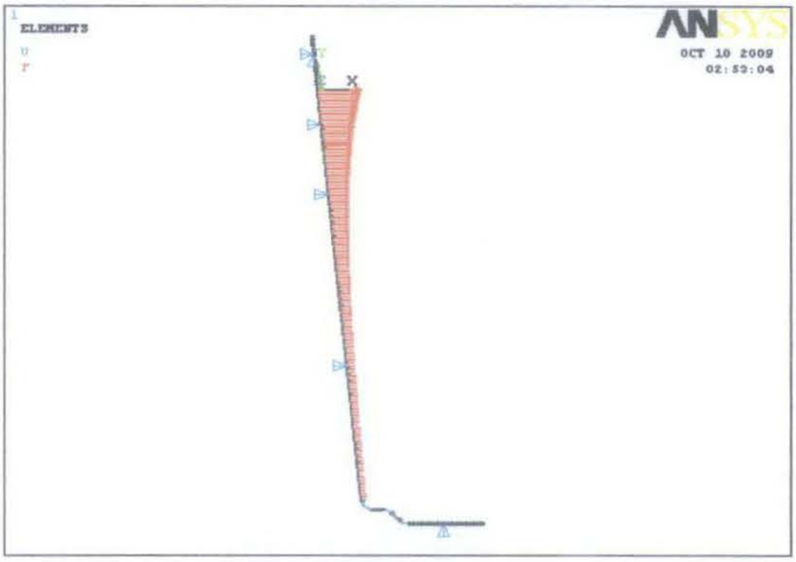


Figure 3.8: Hydrodynamic force distributions

Hydrodynamic Force

Command: ***Preprocessor – Loads – Define Loads - Apply – Structural – Force – On Nodes***

Pressure

Command: ***Preprocessor – Loads – Define Loads – Apply – Structural – Pressure – On Element***

Temperature

Command: ***Preprocessor – Loads – Define Loads – Apply – Structural – Temperature – On Nodes***

3.5.2 Solver and Postprocessor

Various stress output can be generated by defined the "Element Table". At "Define Table", select type of stress which is needed. For example, Hoop stress and Von Mises stress. "Plot Element Table" will display the final result for each stresses. Each result is analyzed and it will be compared to allowable stress based on PTS 20.214. ANSYS also can be use to define the displacement which occur on riser due to applied load.

3.6 CONFIRMATION OF RESULT

According to PTS, allowable stress must be greater than the generated stress. If not, the designed riser is considered not safe for operation.

3.7 ASSUMPTIONS

- Static (no dynamic responses)

  The analysis is static because for shallow water, rigid riser is used, not flexible riser. Rigid riser is clamped to the jacket leg which restraint the movement of riser. Dynamic analysis is more suitable for flexible riser which is used for deep water.

- Internal pressure and temperature constant along riser

  Maximum internal pressure and temperature are applied constantly along the riser to check the capability of each section of riser to sustain maximum load. This is for worse case scenario.

- No soil reaction

  Riser is the vertical section of pipeline. The contact between riser and soil is very small and can be neglected.

3.8 TOOLS

In this project, author used software such as:

- ANSYS = For modeling of riser
- Wave Load Calculator – To calculate hydrodynamic load
- Microsoft Office (Word and Excel) – To calculate velocity distribution and final report

3.9 GANTT CHART

No	Detail/Week	1	2	3	4	5	6	7	8	9		10	11	12	13	
1	Research on Project															
2	Definition of Problem															
3	Data Gathering															
4	Define Figure and Parameter of Riser															
5	Perform all related calculation before modeling															
6	Perform FE analysis using ANSYS															
7	Evaluation of Result															
8	Oral Presentation															

Work done on first semester

Work done on second semester

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS THROUGHOUT PROJECT

Figure 4.1shows the result for Hoop stress. Maximum hoop stress is 74.189 MPa which occurs at vertical section and horizontal section of the riser which is connected to submarine pipeline. Hoop stress is due to internal and external pressure as referred to the Barlow's Formula. Maximum hoop stress at vertical section is mainly due to variation of pressure. Internal pressure give huge effect to the hoop stress compared to external pressure. This can be proved by the maximum value of both pressures. Internal pressure is 13.8 MPa whereas external pressure is 0.54 MPa.

