STRESS ANALYSIS & DESIGN OF OFFSHORE PIPELINES

TENGKU MOHD SHAHRU HASLAN
BIN TUAN YUSOFF

CIVIL ENGINEERING
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Stress Analysis & Design of Offshore Pipelines

by

Tengku Mohd Shahru Haslan Bin Tuan Yusoff (6807)

Dissertation submitted in partial fulfilment of
the requirements for the
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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

Narayanan

(Assoc. Prof. Dr Narayanan Sambu Potty)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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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.

TENGKU MOHD SHAHRU HASLAN BIN TUAN YUSOFF

ABSTRACT

Pipelines system can be defined as a series of pipes used for fluid transportation over extended distances. The design of offshore pipelines shall be based on Codes and Standards such as PETRONAS Technical Specification (PTS), American Petroleum Institute (API), Det norske Veritas (DnV), etc.

This project is concentrating on design of offshore pipeline based on Malaysia's environmental condition. Therefore, environmental data where the pipe will be placed should be taken into consideration in design phase.

Besides, this project also focusing on stress analysis of offshore pipeline. Stress analysis is required to ensure the pipeline are not overstressing and overloading, indirectly prevent pipeline failure to occur. Therefore, the author is investigating the relationship between pipeline parameters and pipeline stress. The examples of pipeline parameter are pipe wall thickness, pipe diameter, pipe end-condition, pipe loading and pipe span length.

This project is very important in order to ensure the pipeline integrity in order to prevent pipeline from failure. The methodology used to determine pipeline stress is by using commercial software, ANSYS Workbench. However, the author should do manual calculation to verify the pipe stress generated by ANSYS Workbench.

By the end of this project, the author is expected to come out with the discussion on behavior of pipeline stress resulting from variation of pipeline parameters.

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1.1 Background of Study

Nowadays, oil and gas are major participants in the supply of energy, and pipelines are the primary means by which they are transported. Pipelines are used to transport hydrocarbon fluid from producing fields to processing plants or refiners. Pipelines carry large volumes of natural gas, crude oil, and others product in continuous streams.

According to PETRONAS Technical Specification (PTS), pipeline is defined as a system of pipes for the transportation of fluids in the liquid or gaseous phase, or a combination of both phases, between wellhead facilities, production plants, and pressure boosting stations, processing plants or storage facilities.

In other way, stress analysis is an engineering discipline that determines the stress in materials and structures subjected to static or dynamic forces or loads. The aim of the analysis is usually to determine whether the element or collection of elements, usually referred to as a structure, can safely withstand the specified forces.

This is achieved when the determined stress from the applied forces is less than the ultimate tensile strength, ultimate compressive strength or fatigue strength the material is known to be able to withstand, though ordinarily a factor of safety is applied in design.

The factor of safety is a design requirement for the structure based on the uncertainty in loads, material strength (yield and ultimate), and consequences of failure. Often a separate factor of safety is applied to the yield strength and to the ultimate strength. The factor of safety on yield strength is to prevent detrimental deformations and the factor of safety on ultimate strength is to prevent collapse.

A key part of analysis involves determining the type of loads acting on a structure, including tension, compression, shear, torsion, bending, or combinations of such loads.

Sometimes the term stress analysis is applied to mathematical or computational methods applied to structures that do not yet exist, such as a proposed aerodynamic structure, or to large structures such as a building, a machine, a reactor vessel or a piping system.

1.2 Problem Statement

From history, there are several cases where pipeline failure occurred. Pipeline failure can cause pollution to environment. Therefore it is required for designer to do pipeline stress analysis to prevent/ reduce possibility pipeline failure to happen.

Therefore, the relationship between pipeline parameters and pipeline stress shall be determined. Then, the author may determine in which condition, the pipeline stress will be minimized. Stress analysis of offshore pipelines usually done by using commercial software, CAESAR II but for this project the author take initiative to use commercial software which is ANSYS Workbench.

Besides, the design of offshore pipelines is vary to one another because of different environmental condition where the pipeline will be installed. Therefore, this project will be taking all environmental data in Malaysia in order to come out with design of offshore pipeline based on Malaysia's environmental condition (i.e. water depth, storm surge, marine growth, etc)

1.3 Objectives and Scope of Study

1.3.1 The Relevance of the Project

The objectives of the project are:

- To design 12 inch offshore pipelines based on Malaysia's environmental condition.
- To model and do simulation on designed 12 inch offshore pipeline by using commercial software, ANSYS Workbench.
- To determine the relationship between pipeline parameters and pipeline stress.

1.3.1 Feasibility of the Project within the Scope and Time Frame

The feasibility study of the project within the scope is to get the best way how to manage the task given and gather the required information about the stress analysis and design of offshore pipelines.

In order to come out with relationship between pipeline parameters and pipeline stress, the author need to model and do simulation of offshore pipeline by varying the pipeline parameters.

The stress analysis of offshore pipelines can be done by using Finite Element Method (FEM) and commercial software, ANSYS Workbench.

1.4 Codes and Standards

The design of the pipeline system in order of priority satisfies the requirements of the latest editions of the PETRONAS Technical Standards (PTS) and International Codes and Standards. If the Government or Local Authority Laws and Regulations are more stringent than the PTSs, the former takes precedence.

Basically, in order to design offshore pipelines in Malaysia, the author need identify and obey The Government or Local Authority Laws and Regulations.

The relevant codes, regulations and standards are listed below;

1.4.1 Malaysian Government and Local Authority Laws and Regulations

- Petroleum (Safety Measures) Act 301, 1984;
- Petroleum (Safety Measures) (Transportation of Petroleum by Pipeline) Regulation, 1985;
- Royal Malaysian Navy Chart;
- EQR (Clean Water) / (Sewage and Industrial Effluences) 1979 / Act 127;
- EQR (Clean Air) 1978/Act 127;
- Applicable Department of Environment Regulations;
- Applicable Department of Labour Regulations;
- Applicable Federal Machinery Department Regulations;
- Applicable Local Authority Regulations.

1.4.2 PETRONAS Technical Standards (PTS)

- PTS 00.00.05.05, Jan. 1996; Design and Engineering Practice;
- PTS No. 20.082, June 1991; Submarine Pipeline and Riser Design;
- PTS No. 20.196, Sep. 1994; Pipeline Engineering;
- PTS No. 20.117, Aug. 1989; Cleaning, Pigging and Hydrostatic Testing of Offshore Pipelines;
- PTS No. 20.118, March 1984; Dewatering and Drying of Offshore

Pipelines;

- PTS No. 20.120, Sep. 1991; Installation of Offshore Pipelines and Risers;
- PTS No. 20.121, Aug. 1989; Trenching and Backfilling Operations;
- PTS No. 20.147, Oct. 1994; Concrete Coating of Line Pipe;
- PTS No. 20.146, Oct. 1994; Coating and Wrapping of Line Pipe;
- PTS No. 20.144, April 1991; Pipeline Bends;
- PTS No. 31.40.20.31, Dec. 1993; Line Pipe for Use in Oil and Gas Operations under Sour Conditions;
- PTS No. 20.149, Feb. 1984; Splash Zone Coating for Riser Pipes;
- PTS No. 20.173, Nov. 1989; Sacrificial Bracelet Zinc Anodes for Submarine Pipelines;
- PTS No. 20.114, Sep. 1983; Installation of Sacrificial Zinc Anodes;
- PTS No. 20.165, April 1990; Pigging Philosophy.

1.4.3 International Codes and Standards

1.4.3.1 *American Petroleum Institute (API)*

- SPEC 5L Specification for Line Pipe
- SPEC 6H Specification for Pipeline Valves, End Closures Connectors and Swivels
- STD1104 Standard for Welding Pipelines and Related Facilities

1.4.3.2 *Det norske Veritas (DnV)*

- DnV (1981) Rules For Submarine Pipeline Systems, 1981 Edition.
- RP B401 Cathodic Protection Design
- RP E305 On-Bottom Stability of Submarine Pipeline

Basically, pipeline engineering field can be categorized into eight (8) main subtopic which are pipeline materials, pipelines system, pipeline stress, pipeline location, pipeline engineering economics, pipeline maintenance, pipeline construction and support area. However, the design of offshore pipelines will be focusing on pipeline materials and pipeline stress.

This literature review consists of four (4) main elements related to the FYP topic *Stress Analysis and Design of Offshore Pipelines* which are:

a) Design of Offshore Pipelines
b) Environmental Condition
c) Pipeline Material
d) Finite Element Method (FEM) & Stress Analysis

2.1 Design of Offshore Pipelines

2.1.1 Design Life

Usually, the design life of pipeline system and associated facilities in Malaysia is 25 years. Design life for a pipeline system shall be the same as the design life of the production facilities facility and or hydrocarbon field which is intended to serve.

2.1.2 Pipeline Mechanical Design Consideration

The mechanical design of pipelines usually requires consideration of several factors. These include:

a) Internal Pressure
  - Internal pressure from the contained fluid is the most important loading a pipeline has to carry.

- 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.

Three pipeline codes typically used for design are ASME B31.4 (ASME, 1989), ASME B31.8 (ASME, 1990) and DnV 1981 (DnV, 1981). The nominal pipeline wall thickness can be calculated as follows:

Equation 2.1: $$t_{NOM} = \frac{P_d D}{2 E_w \eta \sigma_y F_t} + t_a$$ (Source: Boyun G, 2005)

Where t_{NOM} = Nominal pipeline wall thickness (inches)

P_d = difference between internal and external pressure (psig)

t_a = thickness allowance for corrosion (inches)

σ_y = minimum yield strength (psi)

E_w = efficiency factor (for seamless, ERW, DSAW, E_w=1.0)

η = usage factor (refer to table 1 and 2)

Ft = temperature de-rating factor *(Ft)* is equal to 1.0 for temperatures under 250°F

D = Nominal outer diameter (inches)

Table 2.1: Design and hydrostatic pressure definition s and usage factors for oil lines (Source, Boyun G., 2005)

Oil	ASME B31.4, 1989 Edition	DnV 1981
Normal Operations		
$P_d^{(1)}$	$P_i - P_e$ [401.2.2]	$P_i - P_e$ [4.2.2.2]
η for pipelines	0.72 [402.3.1(a)]	0.72 [4.2.2.1]
η for riser sections	no specific value use 0.50	0.50 [4.2.2.1]
P_h	1.25 $P_i^{(2)}$ [437.4.1(a)]	1.25 P_d [8.8.4.3]

Notes:
1. Credit can be taken for external pressure for gathering lines or flowlines when the MAOP (P_i) is applied at the wellhead or at the seabed. For export lines, when P_i is applied on a platform deck, the head fluid shall be added to P_i for the pipeline section on the seabed.
2. If hoop stress exceeds 90% of yield stress based on nominal wall thickness, special care shall be taken to prevent overstrain of the pipe.

Table 2.2: Design and hydrostatic pressure definitions and usage factors for gas lines (Source: Boyun G, 2005)

Gas	ASME B31.8 1989 Edition 1990 Addendum	DnV 1981
Normal Operations		
$P_d^{(1)}$	$P_i - P_e$ [A842.221]	$P_i - P_e$ [4.2.2.2]
η for pipeline	0.72 [A842.221]	0.72 [4.2.2.1]
η for riser sections$^{(2)}$	0.5 [A842.221]	0.5 [4.2.2.1]
P_h	1.25 $P_i^{(3)}$ [A847.2]	1.25 P_d [8.8.4.3]

Notes:

1. Credit can be taken for external pressure for gathering lines or flowlines when the MAOP (P_i) is applied at the wellhead or at the seabed. For export lines, when P_i is applied on a platform deck, the head of fluid shall be added to P_i for the pipeline section on the seabed (particularly for two-phase flow).
2. Including pre-fabricated or retrofit sections and pipeline section in a J-tube.
3. ASME B31.8 imposes $P_h = 1.4\ P_i$ for offshore risers but allows onshore testing of prefabricated portions.

b) External Pressure

- A large external pressure tends to make a pipeline oval, and eventually causes it to collapse
- This is mainly of concern for deep-water pipelines, where the external hydrostatic head is an important factor. Onshore buried pipelines may also be affected by the weight of the overburden and vehicles etc.
- The use of higher-grade steel or thicker wall pipe would protect an offshore pipeline against the external hydrostatic pressure.

For pipeline design for external pressure, it is recommended to use 'propagation criterion' for pipeline diameters under 16 inches and 'collapse criterion' for pipeline diameter above or equal to 16 inches.

The propagation criterion is more conservative and should be used where wall thickness is not required or for pipeline installation methods not compatible with the use of buckle arrestors.

For greater diameters, the wall thickness penalty is too high. When a pipeline is designed based on the collapse criterion, buckle arrestor is recommended.

c) Stability

- A pipeline has to be stable on the seabed. If it is too light, it will slide sideways under the action of currents and waves.
- Additional weight may be provided by either increasing the wall thickness or by adding concrete weight coating. Another way to reduce the environmental loads on the pipe by lowering it into a trench or burying it.

d) Free Spans

- A pipeline laid on an uneven seabed does not usually conform to the seabed profile, but instead forms free spans.

e) Expansion Stresses

- Expansion stresses may arise from the difference between the pipeline operating temperature and the installation temperature.
- If sufficient flexibility is not built in, for example, by providing an expansion loop, buckling may occur.

f) External Damages.

- External damage for offshore pipelines mainly results from ship anchors, trawling gears, or other natural hazards.
- Most offshore pipelines are buried below the ocean floor or covered by gravel/rock to protect them from such external damages.

Figure 2.1: Internal Pressure

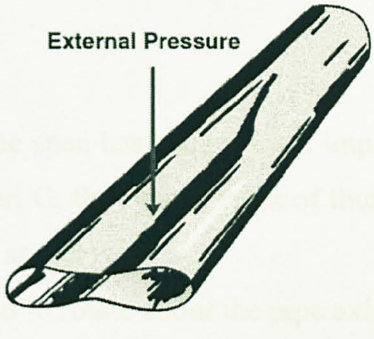


Figure 2.2: External Pressure

(Source: A Mutalib Shafiai, 2008)

2.1.3 Pipeline Span

Besides, the author shall design pipeline span as well. Pipeline spanning can occur when the contact between the pipeline and seabed is lost over an appreciable distance on a rough seabed. An evaluation of an allowable free-span length, correction is then necessary to reduce the span to avoid pipeline damage.

