STRESS ANALYSIS OF UNDERWATER PIPELINE FOR IRREGULAR SEABED TOPOGRAPHY USING CAESAR II.

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CERTIFICATION OF APPROVAL

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the Mechanical Engineering Program
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Approved by,

____

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January 2012

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.

NURUL ALIA BINTI MOHD ANUAR

ABSTRACT

Offshore oil and gas pipelines are being subjected to deeper water depths, more extreme environmental conditions, and harsher operating requirements than ever before. Given these conditions, free spanning pipelines are becoming more common and are often unavoidable during pipeline installation. Free spans occur as a result of irregular seafloor topography at installation or during pipeline operation as a result of vibration and scour [1].

A linear-elastic finite element model is applied to the solution of stress analysis problems involving submarine pipelines freely resting upon irregular seabed profiles. This report describes a finite element (FE) modelling procedure and parametric study leading to the investigation of stress distribution and deformation subjected on pipeline. The objective of this project is to model underwater pipeline using pipe stress analysis software, CAESAR II. The pipeline will be examined on various conditions according to the geometry of the seabed. The input or load cases of the pipeline system are ocean current and wave. The FE analyses are carried out for both the fully fixed and simply supported pipes, which form the two extreme conditions of pipelines under service conditions. Expected result is that the stress of the pipelines should not exceed the maximum allowable stress set by the regulations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

CHAPTER 1: INTRODUCTION

1.1 Project Background

Marine pipelines for the transportation of oil and gas have become a safe and reliable part of the expanding infrastructure put in place for the development of the valuable resources below the world's seas and oceans [2]. Route selection for pipeline is a crucial activity. A poorly chosen route can be much more expensive than a well chosen route. Understanding of the seabed geotechnics and the oceanographic conditions: knowledge of the locations of geotechnically uniform and smooth seabed, free of obstructions or existing pipelines and not in conflict with other fields, existing or planned subsea installations [3].

Stress is classified into three major categories namely primary stress, secondary stress and tertiary stress. Primary stress is developed by imposed loading and necessary to satisfy the equilibrium between external and internal forces and moments of the pipeline. Secondary stress is a self-limiting stress which is developed by constraint of the displacement of a structure. The displacement is caused by thermal expansion or by outwardly imposed restraint. Tertiary stress is a peak stress which causes no significant distortion. It is the highest stress under consideration and responsible for causing fatigue failure [4].

A pipeline rests on or in the seabed. Based on research typically for Malay basin, most of the underwater pipelines are not supported [5]. Depending on the seabed topography, sometimes rocks are dumped surrounding the pipeline as a means of support. The pipelines are also being anchored on the seabed as a means of fixed support or rather being laid by the concrete mattress. Thus, this particular study is generally focus on the stress analysis accounted for pipeline that is laid on different type of seabed topography such as inclined slope, uneven seabed, etc.

Sea current and pressure difference around a pipeline will create hydrodynamic forces. The stress on the pipeline is determined by the relative magnitude of the agitating hydrodynamic force and the resulting force due to the submerged of pipeline. The pipeline will be displaced when the resultant of drag and lift forces exceed the resisting force due to the submerged weight of pipeline [6].

CAESAR II is used rather that ANSYS are for various reasons. CAESAR II user creates a model of the piping system using simple beam elements and defines the loading conditions imposed on the system. With this input, CAESAR II produces results in the form of displacements, loads and stresses throughout the system. Additionally, CAESAR II compares these results to limits specified by recognized codes and standards [7].

Unlike ANSYS, CAESAR II is a simplified version of finite element analysis software. CAESAR II does not encounter mesh analysis, thus the steps to complete an analysis are fewer which means faster than ANSYS that acquire more steps. The simulation using CAESAR II is on the whole pipe and demonstrates 3-dimensional analysis compared to ANSYS which only focus at one point where analysis is done. There are few assumptions needed to be made when using CAESAR II to increase the accuracy level. Furthermore, CAESAR II is a more comprehensive software to be used for pipeline stress analysis as the software are designed specifically for pipes.