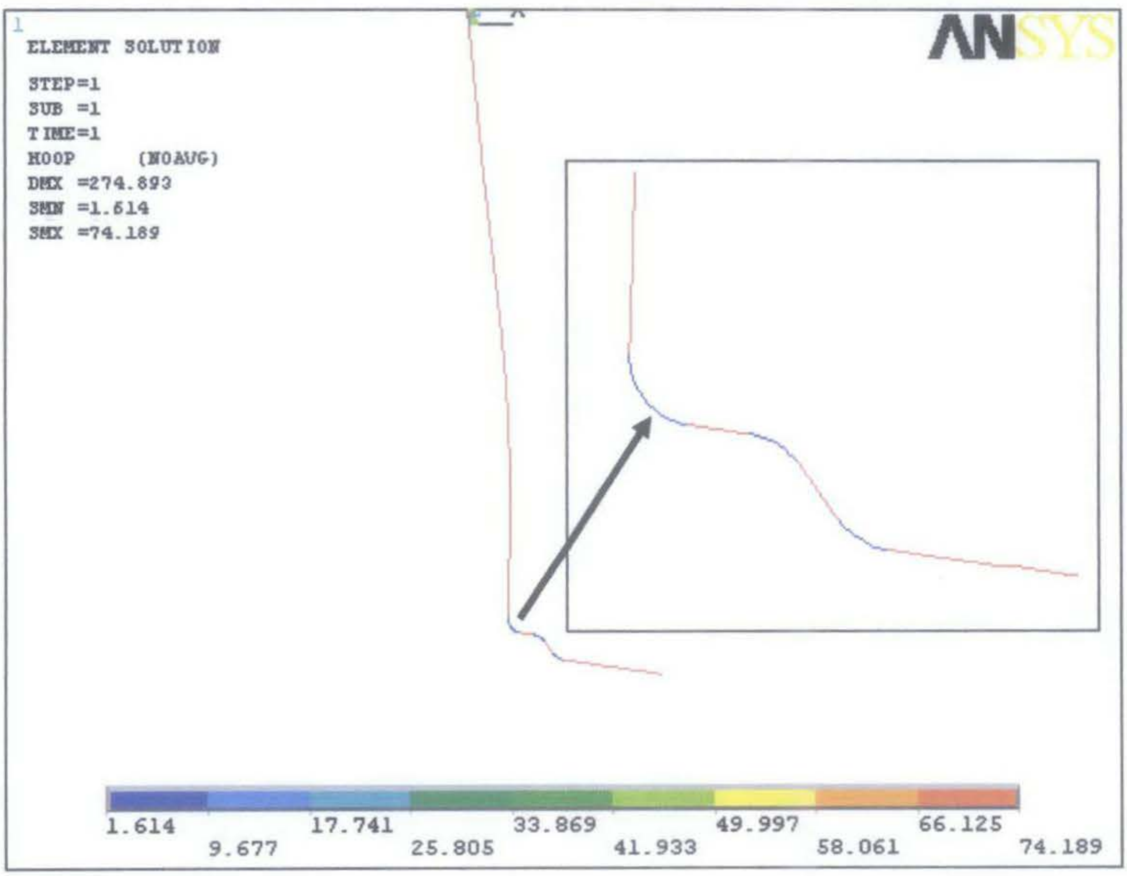


Figure 4.1: Hoop Stress

Figure 4.2 shows the result for Von Mises stress. The maximum Von Mises stress is 148.577 MPa which occurs below the lowest riser clamp. From definition, Von Mises stress is an equivalent stress, which means it is a combination of various stress such as thermal stress, longitudinal stress and etc. And because of these combination stresses, the location of maximum Von Misses stress might be different from the location of maximum hoop stress. Von Mises stress is affected by the existence of current and waves but by a little means. This can be proved by comparing the minimum Von Mises stress (125.132 MPa) with the maximum Von Mises stress (148.577 MPa). Small different between these two values may be due to small value of drag and inertia force.