According to Boyun G, the determination of allowable pipeline span length is needed to vortex shedding induced oscillations. Free span can result in failure of pipelines due to excessive yielding and fatigue. Free span can occur due to unsupported weight of the pipeline section and dynamic loads from wave and currents.

Besides, design of offshore pipelines shall take dynamic stress into consideration. The presence of bottom currents can cause significant dynamic stresses, if fluid structure interaction in these free-span areas causes the pipeline to oscillate. These oscillations can result in fatigue of the pipeline welds, which can reduce pipeline life.

If the vortex shedding frequency is synchronized with one of the natural frequencies of the pipelines span, then resonance occurs and the pipe span vibrates. Pipeline failure due to vortex excited motions can be prevented if the vortex shedding frequency is sufficiently far from the natural frequency of the pipe span such that dynamic oscillation of the pipe are minimize (H.S. Choi, 2000).

The selection of the proper end conditions for the pipe free span has a significant impact on the allowable span length selected. According to Boyun G, the typical rules of thumb for selecting the proper model for the end connections are as follows:

Pinned-Pinned: Used for spans where each end is allowed to rotate about the pipe axis.

Pinned-Fixed : Used for the majority of spans, any span that does not fit the other two categories.

Fixed-Fixed : Should be used only for those spans that are fixed in place by some sort of anchor at both ends of the span.

2.1.3.1 *Vortex-Shedding Frequency (Strouhal Frequency)*

The vortex-shedding frequency is the frequency at which pairs of vortices are shed from the pipeline. Vortex-shedding frequency can be calculated using equation 1 as below:

Equation 2.2: $$f_s = \frac{SU_C}{D}$$ (Source: Boyun G, 2005)

Equation 2.3: $$R_e = \frac{U_C D}{v_k}$$ (Source: Boyun G, 2005)

Where f_s = vortex-shedding frequency

S = Strouhal number

U_c = design current velocity

D = pipe outside diameter

R_e = Reynolds number

v_k = kinematic viscosity

2.1.3.2 *Pipeline Natural Frequency*

The natural frequency of the pipeline span depends on pipe stiffness, end conditions of the pipe span, length of span, and effective mass of pipe. The equation of natural frequency is given by:

Equation 2.4: $$f_n = \frac{C_e}{2\pi}\sqrt{\frac{EI}{M_e L_s^4}}$$ (Source: Boyun G, 2005)

Where f_n = pipe span natural frequency

L_s = span length

M_e = effective mass

C_e = end condition constant

The end condition constant is a function of the type of model that is selected in determining the support conditions of the pipeline span. The following values are used based on these end conditions:

$$C_e = (1.00\pi)^2 = 9.87 \text{ (pinned-pinned)}$$

$$C_e = (1.25\pi)^2 = 15.5 \text{ (clamped-pinned)}$$

$$C_e = (1.50\pi)^2 = 22.2 \text{ (clamped-clamped)}$$

The effective mass (M_e) is the sum of total unit mass of the pipe, the unit mass of the pipe contents, and the unit mass of displaced water (added mass).

Equation 2.5: $$M_e = M_p + M_c + M_a$$ (Source: Boyun G, 2005)

Equation 2.6: $$M_a = \pi D^2 \rho / 4$$ (Source: Boyun G, 2005)

Where M_p = unit mass of pipe including coating

M_c = unit mass of contents

M_a = added unit mass (mass of displaced water)

ρ = mass density of fluid around pipe (1030kg/m^3 for seawater)

2.1.3.3 *Reduced Velocity*

The reduced velocity, U_r is the velocity at which vortex shedding induced oscillations may occur. U_r may be represents as:

Equation 2.7: $$U_r = \frac{U_c}{f_n D}$$ (Source: Boyun G, 2005)

2.1.3.4 *Stability Parameter*

Significance for defining vortex-induced motion is the stability parameter, K_s:

Equation 2.8: $$K_s = \frac{2 M_e \delta_s}{\rho D^2}$$ (Source: Boyun G, 2005)

Where δ_s is logarithmic decrement of structural damping (=0.125)

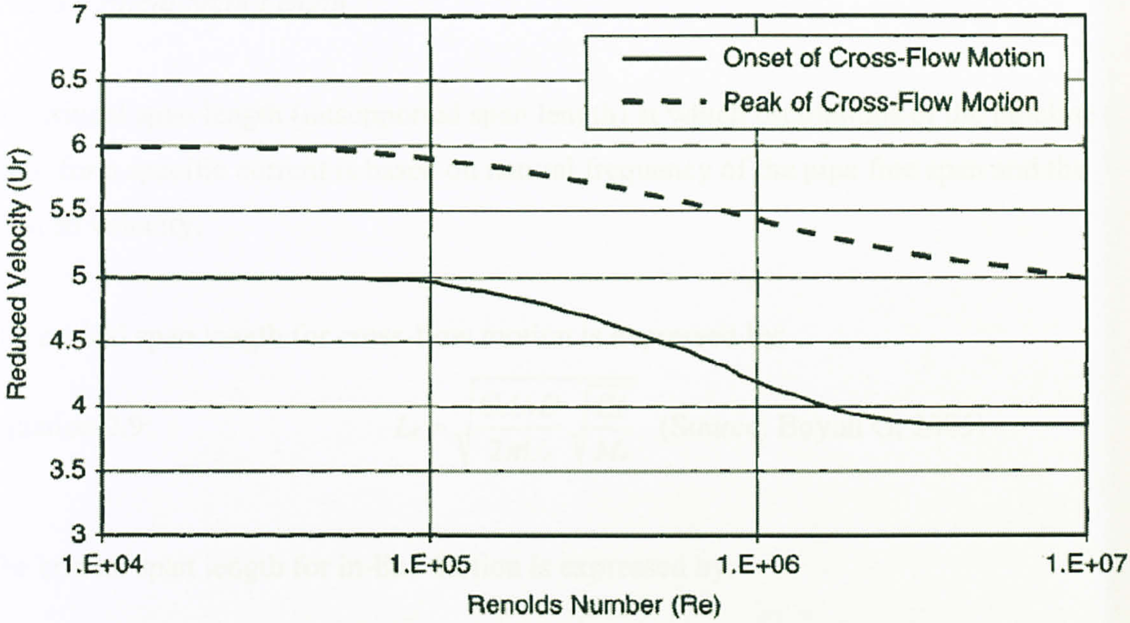


Figure 2.3: Reduced velocity for cross-flow oscillations based on Reynolds Number (Source: Boyun G, 2005)

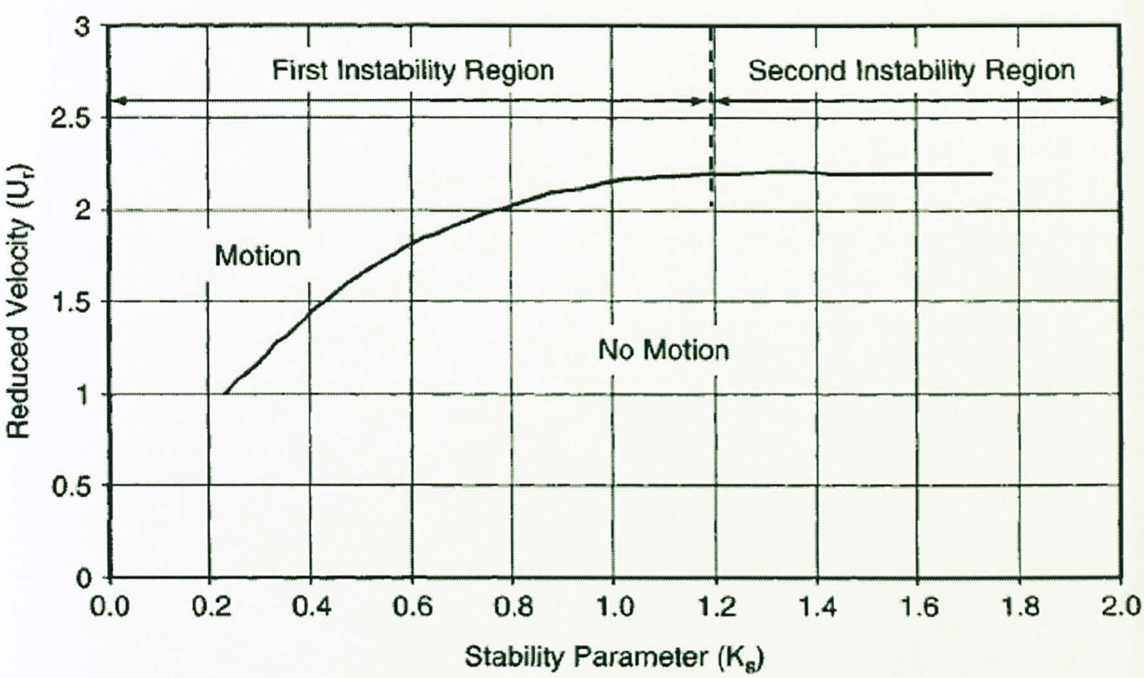


Figure 2.4: Reduced velocity for in-in oscillations based on stability parameter (Source: Boyun G, 2005)

2.1.3.5 *Critical Span Length*

The critical span length (unsupported span length) at which oscillations of the pipeline occur for a specific current is based on natural frequency of the pipe free span and the reduced velocity.

The critical span length for cross-flow motion is expressed by:

Equation 2.9: $$L_c = \sqrt{\frac{C_e U_r D}{2\pi U_c}\sqrt{\frac{EI}{M_e}}}$$ (Source: Boyun G, 2005)

The critical span length for in-line motion is expressed by:

Equation 2.10: $$L_c = \sqrt{\frac{C_e f_n}{2\pi}\sqrt{\frac{EI}{M_e}}}$$ (Source: Boyun G, 2005)

2.2 Environmental Condition

The environment condition that related in designing offshore pipelines are water depth, tidal data, storm surge, wave data, current data, seawater properties, seawater temperature, marine growth, splash zone, seabed condition, soil design parameter & properties and hydrodynamic coefficient.

2.2.1 Water Depth

Water depth is one of the important environmental criteria in designing offshore pipeline. By having water depth, wave height, and wave period data, the author may determine wave particle velocity by using an equation. As water depth is shallower, the wave particle velocity also become slower.

Besides, water depth also affecting types of insulation material. For example, Polypropylene foam is used as insulation for water depth 2100 ft, and solid Polypropylene are used as insulation for water depth 5000 ft.

For this project, the author intended to use the finite element method which is applicable in all water depths for small or large deflections (Martinsen, 1998). For this project, the water depth where the pipe will be install as below:

Table 2.3: Water depth of Sarawak Operation (SKO)

	Water Depth (m)
Shallowest	19.82
Deepest	28.82

(Source: SKO Pipeline Replacement Project, 2008)

2.2.2 Design and Operating Data Pressures/Temperatures

These are the design, operational, pressure and temperature for the designed pipeline:

Table 2.4: Design and Operation Data

Parameter	Units	Value
Outer Diameter (OD)	inch	12
Inner Diameter (ID)	inch	11.25
Service	-	Crude oil
Product density	kg/m^3	1000
Design Pressure	psi	1144
Maximum Operating Pressure	psi	365
Design & Operating Temperature	^oC	66
Design Service Life	Years	25

(Source: SKO Pipeline Replacement Project, 2008)

2.2.3 Tidal Data

Tidal data is needed in offshore pipeline design in order to determine highest astronomical tide (HAT), mean sea level (MSL) and lowest astronomical level (LAT) (Metocean Criteria and Data).

These are the characteristic tidal level where the designed pipeline will be installed:

Table 2.5: Tidal Characteristic of Sarawak Operation (SKO)

Level	Description	Height (m)
HAT	Highest Astronomical Tide	+0.98
MSL	Mean Sea Level	0.0
LAT	Lowest Astronomical Tide	-1.22

(Source: SKO Pipeline Replacement Project, 2008)

2.2.4 Storm Surge

Storm surge or tidal surge is an offshore rise of water associated with a low pressure weather system, typically a tropical cyclone. Storm surge is caused primarily by high winds pushing on the ocean's surface.

The wind causes the water to pile up higher than the ordinary sea level. It is this combined effect of low pressure and persistent wind over a shallow water body which is the most common cause of storm surge flooding problems *(Anthes, Richard A, 1982)*.

In areas where there is a significant difference between low tide and high tide, storm surges are particularly damaging when they occur at the time of a high tide.

Table 2.6: Storm Surge of Sarawak Operation (SKO)

	1-year	**10-year**	**100-year**
Storm Surge	+0.3	+0.3	+0.6

(Source: SKO Pipeline Replacement Project, 2008)

2.2.5 Wave data

Wave data required in designing offshore pipelines are significant wave height, mean zero crossing period, maximum wave height and maximum period.

Since this project is designing offshore pipelines based on Malaysia's environmental condition, these are the wave data of Sarawak Operation (SKO) where the pipeline will be install at water depth of 28.82 m:

Table 2.7: Wave data of Sarawak Operation (SKO)

Wave Parameter	Units	Operating Criteria	100-year Storm Event
Significant Wave Height	m	3.2	4.4
Mean Zero Crossing Period	sec	9.2	10.5
Maximum Wave Height	m	5.8	8.4
Peak Period	sec	11.1	13.8

(Source: SKO Pipeline Replacement Project, 2008)

2.2.6 Wave current

There are three (3) data required for wave current which are at surface, at mid-depth and at near seabed. The table below shown wave current data for Sarawak Operation (SKO) at water depth of 28.82 m:

Table 2.8: Wave current data of Sarawak Operation (SKO)

Ocean Current Parameter	Units	Operating Criteria	100-year Storm Event
At Surface	m/s	0.58	0.77
At near seabed (0.01xD)	m/s	0.37	0.47

(Source: SKO Pipeline Replacement Project, 2008)

2.2.7 Seawater Properties

The seawater properties are tabulated in table as below. The data below assumed to be applicable for all return period (1-year and 100-year).