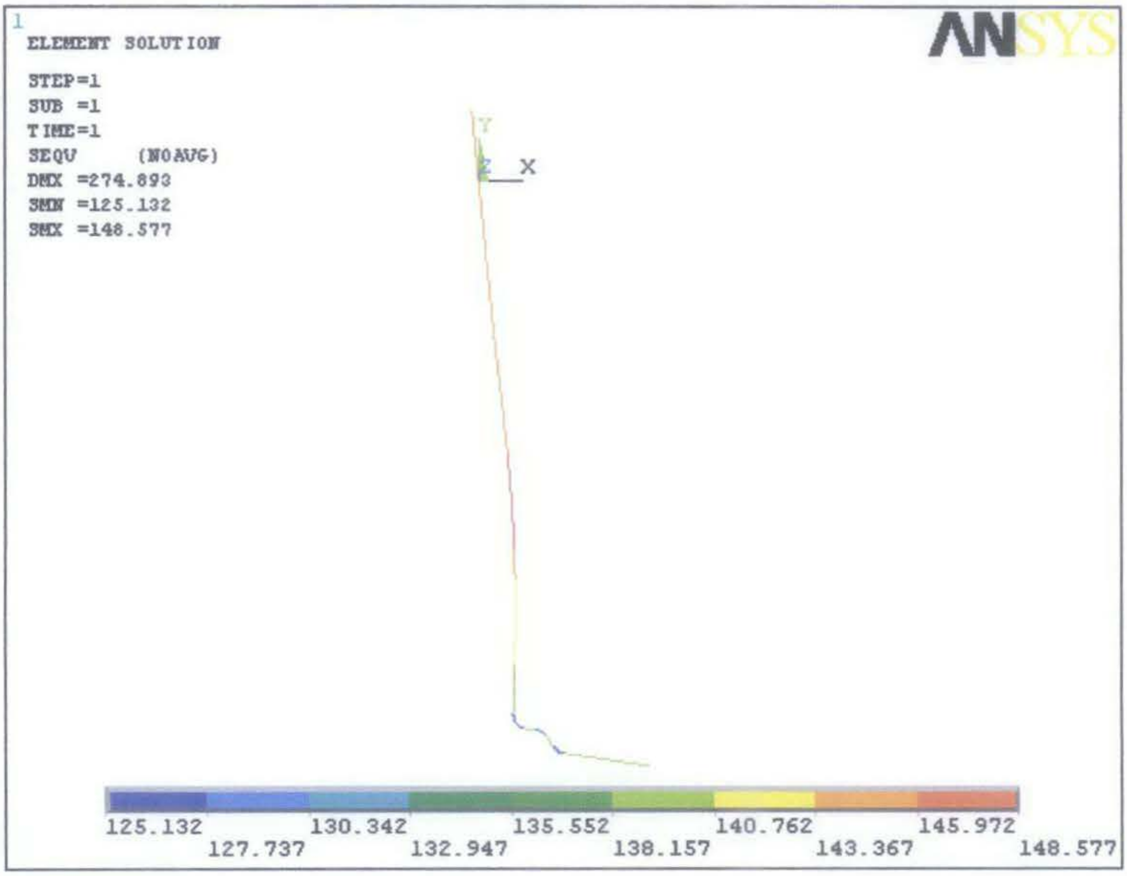


Figure 4.2: Von Misses Stress

Table 4.1: Maximum generated stress

Type of stress	Maximum generated stress (MPa)
Hoop	74.189
Von Misses	148.577

From the generated stress, result would be compared to the allowable stress as stated on PTS 20.214.

Displacement in x-direction and y-direction is due to thermal expansion. When high temperature of fluid flows inside the riser, riser tends to expand and displaced. Other than that, pipeline which is connected to the end of riser also give displacement to riser. When pipeline expand due to high temperature, it gives displacement in x-direction which cause the riser to displace and also increase the stresses along riser. Based on the generated result, displacement in x-direction greater than y-direction. The distance of the displacement is not too far. In this case, the displacement of riser does not give an effect to the whole structure of riser and jacket leg. So, the riser is considered safe for operation.