Table 2.9: Seawater Properties of Sarawak Operation (SKO)

Seawater Properties	Unit	Value
Mass Density	kg/m^3	*1025*
Max Near Seabed Temperature	°C	*30*
Min Near Seabed Temperature	°C	*24*
Kinematics Viscosity	m^2/s	0.96×10^{-6}(25°C) 0.85×10^{-5}(35°C)
Specific Heat Capacity	J/kg.K	3950
Electrical Resistivity	Ohm.m	0.3

(Source: SKO Pipeline Replacement Project, 2008)

2.2.8 Seawater Temperature

The following tables are seawater and air temperatures shall be applied in the design:

Table 2.10: Seawater Temperature of Sarawak Operation (SKO)

Properties	Unit	Value
Minimum ambient seawater at seabed	°C	22
Maximum ambient seawater at seabed	°C	27
Minimum ambient seawater at surface	°C	27
Maximum ambient seawater at surface	°C	30

(Source: SKO Pipeline Replacement Project, 2008)

2.2.9 Marine growth

Marine growth is a common designation for a surface coat on marine structures, caused by plants, animals and bacteria. Marine growth is accumulated on submerged members. Its main effect is to increase the wave forces on the pipelines by increasing not only exposed area and volumes, but also the drag coefficient due to higher surface roughness.

Depending upon geographic location, the thickness of marine growth can reach 0.3m or more. The thickness of marine growth may be assumed to increase linearly to the given values over a period of 2 years after pipelines have been placed in the sea (Saied. S, 2008).

There are two (2) effects of marine growth which are:

a) Change of diameter

b) Change of roughness

2.2.10 Splash zone

As per PTS.20.196, section 3.A.5, the splash zone on the riser shall be considered to be between EL +8.0 m and EL -4.0 m referenced from MSL. Neoprene or an alternative acceptable coating shall be applied at the splash zone coating pipe joint.

As per PTS 20.196 and PTS 31.40.10.10, the splash zone range is defined as the astronomical tidal range plus the wave height having a probability of exceedence of 0.01. The upper limit of splash zone is determined by assuming 65% of this wave height above HAT and lower limit by assuming 35% below LAT.

2.2.11 Seabed condition

Pipelines installed on the seabed are subjected to hydrodynamic forces. Waves and steady currents that are characteristics of all offshore areas subject the pipeline on the seabed to drag, lift and inertia force. For lateral stability, the pipeline resting on seabed must resist these forces and at a minimum be at equilibrium.

2.2.12 Hydrodynamic Parameter

The drag force, F_d due to water particle velocities is given by:

Equation 2.11: $$F_d = \frac{1}{2}\rho C_d D(U+V)^2$$ (Source: Boyun G, 2005)

Equation 2.12: $$F_i = \rho C_m \frac{\pi D^2}{4}\left(\frac{du}{dt}\right)$$ (Source: Boyun G, 2005)

Where

F_d	=	drag force/unit length
ρ	=	mass density of seawater
C_d	=	drag coefficient
D	=	outside diameter (including coating)
U	=	water article velocity due to waves
V	=	steady current
F_i	=	inertia force/unit length
C_m	=	inertia coefficient
du/dt	=	water particle acceleration due to waves

2.2.13 Soil design parameter & properties

In order to design offshore pipelines, we need to identify what types of soils involve, together with its axial friction and lateral friction. The information on bathymetry, seabed features and geophysical profile shall be obtained from the results of the route survey and soil report.

Sand production affects the pipeline design and operations mainly in three areas. One is that sands in the pipeline increase pipeline erosion. Another is that fluid velocity would have to be high enough to carry the sands out of the flowline. Otherwise the sands can deposits inside the pipeline and block the flow. Finally, sand deposition inside the pipeline can prevent inhibition chemicals, like corrosion chemicals, from touching the pipe wall, thus reducing the effectiveness of chemicals.

The most challenging task of assessing the sand impacts on pipeline design are determining the particles sizes and determining the concentration of the sands that would be transported by the pipelines.

2.2.14 Hydrodynamic coefficient

The hydrodynamic force coefficients presented herein are for use in the calculation of quasi-static forces on pipelines resulting from fluid (seawater) motion. Overall, the coefficient shall be as following Table 11:

Table 2.11: Hydrodynamic Coefficient (Source: DNV RP-E305)

Hydrodynamic Coefficients	Pipeline	Riser
Drag	0.7 – 1.2	0.7(No marine growth)
		1.0(Marine growth)
Lift	0.9	0.0
Inertia	3.29	2.0

2.3 Pipeline Material

In order to transport large volumes of gas or liquid economically over long distances, the system design requires a particular combination of pipe size and operating pressure. The system operating pressure, pipe diameter, wall thickness and pipe grade specifications are based on the detailed design of facility.

The severity of the external environment and the nature of the fluid transported (i.e. corrosive, abrasive). Once these specifications have been established, material selection can take place. These are the performance criteria's in selecting material of pipelines:

a) Resistance to fracture initiation and propagation
b) Material strength
c) Good weldability in both shop and filed conditions
d) Fit-up requirements
e) Acceptable defect size

Design of pipeline involves selection of pipeline diameter, thickness, and material to be used. Pipeline diameter should be selected on the basis of flow capacity required to transport production fluid at an expected rate. Meanwhile, the lower grades of material are selected for pipelines in shallow water or low-pressure.

Large diameter pipelines are used to reduce material cost, or in cases where ductility is required for improved impact resistance (Boyun G, 2005). Pipe types which are used for pipelines are Seamless, Submerged Arc Welded (SAW or DSAW), Electric Resistance Welded (ERW) and Spiral Weld.

Pipeline wall thickness can be determined based on the design internal pressure or the external hydrostatic pressure. Maximum longitudinal stresses and combined stresses are sometimes limited by applicable codes and must be checked for installation and operation. Increasing wall thickness can sometimes ensure hydrodynamic stability in lieu of other stabilization method. This is not normally an economic except in deepwater where the presence of concrete may interfere with the preferred installation method.

2.3.1 Pipe material selection

The selection of the pipeline material type is a fundamental issue to be decided at the conceptual design stage of a pipeline project. The most frequently used pipeline materials are metallic. Non-metallic materials (e.g. GRP/GRE, flexible pipe) may be cost effective for specific applications, especially when the fluid is corrosive (Bai, Yong; Bai, Qiang, 2005).

The occurrence and rate of internal corrosion is governed by a variety of process conditions which include:

- Corrosivity of the fluid, in particular due to the presence of water combined with hydrogen sulphide (sour corrosion), carbon dioxide (sweet corrosion), or oxygen. Temperature and pressure can have a great impact on the corrosion rates.
- Velocity of the fluid, which determines the flow regime in the pipeline. In pipelines transporting fluids containing water, too low velocities lead to settlement of water, which may lead to bottom of pipe internal corrosion; too high velocities can increase the overall corrosion rate and also destroy any protective scale or inhibitor films.
- Deposition of solids, which may prevent adequate protection by inhibitors, and can create anaerobic conditions for the growth of sulphate reducing bacteria.

2.3.2 Steel Quality

Pipelines are commonly constructed with linepipe in steel grades X42 to X65 as defined in API Spec 5L. Lower grades such as Grade B and higher grades may be appropriate in some cases.

Problems have been encountered in the industry for higher grades (hydrogen embrittlement caused by cathodic protection, weldability, required tensile to yield ratio).

Attention shall be given to the fracture toughness properties of pipe material for gas pipelines to prevent the possibility of long running fractures. This is particularly critical when low temperatures are possible, e.g. downstream of pressure reduction stations and at exposed above ground locations.

2.3.3 Pipe/ Steel (Material) Properties

There are three (3) types of material which are:

a) Isotropic – Properties are the same in any direction or at any cross section
b) Anisotropic – Properties differ in two or more direction
c) Orthotropic – Specific type of anisotropic in which planes of extreme values are orthogonal.

However in this FYP, the author performed the analysis by assuming the material properties are isotropic and homogenous. Homogenous materials have consistent properties throughout the volume. Basically, material strength depends on modulus of elasticity (E), Poisson's ratio (v), Young's modulus, density, thermal conductivity, resistivity and linear thermal expansion coefficient.

These are the properties of selected pipeline material:

Table 2.12: Material Properties

Properties	Unit	Value
Density	kg/m^3	7,850
Minimum Yield Strength of Pipe	psi	52,000
Young's Module	MPa	2.0×10^5
Poisson's Ratio	-	0.3
Linear Thermal Expansion Coefficient	/°C	11.7×10^{-6}
Thermal Conductivity	W/m°C	45.0
Resistivity	ohm.m	180×10^{-9}

- The minimum yield strength is the key property of steel used in pipeline design. Figure 2.5 shows the relationship between stress and strain.
- The minimum yield strength is defined as the tensile stress required to produce a total elongation of 0.5 %.
- The most common industry standard for steel pipeline is the API 5L.
- The most common grades used in pipeline design are grades X42 through X65. Lower grades, such as Grade B, and higher grades are used in some cases.
- When using higher grades, problems have been encountered, such as weldability and hydrogen embrittlement caused by cathodic protection.

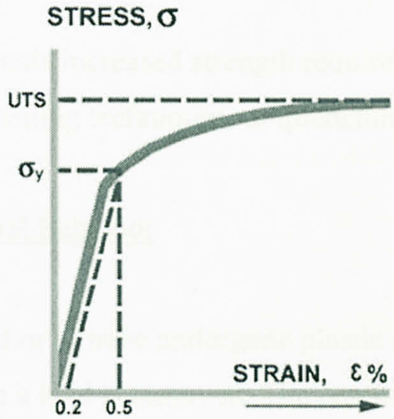


Figure 2.5: Stress-Strain Curve for Pipeline Material

Table 2.13: Pipe Yield Strength

Steel Grade	Minimum Yield Strength, σy (MPa)	Ultimate Tensile Stress, σT (MPa)
B	240	413
X42	290	413
X52	358	455
X60	413	517
X65	448	530
X70	482	565

Table 2.14: Commercially Manufactured Pipes

Type	Diameter Range		Maximum Wall Thickness		Maximum Grade
	D (mm)	D (inch)	D (mm)	D (inch)	
Seamless	50-450	2-18	38	1.5	X70
ERW	50-500	2-24	11	0.438	X65
Long SAW	400-1200	16-56	38	1.5	X70
Spiral SAW	450-2000	18-80	25	1.0	X70

- Lower grade pipe, up to grade X52, generally obtains adequate strength from normalized carbon steels.
- For grades X52 and upwards increased strength requires either additions of other strengthening elements, rolling techniques, or quenching and tempering.

2.3.4 Ductile/ Brittle Material Behavior

A body is said to have yielded or to have undergone plastic deformation if it does not regain its original shape when a load is removed. The resulting deformation is called permanent set. If permanent set is obtainable, the material is said to exhibit ductility. A measure of ductility comes from the percent of elongation or strain at failure.

Brittle material will have a much lower elongation and area reduction than ductile material. The amount of necking and the corresponding dip in the engineering stress-strain curve is indicative of the ductility of the material.

These are the rules of thumb used to determine whether the material is brittle or ductile material:

a) If the percent elongation $\leq$ 5%, assume brittle material
b) If the published ultimate compressive strength is greater than the ultimate tensile strength, assume brittle material
c) If no yield strength is published, assumes as brittle material

2.3.5 Typical Failure Modes of Pipe

There are the common types of mechanical failure of pipe:

a) Fracture

   Occurs when new cracks appear or existing crack are extended. However, a brittle material fracture exhibits little plastic deformation

b) Yielding

   Occurs when pipe experience stresses in excess of its yield strength

c) Insufficient Stiffness

   Pipe must be stiff enough to hold tolerance and support required loads. However, resonant frequencies may be generated if the pipe is too flexible.

d) Buckling

   The sudden loss of stability or stiffness under applied load. Stress levels need not be high for buckling to occur.

e) Fatigue

   Parts that are subject to variable loading will lose strength with time and may fail after certain number of cycles.

f) Creep

   Pipe under load gradually deform over time.

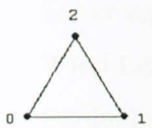
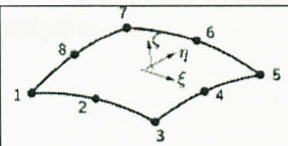
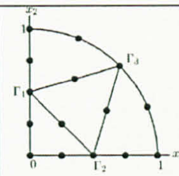
2.4 **Finite Element Modeling (FEM) & Stress Analysis**

2.4.1 Shell Element Basics

Shell elements can be quadrilaterals or triangles. A quadrilateral mesh is usually more accurate than a triangle mesh. Higher order shell elements can provide accurate results with curved initial geometries. The examples of shell element are:

a) Linear Triangle (3 nodes)
b) Linear Quadrilateral (4 nodes)
c) Parabolic Quadrilateral (8 nodes)
d) Parabolic Triangle (6 nodes)

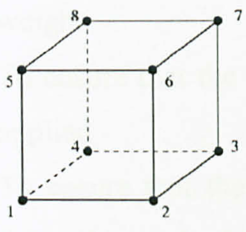
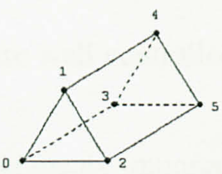
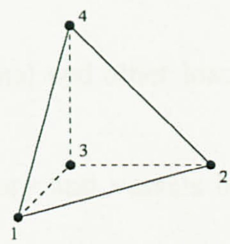
Figure 2.6: Types of Shell Element Basics

			
Linear Triangle (3 nodes)	Linear Quadrilateral (4 nodes)	Parabolic Quadrilateral (8 nodes)	Parabolic Triangle (6 nodes)

2.4.2 Solid Element Basics

There are three types of solid elements commonly used which are:

Figure 2.7: Types of Solid Element Basics

		
8 Node Brick Element	6 Node Wedge Element	4 Node Tetrahedral Element

2.4.3 Stress Analysis

Stress analysis is an engineering discipline that determines the stress in materials and structures subjected to static or dynamic forces or loads.

Typical analysis for pipe stress:

a) Thermal Analysis
   Analysis for free and restrained thermal growth conditions
b) Deadweight Analysis
   Analysis at ambient temperature with a system of hangers at specific locations to support the weight of the system, for allowable stress and reactions at equipment connections
c) Seismic Analysis
   Either equivalent static or dynamic analysis
d) Wind Load Analysis
   Equivalent static stress analysis
e) Transient Analysis
   For various transient loading conditions such as: turbine trip, pipe whip, safety relief valve trip etc.