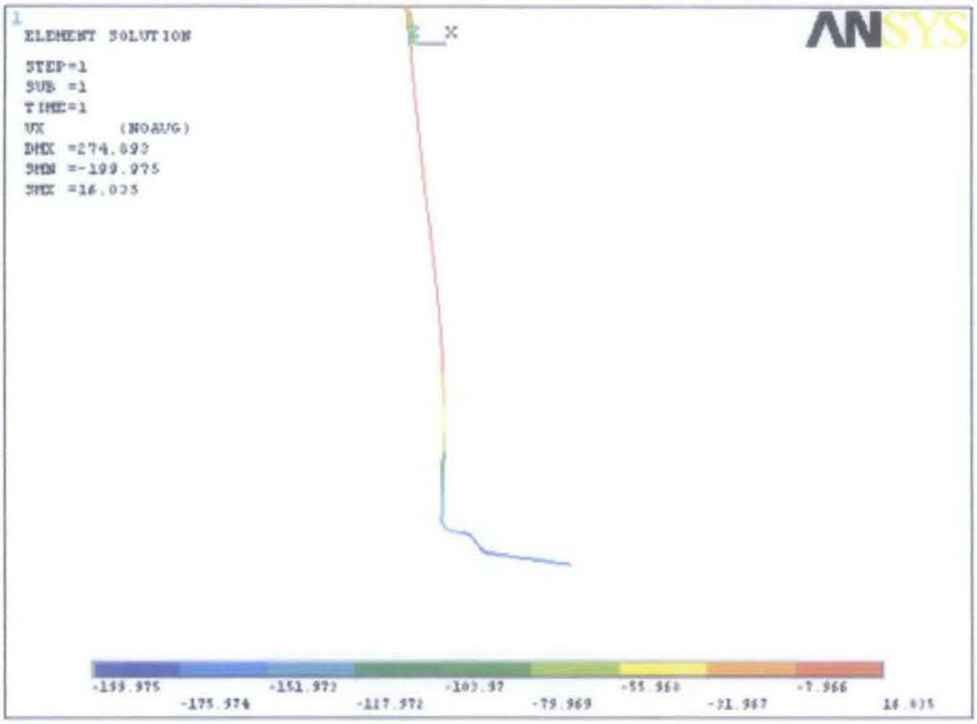


Figure 4.3: Displacement in x-direction

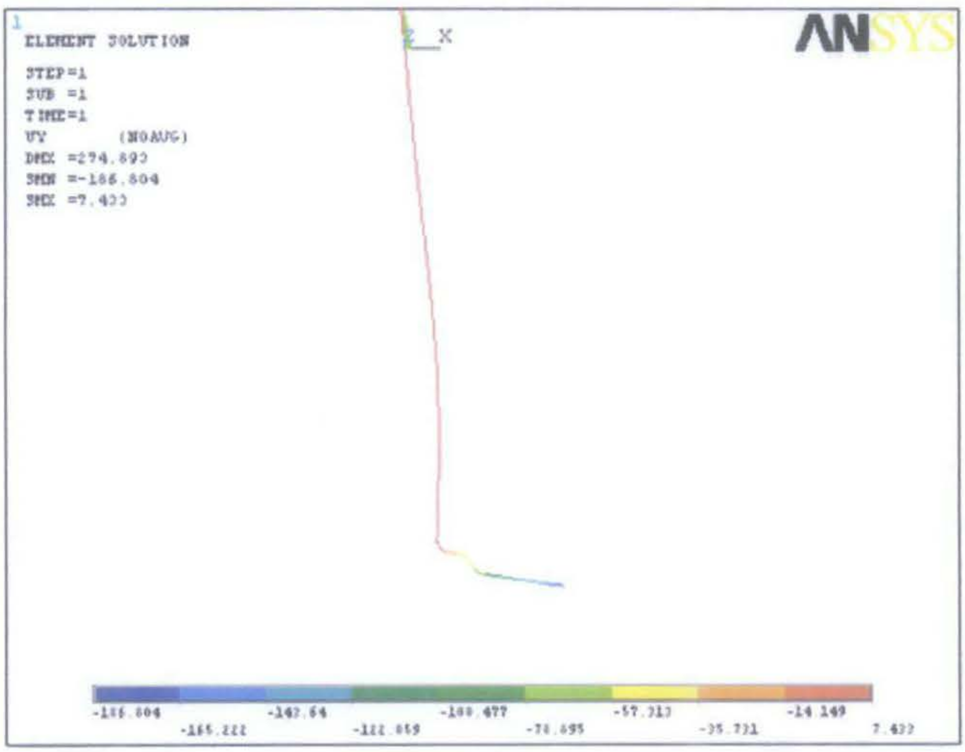


Figure 4.4: Displacement in y-direction

Table 4.2: Maximum displacement

Max. displacement	Maximum displacement (mm)
x-direction	16.035
y-direction	7.433

4.2 COMPARISON WITH ALLOWABLE STRESS

Below is table used to calculate maximum allowable stress based on specified design condition and loading condition. From stress analysis of riser using FEM, the results are the value of hoop stress and von misses stress. Both stresses should not exceed the allowable stress or else, the design of riser has to redesign. For this project, the data for Operating condition and Functional plus Environmental loading condition is referred to.

Table 4.3: Reference table for maximum allowable stress (%SMYS) based on the specified design condition and loading condition [21] for riser and pipeline.

Design Condition	Loading Condition	Stress Classification	Allowable Stress (% SMYS)	
			Zone 1	Zone 2
Operating	Functional	Hoop Stress	72	50
		Von Mises Stress	72	50
Operating	Functional plus Environmental	Hoop Stress	72	50
		Von Mises Stress	96	67

% SMYS which been used

The allowable stress is calculated by:

Allowable Stress = (% SMYS) x (Specified Minimum Yield Stress, SMYS)

Allowable Stress = SMYS (%) X (SMYS of material)

= 0.5 x 448 = 224 MPa (Hoop stress)

= 0.67 x 448 = 300.2 Mpa (Von Misses)

<u>From table 4.1</u>,

Hoop Stress = 74.189 Mpa < 224 Mpa

Von Misses Stress = 148.577 Mpa < 300.2 Mpa

Both stresses are below the allowable stress. Based on PTS 20.214, the result is acceptable and the designed riser is considered safe for operation and fit for purpose.

4.3 UNITY CHECK

Another way to determine whether the result is acceptable or not, unity check is performed.

$$\text{Unity check} = 1 - \left[\frac{\text{Allowable value} - \text{FE value}}{\text{Allowable value}}\right]$$

Table 4.4: Result for stress analysis

Service condition	Result	Unit	FE Value	Allowable Value	Unity check
Design	Max. Von Misses stress	Mpa	148.577	300.2	0.5051
	Max. Hoop stress	Mpa	74.189	224.0	0.6688

Based on the above table, an ideal result is when the unity check is not exceeding one. Unity check below than one meaning that, the responses (Von Misses stress and Hoop stress) are acceptable and the detailed design for riser is safe for operation.

From the FE analysis which has been done, there is no global buckling between pipeline and riser even though without expansion spool. The stress criteria for the riser may not be satisfied if global buckling occurred. In this case, no global buckling, generated stress below than allowable stress and unity check less than one.

4.4 DISCUSSION

As referred to PTS 20.214, the result from FEM is acceptable. This is also mean that the designed riser is relevant according to code and standard. Calculation for allowable stress and unity check is performed to check the relevancy of the designed riser for future use. In modelling, the service condition is not varies. Author only use design condition in modelling because the value of internal pressure and temperature is greater compare to other conditions, which will result in higher generated stress. For worst case scenario, it is suggested to use design condition in modelling. Basically, different approach in modelling gives different result in the generated stress. However, the results are still within the range of allowable stress as stated in code and standard.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the study, there are several conclusions that can be drawn:

- Stress Analysis using FEM is one of the relevant methods to be used in analyzing the detailed design of any structure including submarine structure.
- Wave and current from sea water creates drag and lift forces which then would increase the Von Mises stress.
- Internal pressure from crude oil is greater than maximum external pressure. Because of that, correct wall thickness of riser is important to avoid rupture and failure of riser during operation.
- Hoop stress which causes by the internal and external pressure should not exceed allowable limit for safety. Same goes to Von Mises stress.
- Several methods need to be applied in order to analyze the result, such as unity check and comparison with allowable stress as stated on PTS.
- Referred to relevant code and standard such as PTS 20.214, ASME 31.4 and ASME 31.8 to complete the analysis.

As to date, the FE modelling is found to be successful apart of some difficulties on running the research and study. The study fulfils the objective where:

- To develop a Finite Element modelling of submarine riser
- To determine the stress distribution along the submarine riser
- To compare the maximum hoop and von mises stress with their allowable stress.

From the modeling results, stress distribution along the riser is different, for different type of stresses. The maximum stress occurs at the riser base area (starting from the lowest sliding clamp). The maximum hoop stress is 74.189 MPa while Von misses is 148.577 MPa. Based on the maximum value of the Hoop stress and Von Mises stress, it is not exceeding the allowable stress. As referred to PTS 20.214, the designed riser is considered safe for operation. Displacement in x and y direction is not too large. It is 16.035mm in x-direction and 7.433mm in y-direction. Even though the riser is clamped along the jacket leg, displacements do occur but it is still safe for riser operation. Overall, the detailed design of the riser is considered safe throughout the design life and fit for purpose.

5.2 RECOMMENDATIONS

In the future, some modification can be done in order to get more accurate result. It is suggested to reduce the assumptions made in modeling. Other than that, do:

i. Apply soil reaction in the modeling
ii. Add effect of Vortex Induced Vibration (VIV) during analysis in ANSYS
iii. The length between two nodes can be reduce more so that more nodes can be made and more accurate result can be generated.
iv. Analyze more than one material selection
v. Consider collapse and burst design load