2.4.3.1 *The Reason why Pipe Stress Analysis is needed*

The reasons a pipe stress analysis is carried out on a piping system are as follows:

a) To comply with legislation
b) To ensure the piping is well supported and does not sag or deflect under its own weight
c) To ensure that the deflections are well controlled when thermal and other loads are applied
d) To ensure that the loads and moments imposed on machinery and vessels by the thermal growth of the attached piping are not excessive

e) To ensure that the stresses in the pipework in both the cold and hot conditions are below the allowable limits

2.4.3.2 *How Pipe Stress Analysis is done*

Usually, pipe stress analysis is done by using analysis software, such as CAESAR II, CAEPIPE, AUTOPIPE, SIMFLEX. However for this project, the author had decided to use commercial software, ANSYS Workbench.

Once the system is accurately modeled, boundary conditions are set for the pipeline (i.e. pressure, material, stress limit, etc). Comprehensive stress analysis calculations are done and modifications to the model are made to ensure compliance with the above requirements.

2.4.3.3 *Pipeline Wall Thickness*

a) Minimum wall thickness

The nominal pipe wall thickness shall not be less than 4.8 mm for all pipelines. The diameter to wall thickness ratio should not exceed 60, unless it can be demonstrated that higher values are not detrimental to the construction and in-situ integrity of the pipeline.

b) Determination of Pipeline Wall Thickness

- The most important element in pipeline mechanical design is the determination of pipeline wall thickness.
- Wall thickness is a function of the pipeline's maximum allowable operating pressure and the yield strength of the steel pipe used.
- Operating pressure and wall thickness determine the number and locations of pump or compressor stations along the pipeline.
- If a higher pipeline operating pressure is chosen, the power at each station can be greater, and the stations can be farther apart. This benefit is offset, however, by the additional expense of thicker wall pipe.

- The internal pressure of the transport fluid induces a circumferential stress in the pipe wall, which is commonly known as Hoop Stress.

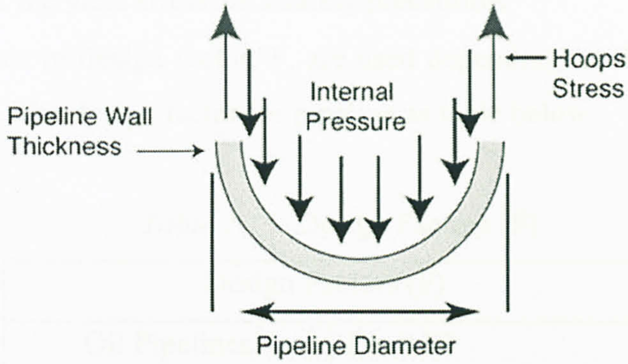


Figure 2.8: Pipeline Pressure

Hoop stress can be calculated by using a simplified formula, usually known as Barlow's formula.

- 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 pipeline design.

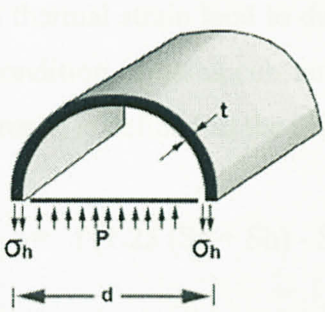


Figure 2.9: Internal Pressure

Barlow's Formula:

$$\sigma h = \frac{PD}{2t} \leq F.\sigma y$$

Where:

F	=	Design Factor
σy	=	Pipe Yield Strength
σh	=	Hoop Stress
P	=	Internal Pressure
D	=	Outer Diameter
t	=	Minimum Wall Thickness

- This formula takes into account an additional parameter, called a design factor, F. The purpose of using a design factor is to keep the circumferential stress of the pipe at a fraction of the yield stress, as a safety precaution.
- Different values of design factor, F, are used depending on the type of service and pipeline route. The design factor for pipeline as table below:

Table 2.15: Design Factors (F)

Design Factors (F)	
Oil Pipelines	F = 0.72
Gas Pipelines	F = 0.72/ 0.6/ 0.5 /0.4
Offshore Risers	F = 0.5

2.4.3.4 *Allowable Displacement Stress Range*

- Displacement stresses may be permitted to attain sufficient magnitude to cause limited overstrain in various portions of the piping system.
- While stresses resulting from thermal strain tend to diminish with time the algebraic difference in displacement condition remains substantially constant during anyone cycle of operation. This difference is defined as the displacement stress range.

$$SA = f(1.25\,(Sc + Sh) - SL)$$

where

SA = Allowable displacement stress range, psi

f = Stress range reduction factor

Sc = Basic allowable stress at minimal temperature, psi

Sh = Basic allowable stress at maximum temperature, psi

SL = Sustained longitudinal stress, psi

Table 2.16: Stress Range Reduction Factor

Number of Equivalent Full Temperature Cycles (N)	Stress Range Reduction Factor (f)
7,000 and less	1.0
7,000 to 14,000	0.9
14,000 to 22,000	0.8
22,000 to 45,000	0.7
45,000 to 100,000	0.6
100,000 and over	0.5

2.4.3.5 *Static Stress Assessment*

Weight and environmental loads shall be determined in accordance with accepted engineering practices and the resulting bending stresses are then determined. Equivalent stresses shall be calculated taking into account these bending stresses, other axial stresses and the hoop stress and be verified against the criteria for permissible stresses in PTS 31.40.00.10.

For calculating bending stresses in spans subjected to an effective axial compressive force (Ne >0), the maximum bending moment in a span may be approximated by:

End condition	Maximum bending moment
Pinned - pinned	$\frac{W}{k^2}\left[\frac{1}{\cos(k.L/2)}-1\right]$
Pinned - fixed	$\frac{W.L}{k}\cdot\frac{\tan k.L.\left[\tan(k.L/2)-k.L/2\right]}{\tan k.L-k.L}$
Fixed - fixed	at support: $\frac{W}{k^2}\left[1-\frac{k.L/2}{\tan(k.L/2)}\right]$
	at centre of span: $\frac{W}{k^2}\left[\frac{k.L/2}{\sin(k.L/2)}-1\right]$

2.4.3.6 *Axial Design Stress*

Stress analysis is required to determine the maximum axial design stresses for the pipeline. The total axial stress acting on a imperfection also includes a residual stress from welding, which, in the case of welds that are not thermally stress relieved, may approach the yield strength of the material (Datta, 1977).

The total of the applied tensile stress and the residual stress may exceed the yield strength and is more conveniently treated as percent strain. **A** yield-strength residual strain of 0.2% was assumed in developing the acceptance criteria given in this appendix. The maximum applied axial strain to be used for a particular pipeline shall be determined by stress analysis and documented by the company. (API 1104, 1999)

3.1 Introduction

Stress analysis of offshore pipeline is very important in order to ensure the pipeline is not overstressing and overloading. Stress analysis is required to prevent/ reduce possibility pipeline failure to happen. It is because pipeline failure may lead to environmental pollution which is harmful to human being and aquatic life.

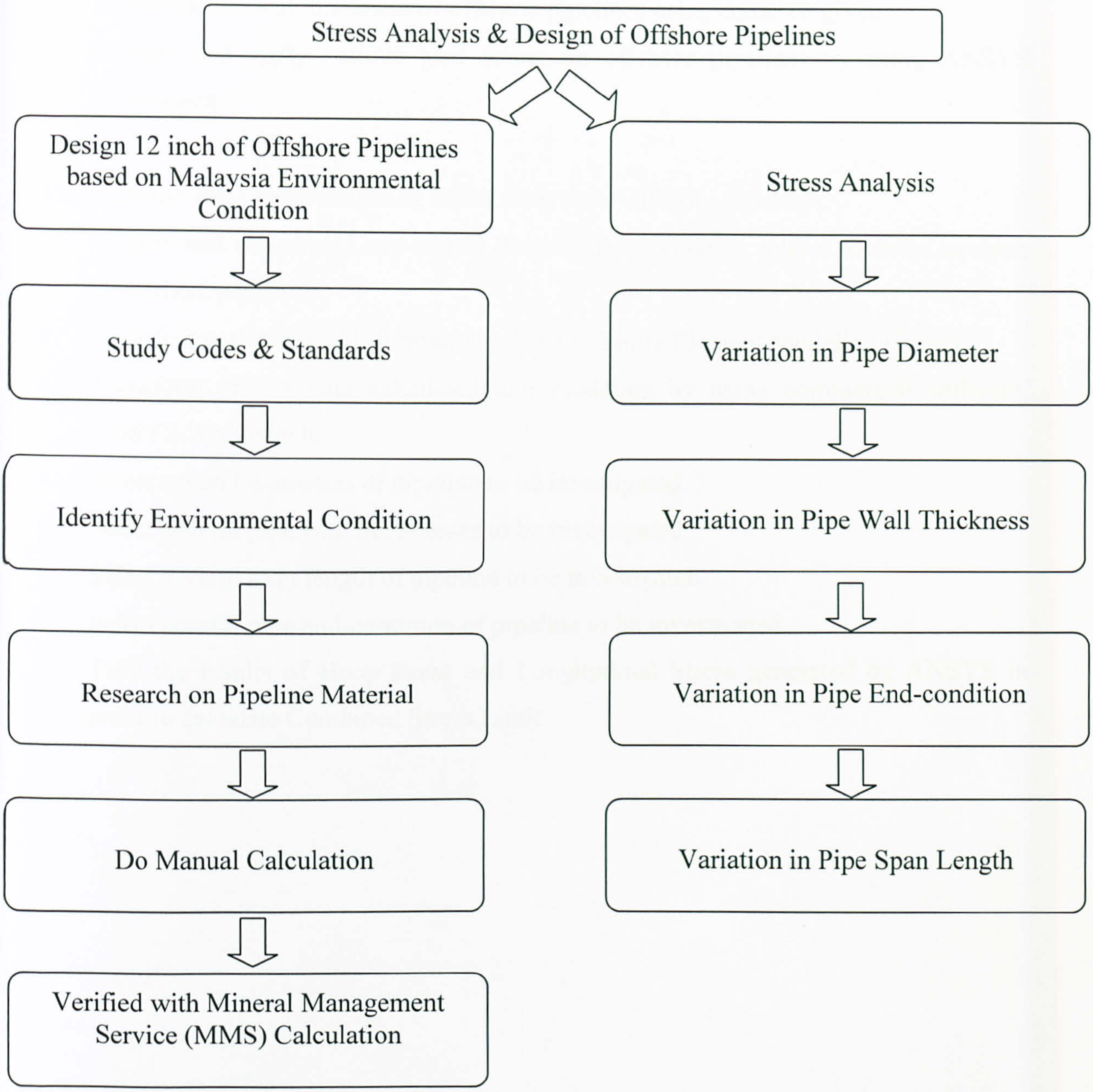
Therefore, the aim of this project is to determine the appropriate designed parameters which offer the lesser stress to the pipeline itself.

3.2 Research Methodology

Methodology is the most important step in designing offshore pipelines. It may guide the author to design an offshore pipeline by following the steps sequence in order to get all the information related to the project whether direct or indirectly.

In order to get theoretical understanding about project *Stress Analysis and Design of Offshore Pipelines*, the author has done several methods in order to accomplish all objective of this project. It simply means that the research methodology shall be based on the objectives of the project.

These are the sequences of the methodology:



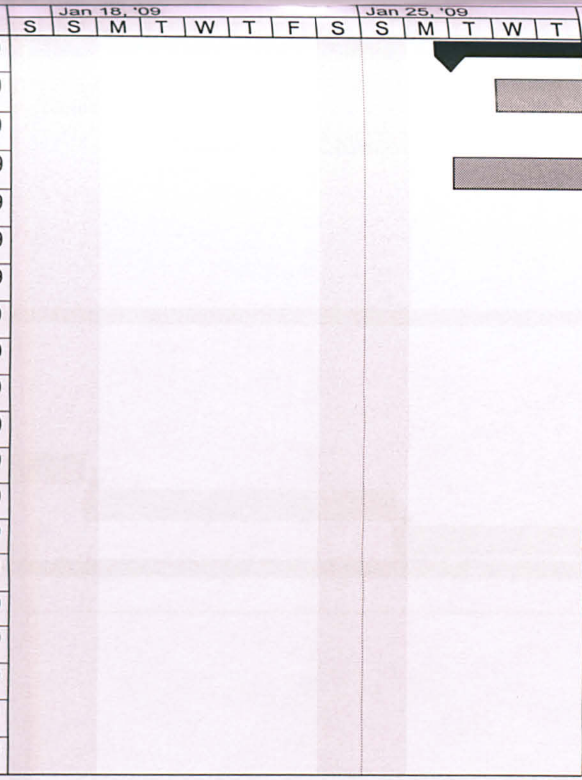
These are the steps of designing an offshore pipeline:

1. Determine the wall thickness of offshore pipelines using equation given.
2. Identify and apply various load acting on offshore pipelines by using ANSYS Workbench.