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APPENDIXES

A: Detailed Design of Submarine Riser

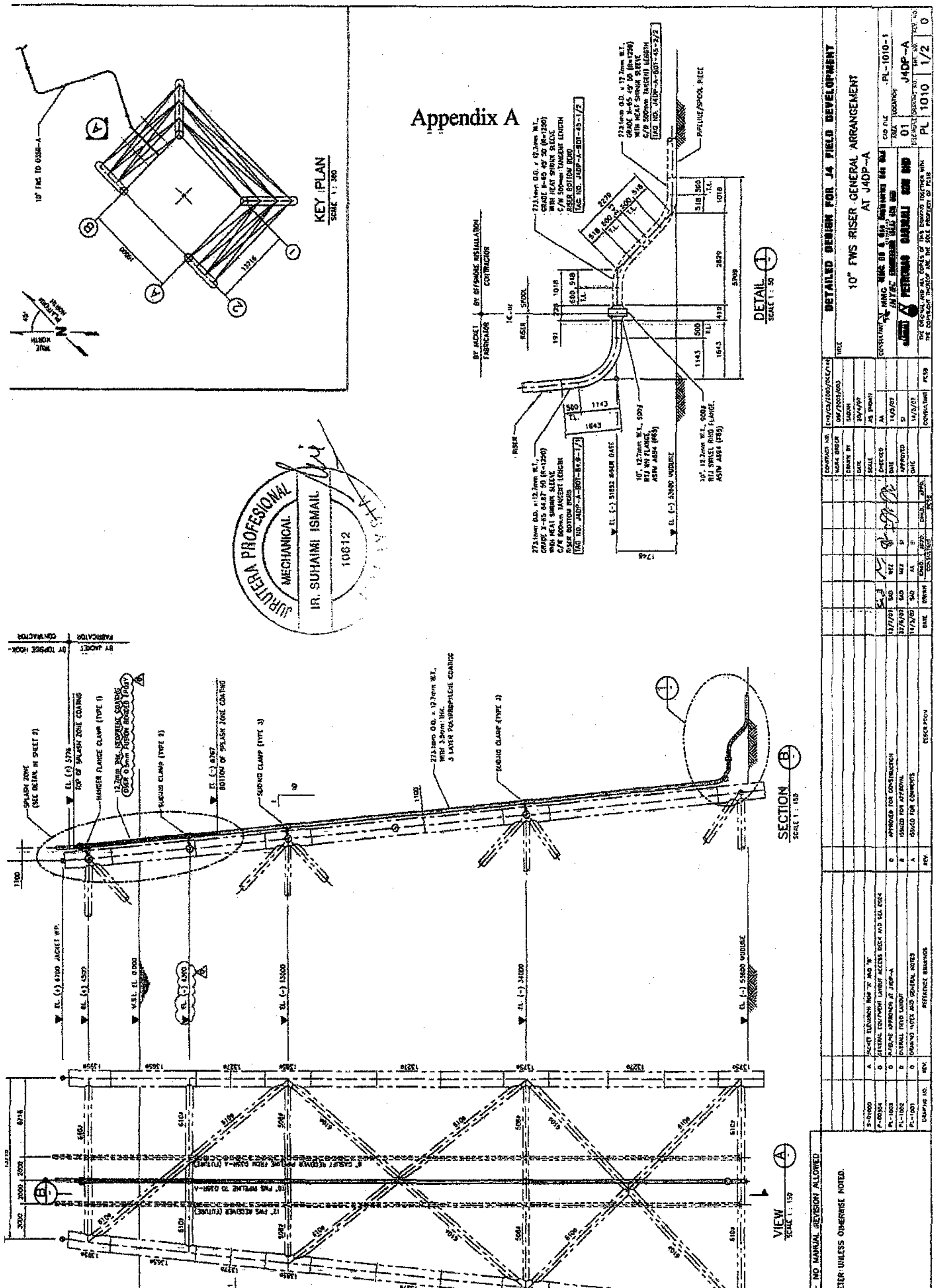
B: Pressure Distribution

C: Velocity Distribution

D: List of Nodes

E: Hydrodynamic Force

Appendix A



DETAILED DESIGN FOR J4 FIELD DEVELOPMENT
10" FWS RISER GENERAL ARRANGEMENT AT J4DP-A
PL 1010 1/2
KEY PLAN
DETAIL 1
SECTION B
VIEW A
JURUTERA PROFESIONAL
MECHANICAL
IR. SUHAIMI ISMAIL
10612
CAD PRODUCED DRAWING - NO MANUAL REVISION ALLOWED
NOTES
1. ALL DIMENSIONS ARE IN MILIMETER UNLESS OTHERWISE NOTED.