These are the steps in investigating stress analysis of offshore pipelines:

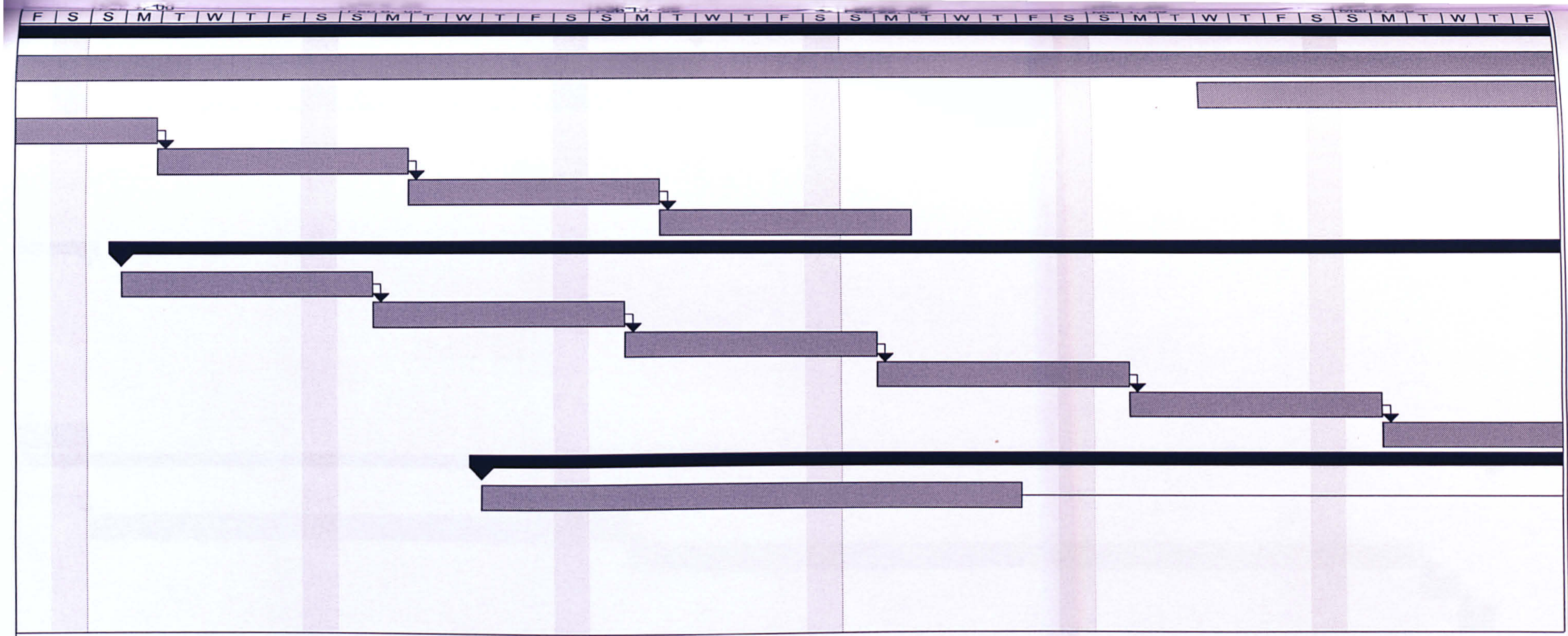
1. Identify and understand any related theoretical information related to stress analysis of offshore pipelines.
2. Identify any theoretical information related to Finite Element Modeling (FEM).
3. Transform all the data calculated into modeling by using commercial software, ANSYS Workbench.
4. Select several diameters of pipeline to be investigated.
5. Select several pipe wall thicknesses to be investigated
6. Select several span length of pipeline to be investigated.
7. Select several pipe end-condition of pipeline to be investigated.
8. Take the results of Hoop stress and Longitudinal Stress generated by ANSYS in order to calculate Combined Stress Limit

ID		Task Name	Duration	Start	Finish
1		**Research**	**54 days?**	**Tue 1/27/09**	**Wed 4/1/09**
2		Study on Journal related to Design of Offshore Pipelines	53 days?	Wed 1/28/09	Wed 4/1/09
3		Research on Mineral Management Service (MMS)	23 days?	Wed 3/4/09	Wed 4/1/09
4		Pipeline Material	6 days?	Tue 1/27/09	Mon 2/2/09
5		Design of Offshore Pipelines	6 days?	Tue 2/3/09	Mon 2/9/09
6		Pipeline Stress Analysis	6 days?	Tue 2/10/09	Mon 2/16/09
7		Finite Element Method (FEM)	6 days?	Tue 2/17/09	Mon 2/23/09
8		**ANSYS Modelling & Simulation**	**36 days?**	**Mon 2/2/09**	**Sun 3/15/09**
9		Modelling on Load/ Force	6 days?	Mon 2/2/09	Sun 2/8/09
10		Modelling on Pipe Wall Thickness	6 days?	Mon 2/9/09	Sun 2/15/09
11		Modelling on Pipe Diameter	6 days?	Mon 2/16/09	Sun 2/22/09
12		Modelling on Pipe Material	6 days?	Mon 2/23/09	Sun 3/1/09
13		Modelling on Span Length	6 days?	Mon 3/2/09	Sun 3/8/09
14		Modelling on Pipe End-Condition	6 days?	Mon 3/9/09	Sun 3/15/09
15		**Report**	**56 days?**	**Thu 2/12/09**	**Thu 4/23/09**
16		Progress Report	13 days?	Thu 2/12/09	Thu 2/26/09
17		Poster Presentation	11 days?	Mon 3/16/09	Mon 3/30/09
18		Dissertation Report	16 days?	Tue 3/31/09	Tue 4/21/09
19		Dissertation Report (Hard-Bound)	1 day?	Wed 4/22/09	Wed 4/22/09
20		Final Year Project (II) Presentation	1 day?	Thu 4/23/09	Thu 4/23/09



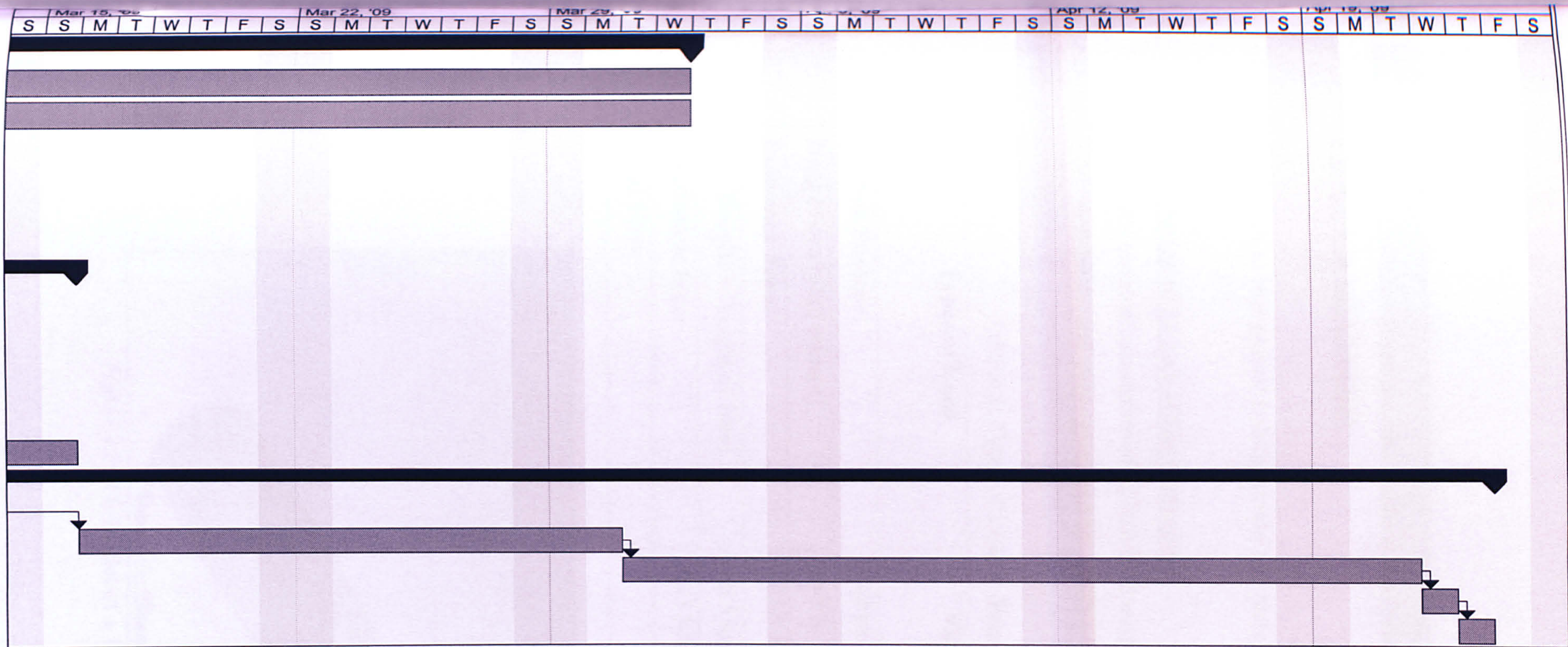
Project: FYP (II) Gantt Chart - FINAL
Date: Tue 5/26/09

Task
Split
Progress
Milestone
Summary
Project Summary
External Tasks
External Milestone
Deadline



Project: FYP (II) Gantt Chart - FINAL
Date: Tue 5/26/09

Task	Milestone	External Tasks	
Split	Summary	External Milestone	
Progress	Project Summary	Deadline	



Project: FYP (II) Gantt Chart - FINAL
Date: Tue 5/26/09

Task	Milestone	External Tasks
Split	Summary	External Milestone
Progress	Project Summary	Deadline

RESULT & DISCUSSION

The result of this project is divided into two parts which are:

1. **Design of 12 inch offshore pipelines**

   The manual calculation of 12 inch offshore pipeline is attached in appendix. The simulation and stress generated by ANSYS Workbench is as below:

Table 4.1: Types of Load & Stress generated by ANSYS

Types of Load	Value	Hoop Stress (psi)	Longitudinal Stress (psi)
Internal Pressure	1144 psi	18425.6	9495.33
Drag Force (with current)	3397 N	3542.4	1935.67
Buoyancy Force	8970.3 N	9355.81	5112.44
Self Weight + Weight of Fluid	133.5 kg/m	1249.47	682.765
Hydrostatic Force	2912 N/m^2	843.192	422.074
Total Force			

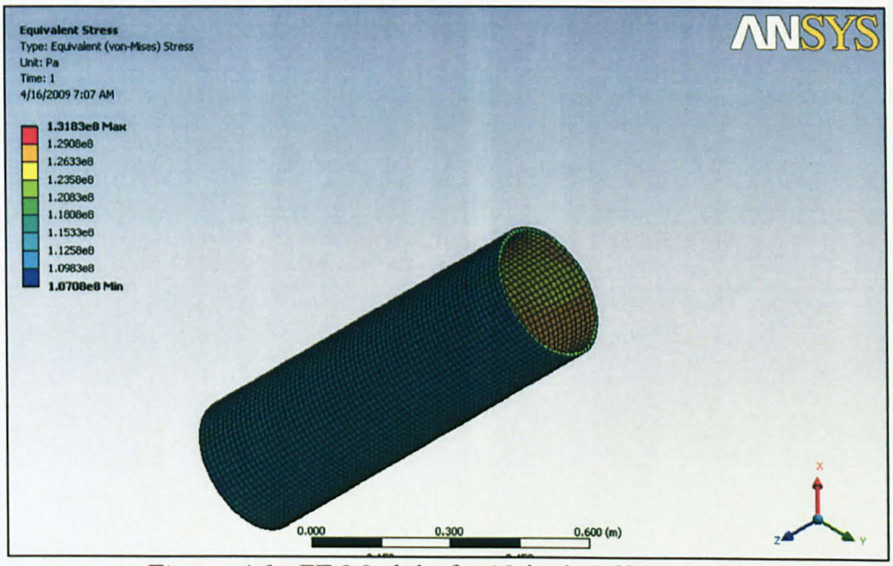


Figure 4.1: FE Model of a 12 inch Offshore Pipeline

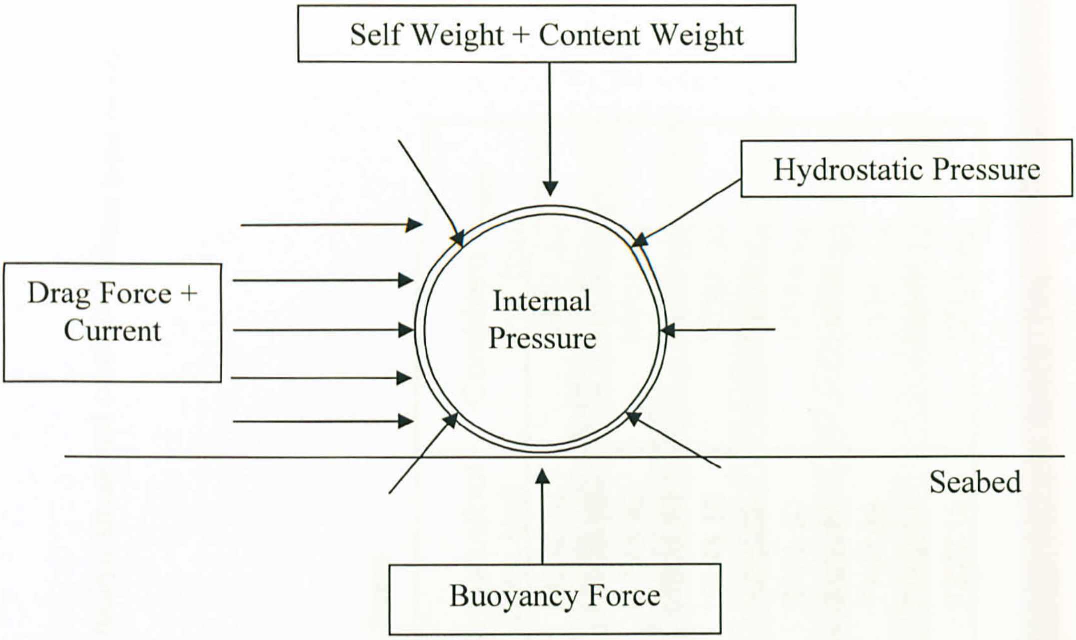


Figure 4.2: Types of forces acting on pipeline

Basically, a pipeline are exposed to various forces such as hydrostatic pressure, drag force, current, buoyancy force, internal pressure and self weight of the pipe and its contents.

However, from the stress analysis generated by ANSYS Workbench, it is shown that these kinds of force/ pressure help one another in order to reduce the stress of the pipe. For example, the stress is reduced when internal pressure and external pressure acted together

2. Stress analysis of offshore pipeline

Stress analysis is done by varying the pipeline parameters and the hoop stress, longitudinal stress and combined stress limit of offshore pipelines are obtained. These are the pipeline parameters investigated:

a) Pipe Wall Thickness

These are the results on pipe wall thickness and pipe stress:

Table 4.2: Pipe Wall Thickness vs Pipe Stress

Pipe Wall Thickness (inch)	Outer Diameter, OD (inch)	Inner Diameter, ID (inch)	Hoop Stress (psi)	Longitudinal Stress (psi)	Combined Stress Limit (psi)
0.250	12	11.50	27539.80	14052.10	23851.84
0.275	12	11.45	25052.40	12808.60	21697.85
0.300	12	11.40	22978.30	11773.40	19901.82
0.325	12	11.35	21227.70	10895.70	18385.89
0.350	12	11.30	19728.00	10146.80	17087.29
0.375	12	11.25	18425.60	9495.33	15959.54
0.400	12	11.20	17288.50	8926.50	14974.94
0.425	12	11.15	16287.7	8425.97	14108.38
0.450	12	11.10	15401.6	7982.88	13341.16
0.475	12	11.05	14602.4	7582.14	12649.17
0.500	12	11.00	13883.6	7222.16	12026.82

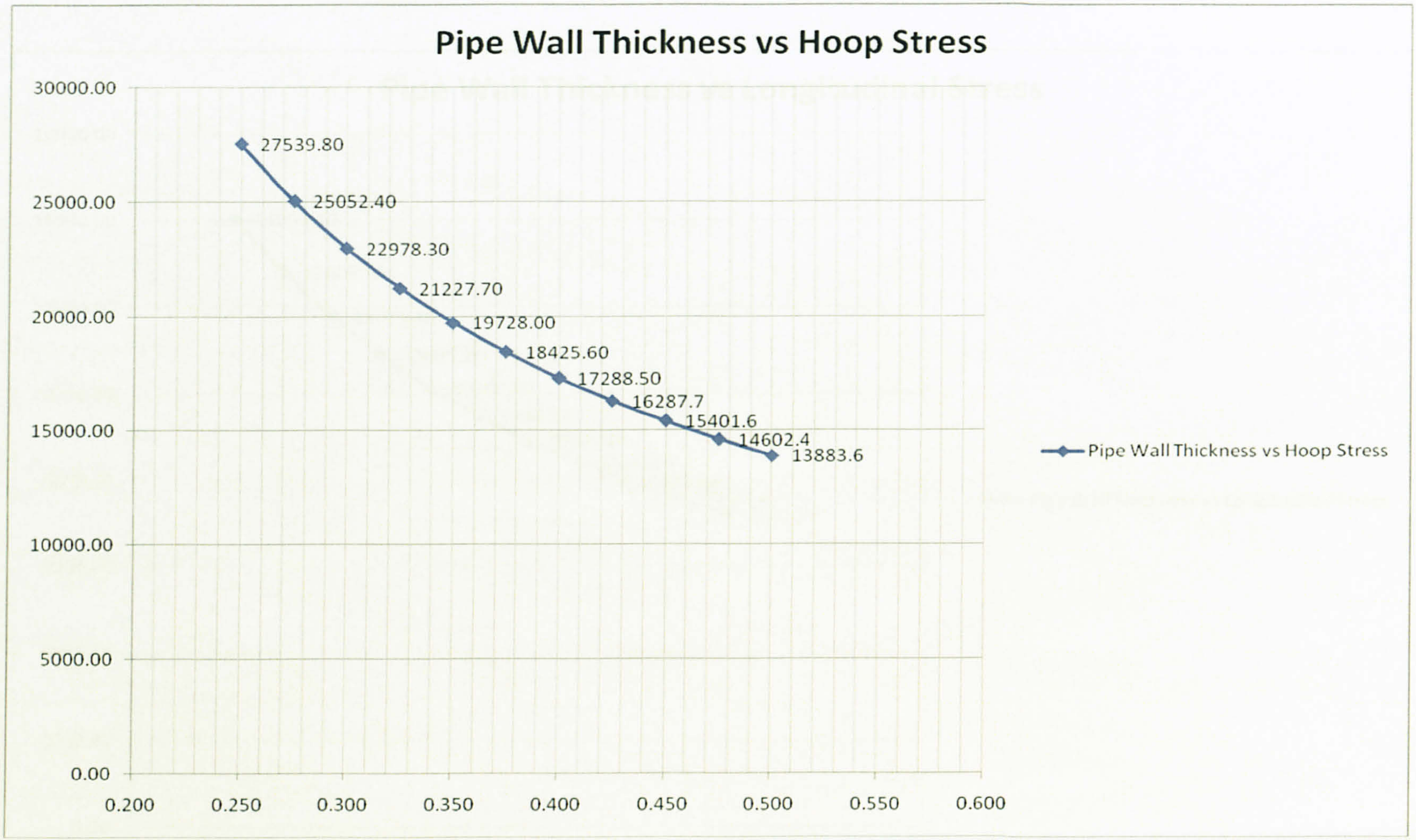


Figure 4.3: Pipe Wall Thickness vs Hoop Stress

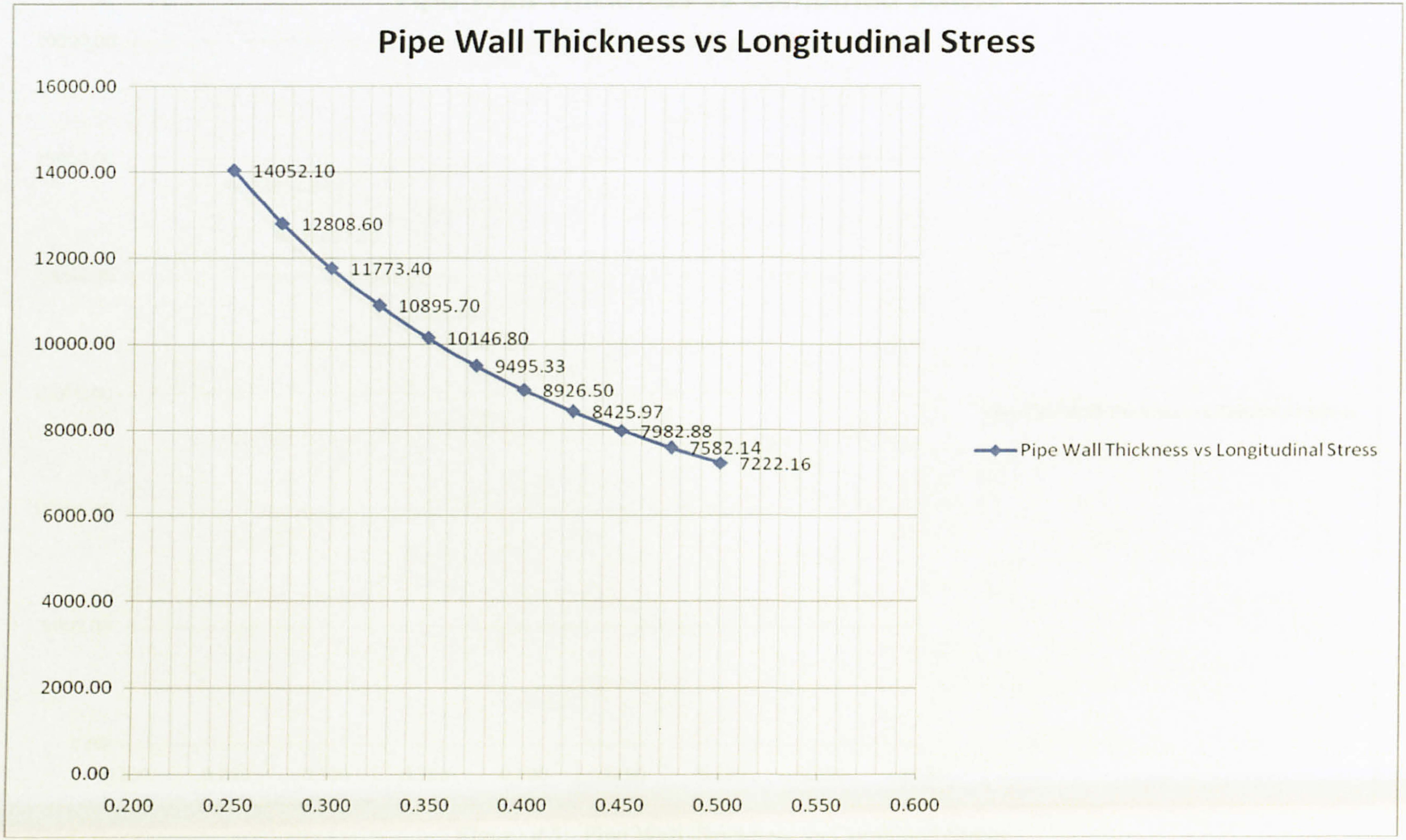


Figure 4.4: Pipe Wall Thickness vs Longitudinal Stress

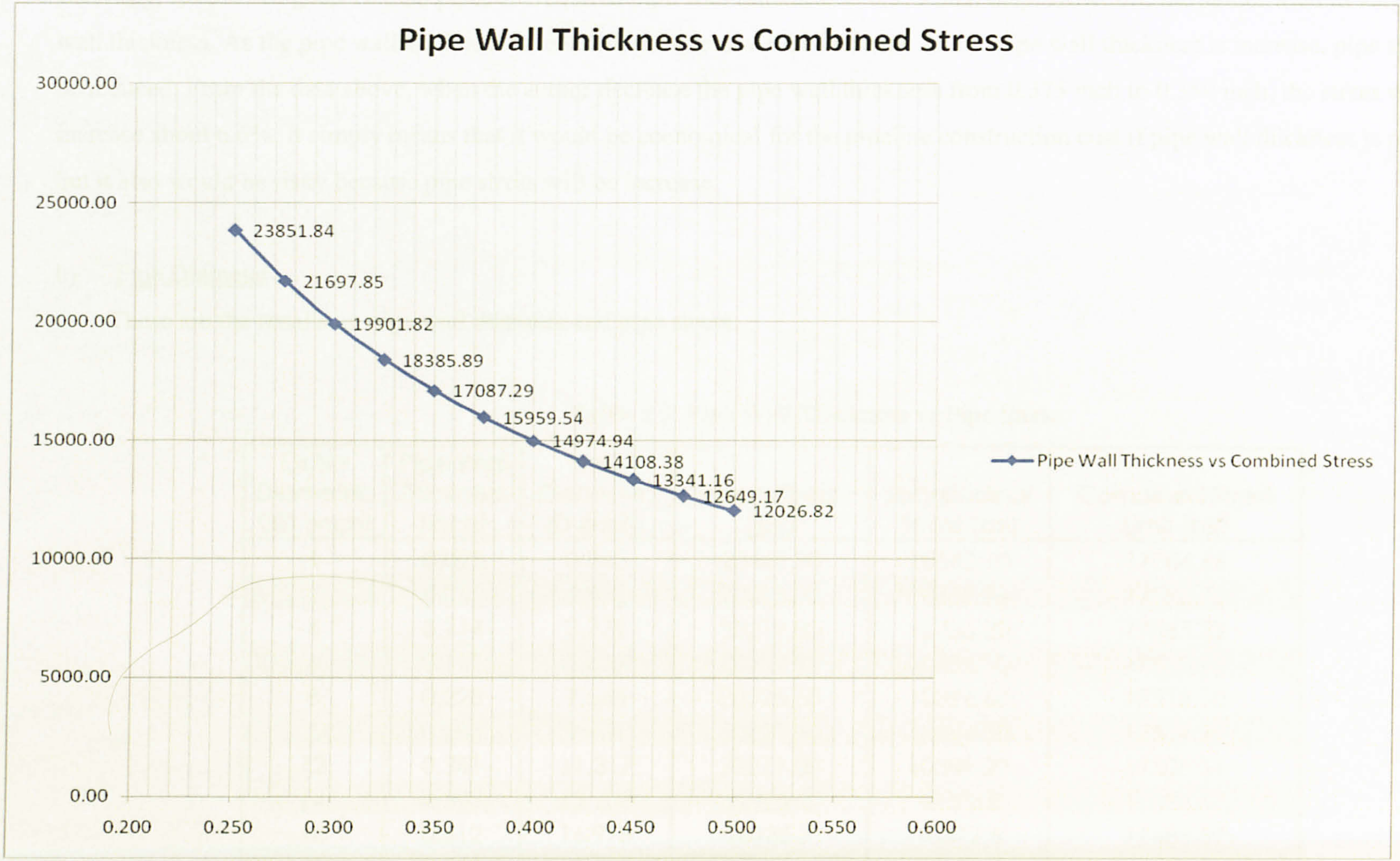


Figure 4.5: Pipe Wall Thickness vs Combined Stress

Basically, for the designed 12 inch pipe, the required pipe wall thickness is 0.375 inch only. However, the author tried to vary the pipe wall thickness. As the pipe wall thickness is reduced, the stress will be increase. As the pipe wall thickness is increase, pipe stress will be reduced. From the data above, when the author decrease the pipe wall thickness from 0.375 inch to 0.350 inch, the stress will be increase about 6.6%. It simply means that it would be economical for the pipeline construction cost if pipe wall thickness is reduced but it also would be risky because pipe stress will be increase.

b) Pipe Diameter

These are the results on pipe wall diameter and pipe stress:

Table 4.3: Pipe Wall Thickness vs Pipe Stress

Outer Diameter, OD (inch)	Pipe Wall Thickness (inch)	Inner Diameter, ID (inch)	Hoop Stress (psi)	Longitudinal Stress (psi)	Combined Stress Limit (psi)
1	0.028	0.943	20440.20	10542.10	17704.66
2	0.057	1.886	20318.30	10457.90	17598.70
4	0.114	3.772	20279.80	10436.20	17565.32
6	0.171	5.659	20242.90	10403.10	17533.13
8	0.228	7.545	20225.50	10396.60	17518.10
10	0.285	9.431	20221.20	10394.30	17514.37
12	0.341	11.317	20211.00	10389.20	17505.54
14	0.398	13.203	20189.3	10373.8	17486.67
18	0.512	16.976	20185.7	10372.6	17483.57
20	0.569	18.862	20181.3	10370.4	17479.76
24	0.683	22.634	20179.1	10367.4	17477.82