Appendix B

External pressure Distribution

Node	Mpa
265	0.538961
264	0.538961
263	0.538961
262	0.538961
261	0.538961
260	0.538961
259	0.538961
258	0.538961
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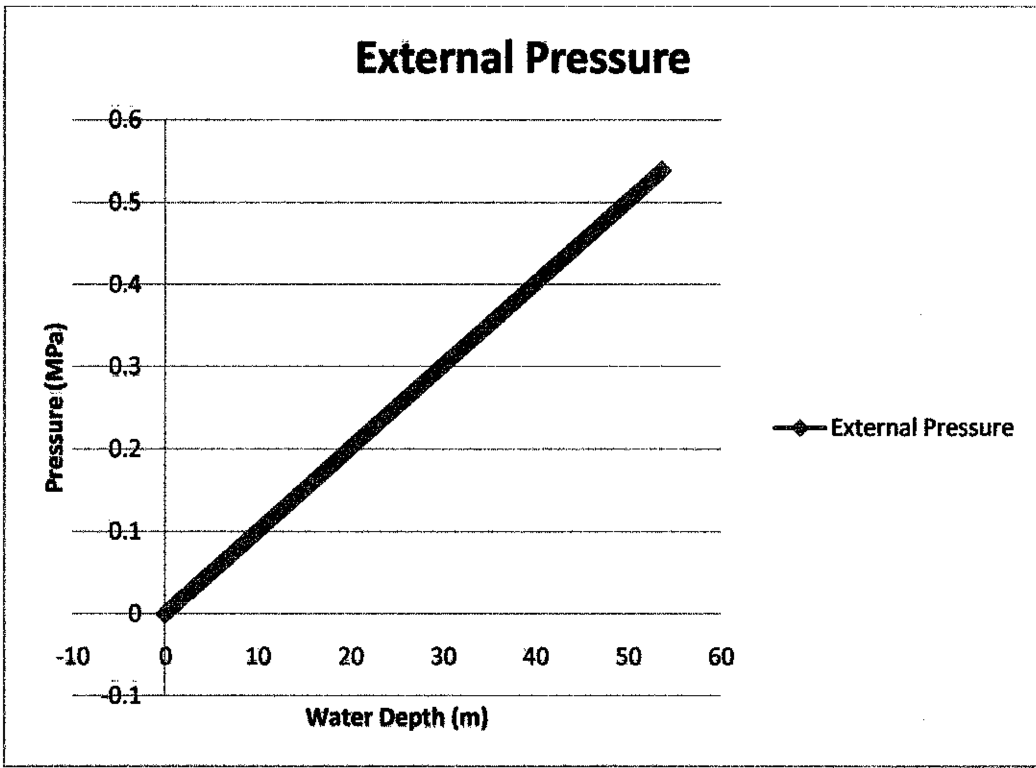
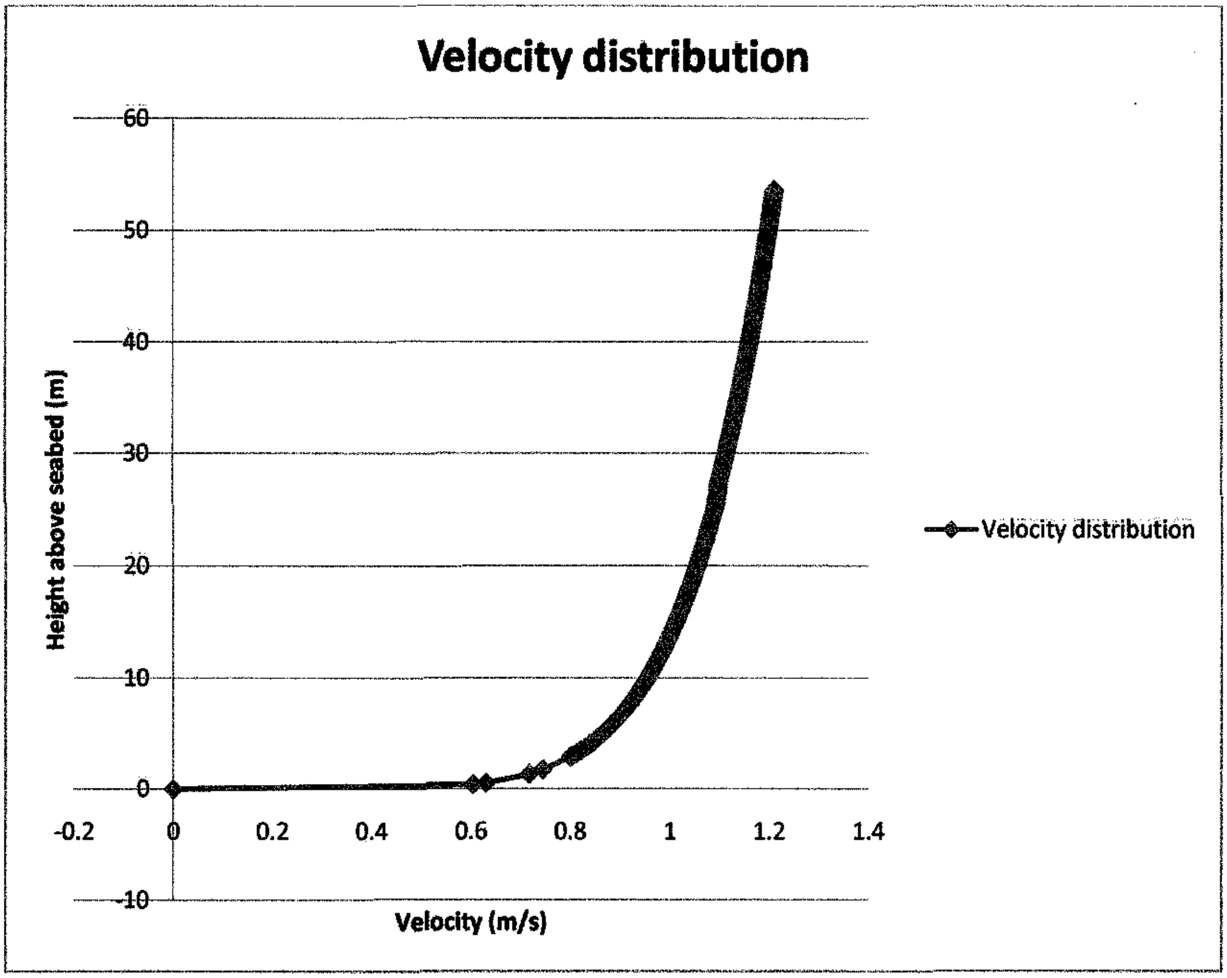
248	0.538961
247	0.538961
246	0.538961
245	0.538961
244	0.538961
243	0.538961
242	0.538961
241	0.538961
240	0.538961
239	0.538961
238	0.538961
237	0.538961
236	0.538961
235	0.538961
234	0.538961
232	0.538961
231	0.534939
230	0.533562
229	0.525406
227	0.521385