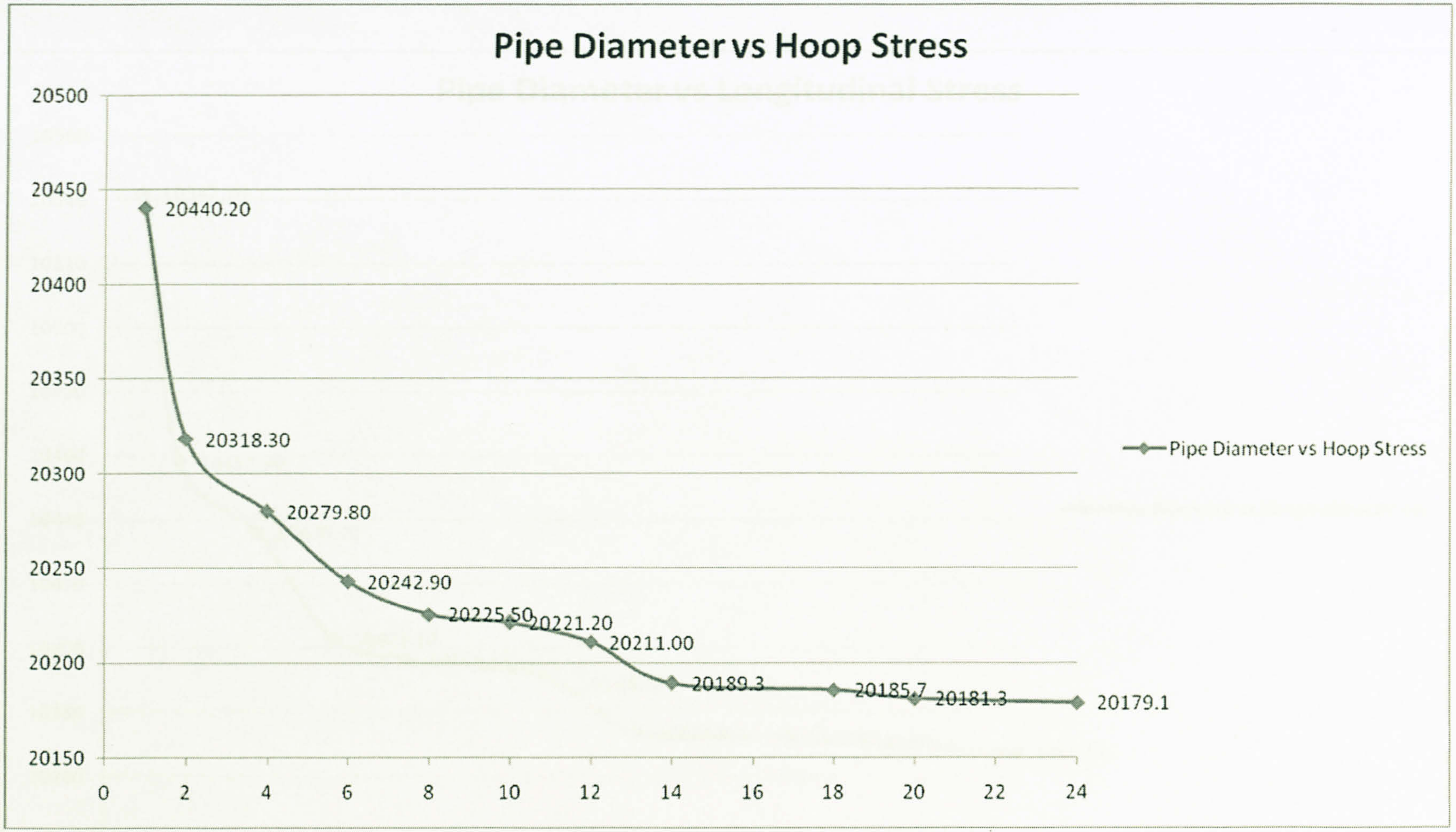


Figure 4.6: Pipe Diameter vs Hoop Stress

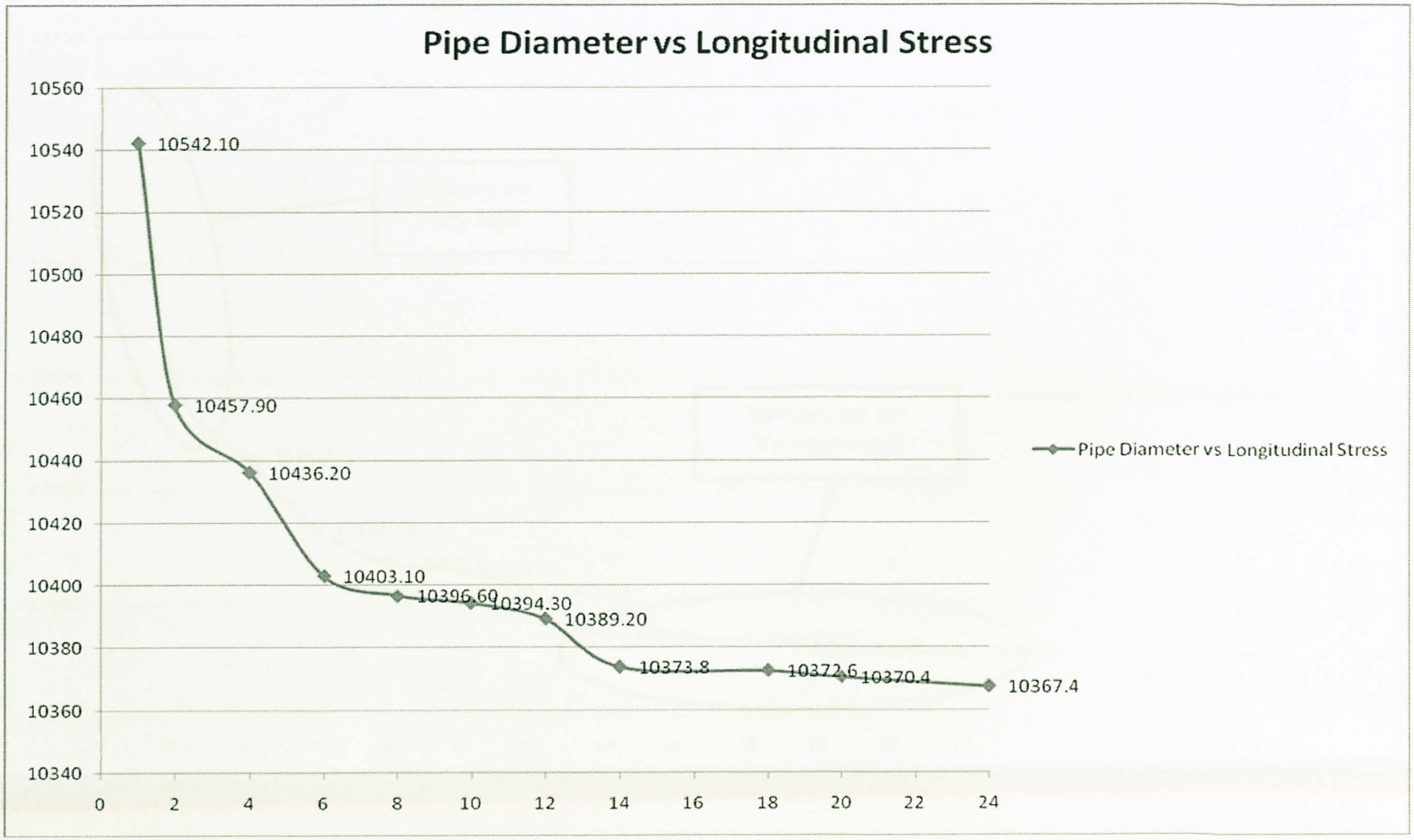


Figure 4.7: Pipe Diameter vs Longitudinal Stress

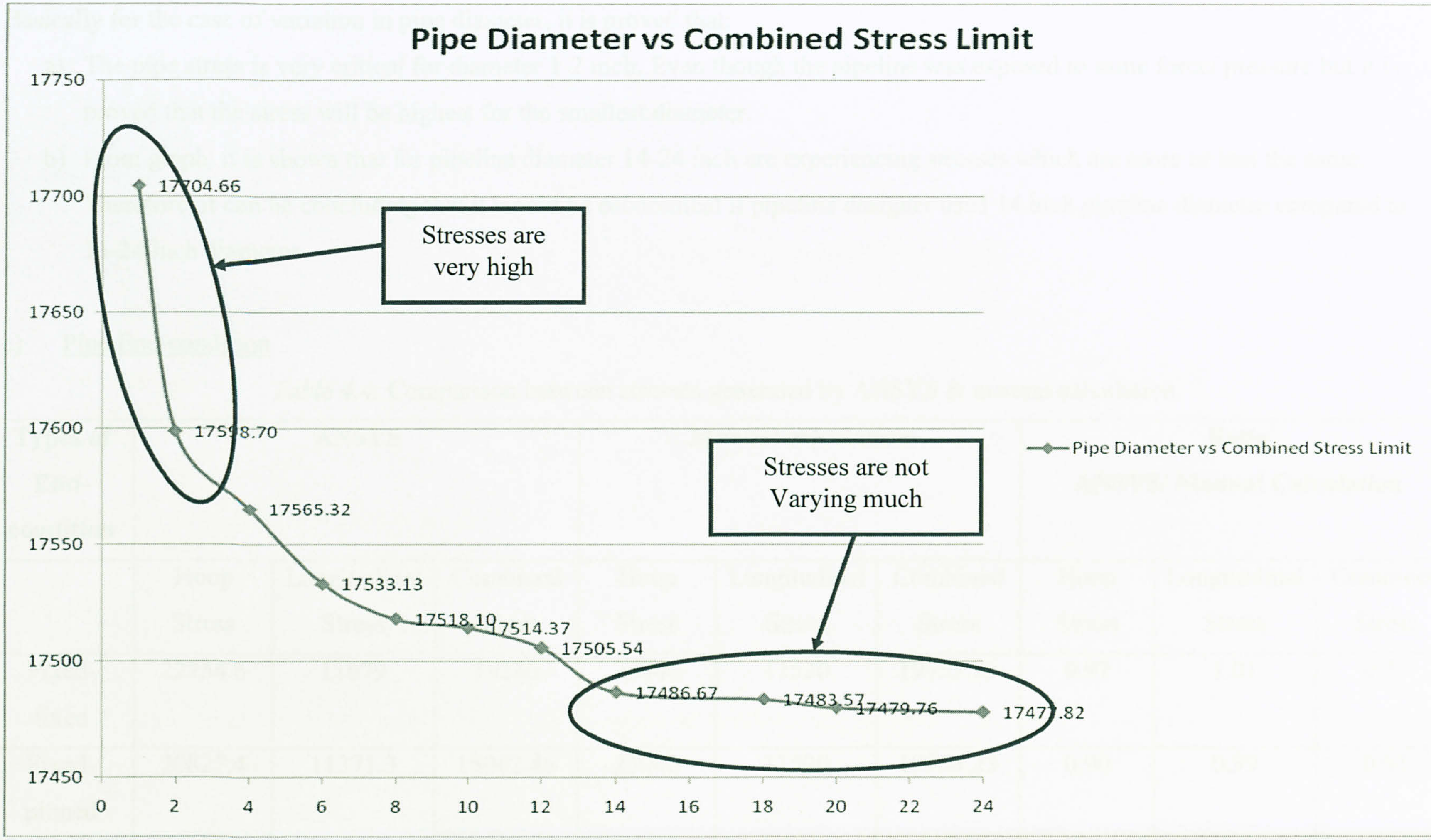


Figure 4.8: Pipe Diameter vs Combined Stress Limit

Basically for the case of variation in pipe diameter, it is proved that:

a) The pipe stress is very critical for diameter 1-2 inch. Even though the pipeline was exposed to same force/ pressure but it is proved that the stress will be highest for the smallest diameter.
b) From graph, it is shown that for pipeline diameter 14-24 inch are experiencing stresses which are more or less the same. Therefore, it can be concluding that it would be economical if pipeline designer used 14 inch pipeline diameter compared to 16-24 inch diameter

c) <u>Pipe End-condition</u>

Table 4.4: Comparison between stresses generated by ANSYS & manual calculation

Types of End-condition	**ANSYS**			**Manual calculation**			**Ratio ANSYS/ Manual Calculation**		
	Hoop Stress	Longitudinal Stress	Combined Stress	Hoop Stress	Longitudinal Stress	Combined Stress	Hoop Stress	Longitudinal Stress	Combined Stress
Fixed-fixed	22254.6	11679	19280	23040	11520	19953.23	0.97	1.01	0.97
Fixed-pinned	20827.4	11371.3	18062.46	23040	11520	19953.23	0.90	0.99	0.91
Pinned-pinned	18425.60	9495.33	15959.54	23040	11520	19953.23	0.80	0.82	0.80

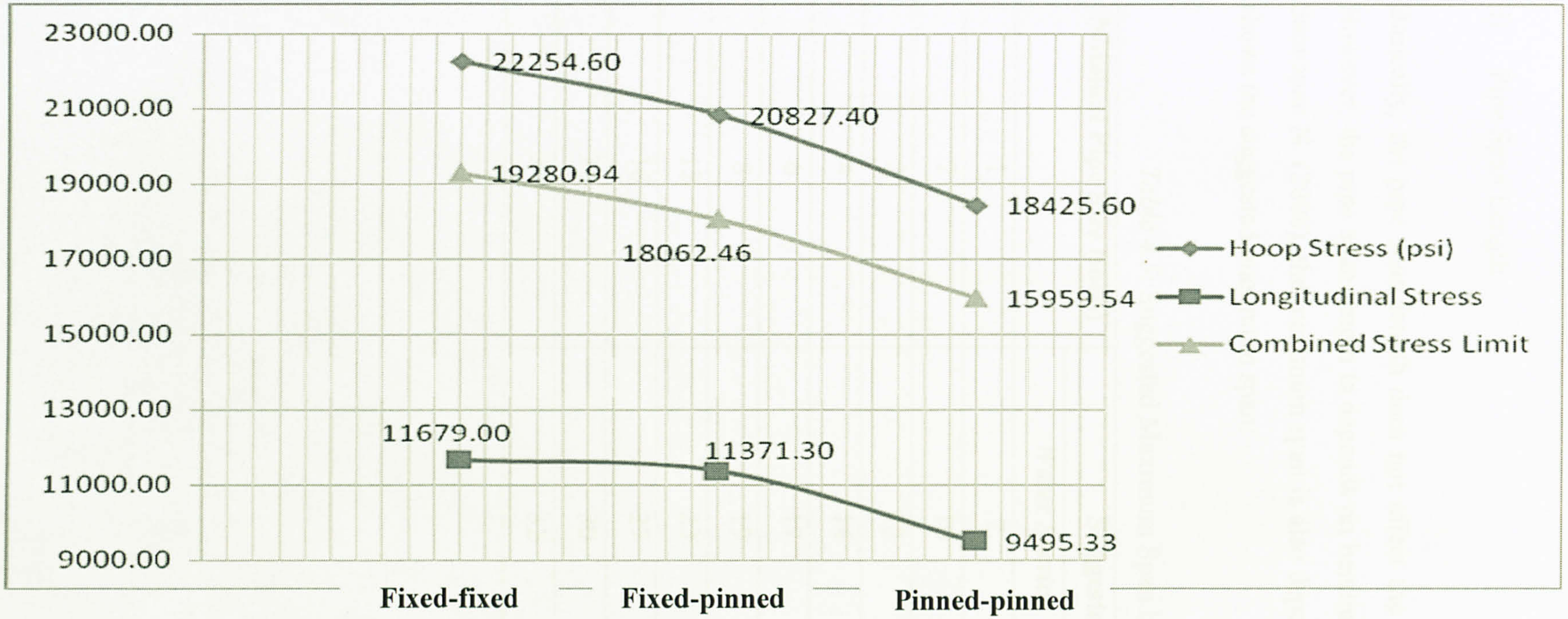


Figure 4.9: Pipe End-condition vs Pipe Stress

From the graph above, it is proved that Fixed-fixed end-condition produced more stress compared to Fixed-pinned and Pinned-pinned. It is because both end of pipeline are fixed, means that any movement of pipeline at any axis is prevented. Therefore, the pipe stress will be higher.