External Pressure
Pressure (MPa)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-10
0
10
20
30
40
50
60
Water Depth (m)
External Pressure

Appendix C

Velocity Distribution

Node	y	y1	u1	u
265	0	0.536	0.63	0
264	0	0.536	0.63	0
263	0	0.536	0.63	0
262	0	0.536	0.63	0
261	0	0.536	0.63	0
260	0	0.536	0.63	0
259	0	0.536	0.63	0
258	0	0.536	0.63	0
257	0	0.536	0.63	0
256	0	0.536	0.63	0
255	0	0.536	0.63	0
254	0	0.536	0.63	0
253	0	0.536	0.63	0
252	0	0.536	0.63	0
251	0	0.536	0.63	0
250	0	0.536	0.63	0
249	0	0.536	0.63	0
248	0	0.536	0.63	0
247	0	0.536	0.63	0
246	0	0.536	0.63	0
245	0	0.536	0.63	0
244	0	0.536	0.63	0
243	0	0.536	0.63	0
242	0	0.536	0.63	0
241	0	0.536	0.63	0
240	0	0.536	0.63	0
239	0	0.536	0.63	0
238	0	0.536	0.63	0
237	0	0.536	0.63	0
236	0	0.536	0.63	0
235	0	0.536	0.63	0
234	0	0.536	0.63	0
232	0	0.536	0.63	0
231	0.4	0.536	0.63	0.604203
230	0.537	0.536	0.63	0.630168



Velocity distribution
60
50
40
30
20
10
0
-10
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Height above seabed (m)
Velocity (m/s)
Velocity distribution

Appendix D

List of nodes

	x	y				
1	-670	6700				Top jacket (riser above SZ)
2	-642.69	6426.9				
3	-615.38	6153.8				
4	-588.07	5880.7	5	-577.6	5776	Splash Zone (SZ)
6	-560.76	5607.6				
7	-533.45	5334.5				
8	-506.14	5061.4				
9	-478.83	4788.3	10	-450	4500	Hanger flange clamp
11	-451.52	4515.2				
12	-424.21	4242.1				
13	-396.9	3969				
14	-369.59	3695.9				
15	-342.28	3422.8				
16	-314.97	3149.7				
17	-287.66	2876.6				
18	-260.35	2603.5				
19	-233.04	2330.4				
20	-205.73	2057.3				
21	-178.42	1784.2				
22	-151.11	1511.1				
23	-123.8	1238				
24	-96.49	964.9				
25	-69.18	691.8				
26	-41.87	418.7				
27	-14.56	145.6	28	0	0	Mean Sea Level (MSL)
29	12.75	-127.5				
30	40.06	-400.6				
31	67.37	-673.7				
32	94.68	-946.8				
33	121.99	-1219.9				
34	149.3	-1493				
35	176.61	-1766.1				
36	203.92	-2039.2				
37	231.23	-2312.3				
38	258.54	-2585.4				

Appendix E

Hydrodynamic Force

Node	Drag Force (N/m)	Inertia Force (N/m)	Sum of force (N/m)	Hydrodynamic Force(N/mm)
60	910.78	155.31	1066.09	1.06609
59	926.07	157.33	1083.4	1.0834
58	941.7	159.38	1101.08	1.10108
57	957.66	161.46	1119.12	1.11912
56	973.97	163.56	1137.53	1.13753
55	985.4	165.03	1150.43	1.15043
54	990.63	165.69	1156.32	1.15632
53	1007.65	167.86	1175.51	1.17551
52	1025.05	170.05	1195.1	1.1951
51	1042.83	172.27	1215.1	1.2151
50	1061	174.52	1235.52	1.23552
49	1079.57	176.8	1256.37	1.25637
48	1098.55	179.12	1277.67	1.27767
47	1117.95	181.47	1299.42	1.29942
46	1137.78	183.85	1321.63	1.32163
45	1152.36	185.58	1337.94	1.33794
44	1158.05	186.26	1344.31	1.34431
43	1178.77	188.7	1367.47	1.36747
42	1199.95	191.18	1391.13	1.39113
41	1221.6	193.69	1415.29	1.41529
40	1243.74	196.24	1439.98	1.43998
39	1266.38	198.82	1465.2	1.4652
38	1289.53	201.43	1490.96	1.49096
37	1313.19	204.08	1517.27	1.51727
36	1337.39	206.77	1544.16	1.54416
35	1362.14	209.49	1571.63	1.57163
34	1387.45	212.25	1599.7	1.5997
33	1413.34	215.05	1628.39	1.62839
32	1439.81	217.89	1657.7	1.6577
31	1466.89	220.76	1687.65	1.68765
30	1494.59	223.67	1718.26	1.71826
29	1522.92	226.51	1749.43	1.74943
28	1536.37	227.5	1763.87	1.76387