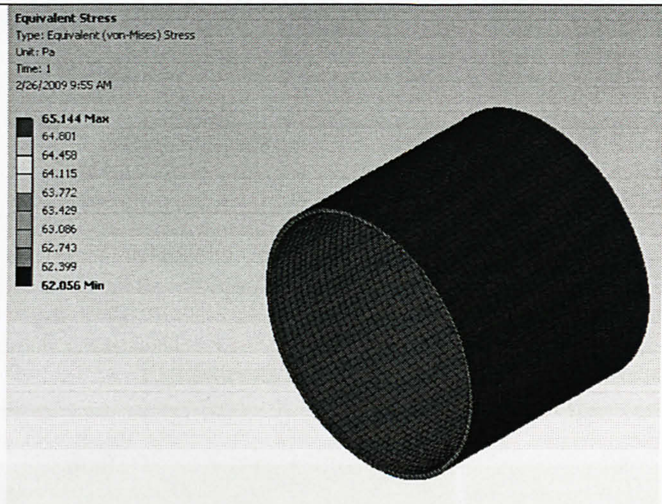
d) Pipe Span Length

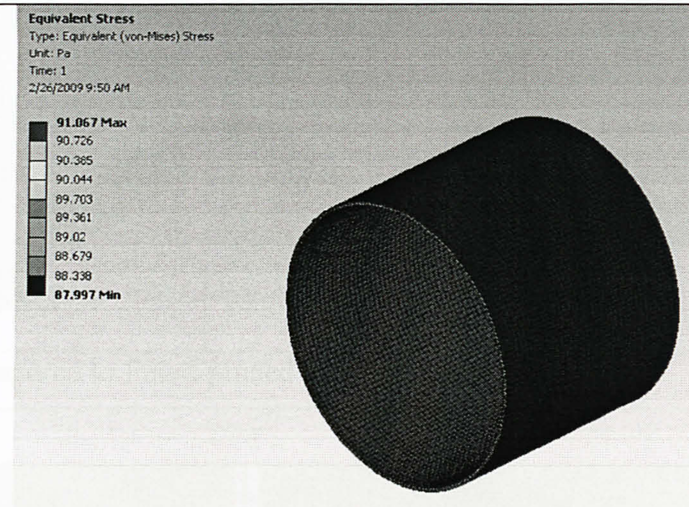
Basically, the pipe span length does not affect the hoop stress and longitudinal stress. However, the pipe span length is depends on bending moment of the pipe. According to Sannapan N. (2008), the maximum span is also depends on the pipe diameter. This table shows the suggested maximum span:

Table 4.5: Suggested Maximum Span based on Pipe Diameter

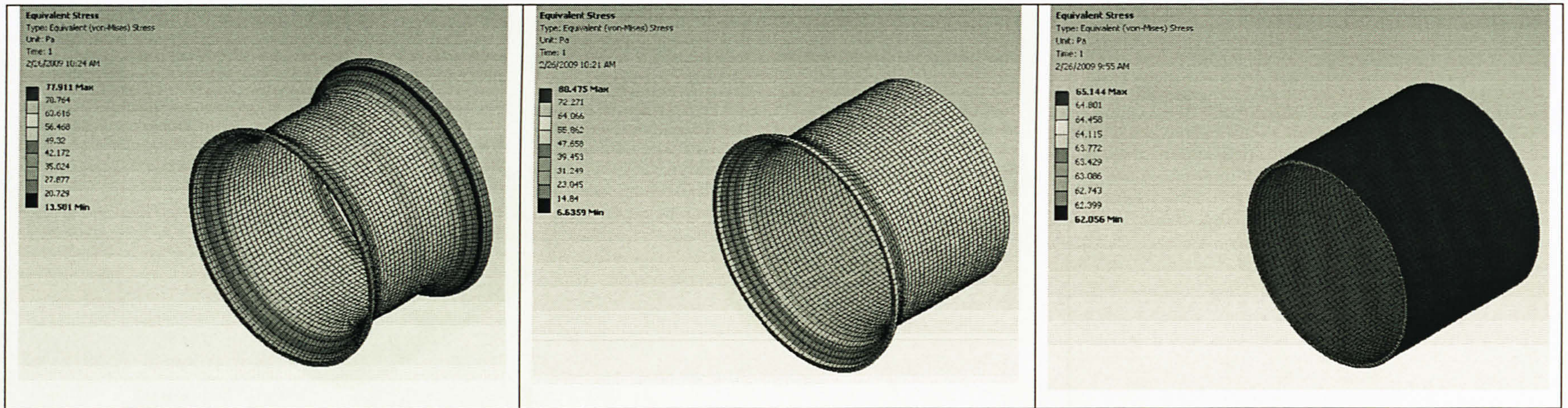
Nominal Pipe Size (inch)	**Suggested Maximum Span (ft)**	
	Water Service	***Steam/ Gas/ Air***
1	7	9
2	10	13
3	12	15
4	14	17
6	17	21
8	19	24
12	23	30
16	27	35
20	30	39
24	32	42

These figures show the offshore pipeline by using commercial software, ANSYS Workbench:

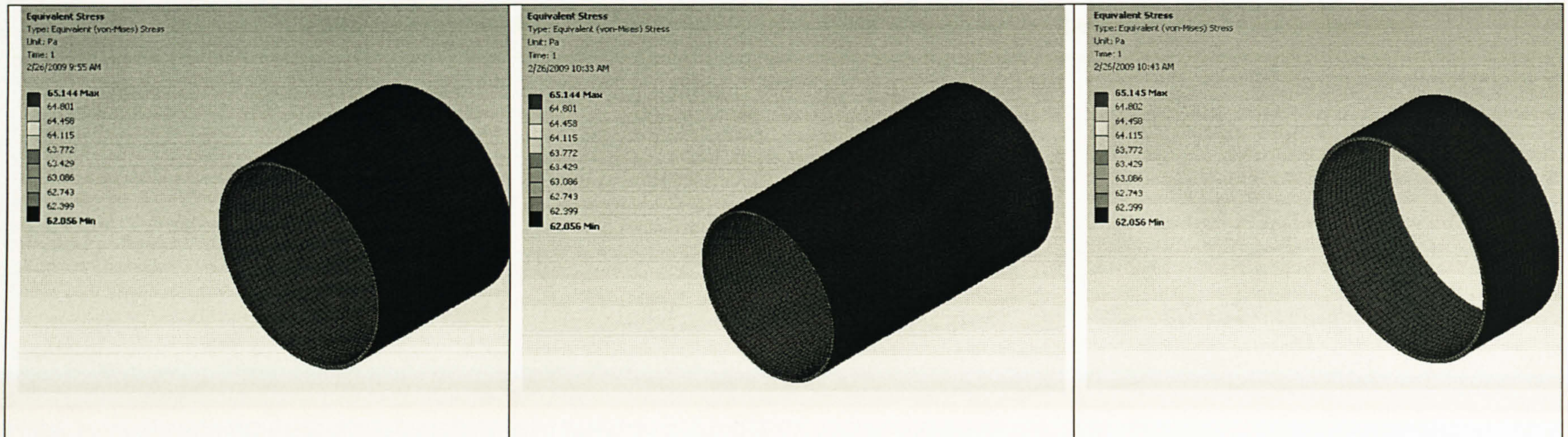




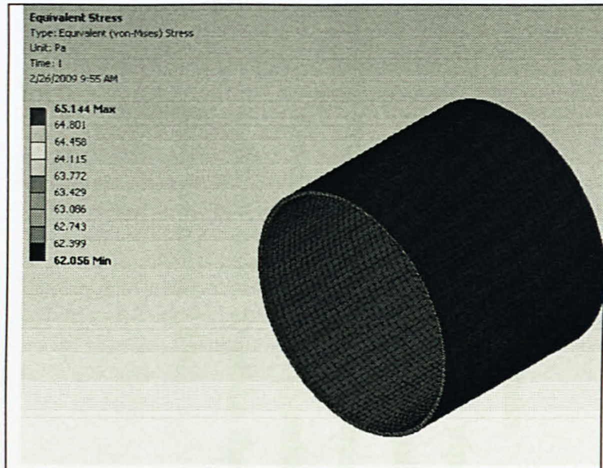
As the pipe wall thickness is reduced, the pipe stress will be increase

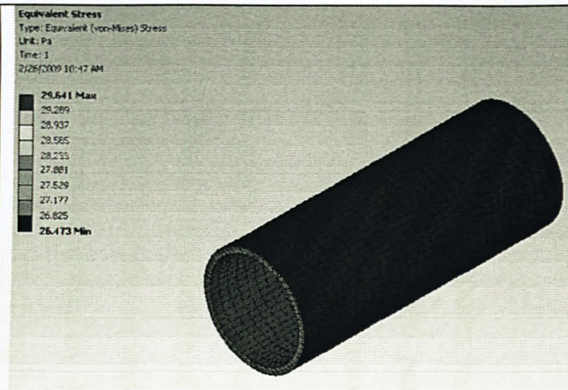


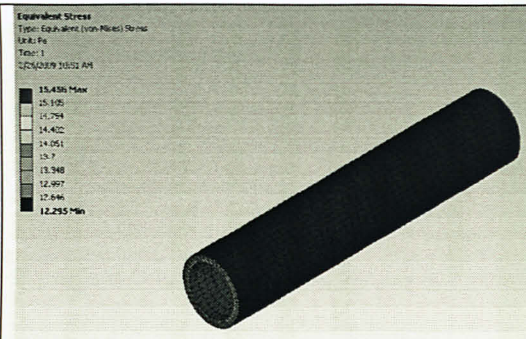
Pipe stress is highest for Fixed-fixed end-condition compared to Fixed-pinned and Pinned-pinned



The pipeline span length does not affect hoop stress and longitudinal stress







As pipeline diameter increase, the pipe stress will be decrease as long as pipeline diameter has been provided with required wall thickness. It simply means that wall thickness of 8 inch diameter should not be the same with 24 inch diameter.

5.1 Introduction

The aim of this project is to analyze and design offshore pipelines based on Malaysia environmental condition. For this purpose, a 12 inch pipeline was considered. The pipeline was designed by hand computation and compare with manual given in United State Mineral Management Service (US MMS).

The pipeline was also modeled using ANSYS Workbench and the stress of the pipeline is determined. The generated stresses results by ANSYS Workbench are compared to hand computation results.

A few parametric studies were also carried out to understand the effect of changing those parameters. The studied parameters are pipe wall thickness, pipe diameter, pipe span length and pipe end-condition.

From the study, the results can be summarized as below:

1. Hand computation of 12 inch offshore pipelines was compared to guideline of US MMS in order to verify the hand computation.
2. Stress generated by ANSYS Workbench was compared to hand computation.
3. The effect of changing the pipeline parameters can be summarized as below:

    a) Pipe Wall Thickness

    As per theory, as the pipe wall thickness is reduced, the pipe stress will be increase. However, the author discovers that as long as pipeline stress does not exceed the permissible stress, the pipeline wills not failure. It simply means that if the designer wants to reduce cost of material by reducing pipe thickness about 6.6% in order to make the project more economical, the risk of failure will be increase about 7.1%.

b) Pipe Diameter

From the research, the author had discovered that the pipe stress will be the highest for the smallest diameter pipeline which is 1-2 inch. It simply means that the 1-2 inch pipeline have higher possibilities to fail compared to other diameter. Besides, the author also discovered that the 14 inch diameter pipeline would be economical compared to 16-24 inch diameter. It is because the stress of 14 inch diameter is more or less the same with diameter 16-24 inch. Therefore, it is advisable to use 14 inch pipeline if the range of designed pipeline is about 14-24 inch.

c) Pipe End-condition

From analysis generated by ANSYS Workbench, the author had discovered the Fixed-fixed end condition wills having the higher stress compared to Fixed-pinned and Pinned-pinned

d) Pipe Span Length

The hoop stress and longitudinal stress does not affected by span length. However, the span length is affecting the bending stress of the pipeline itself.

Recommendation

Personally, the author may conclude that his FYP topic 'Stress Analysis and Design of Offshore Pipelines' is very beneficial for his knowledge and exposure. Even though this topic is very broad, but the author thinks that this topic is very interesting to do research.

Therefore, in order to improve this project in future, the author recommendations are:

a) FYP topic should concentrate on more specific research such as corroded pipelines, pipeline joint, etc.
b) UTP shall provide the widely used pipe stress analysis software in laboratories which is CAESAR II.

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