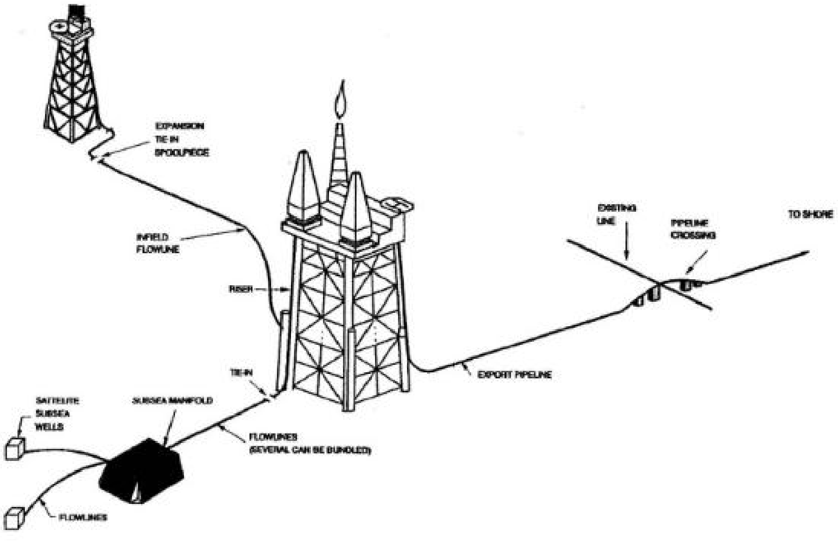


Figure 1: Roles of pipelines in an offshore hydrocarbon field [10]

1.2 Problem Statement

From the pipeline point of view, the ideal seabed is level and smooth so that no spans are formed and is composed of stable medium clay. The pipe settles into the clay and gains enhanced lateral stability [2]. However, the seabed has many types of geometry and not consistently that the pipeline encounters flat and even ocean floor. Some seabeds are highly mobile and include sandwaves (which may be 15 m high and 100 m long) and smaller ripple features (which range in size on many scales from millimeters to meters high) [6].

Information on the seabed topography and geotechnics are needed in order to make a rational choice of pipeline route. This study takes into consideration on several types of irregular seabed topography.

All of the offshore activities are mainly concerns on the safety measure. Thorough inspections are done to ensure that all the facilities and equipment used offshore are safe and reliable. Pipelines in service are subjected to wave and current loadings. Thus, an analysis is required for detailed examination of external hydrodynamics loading on the pipeline.

The input graphics model of CAESAR II facilitates intuitive pipe stress analysis modeling. CAESAR II stress analysis shows piping system flexibility, plus any areas of concern. Pipe stress analysis results, in the form of displacements, loads and stresses, are compared with international piping standards and piping codes [8].

1.3 Objective and Scope of Study

Objectives:

1. To model pipeline and perform the stress analysis using pipe stress analysis interface, CAESAR II.
2. To study the stress distribution of underwater pipeline laying on irregular seabed geometry under ocean current loads and also verifies the design code compliance.

Scope of study:

The scope of this project encompasses all the necessary activities to understand, assess and analyze subsea pipeline stress distribution. The beginning phase of the project includes an extensive research effort. This research begins with the knowledge and experience of engineers from oil and gas industry and also study through recent journals.

The focal point of this project is the simulation of pipe model using CAESAR II that focuses on the pipe stress analysis subjected to the pipeline. For economic reasons, the material that will be used for the fabrication of pipelines (for production and transmission of oil and gas) is carbon steels (API 5L X65). The area of seabed investigated is Malay Basin which is located on the north-west of peninsula Malaysia. Water depth is approximately 100-300 m. The piping code used for the pipeline analysis is ASME B31.3. The subsea pipeline coverage is from the riser that is attached to the processing unit (CPP) to the wellhead platform (WHP). The length for the pipe spool is 20 feet.

CHAPTER 2: LITERATURE REVIEW

Prior to engineering works, the seabed must be thoroughly surveyed along the entire pipeline route to map seabed topography and identify potential obstacles. This is to avoid free spans and seabed peaks and troughs. Uneven topographic conditions mean that the rigid pipelines cannot always be in direct contact with the seabed. Based on some research, the author hasn’t found any study on stress analysis of pipeline particularly for irregular seabed topography. Most previous investigations have only concerned either on the seabed topography alone or the pipeline stress analysis alone. Recent study by F.P. Gao, D.S. Jeng and H. Sekiguchi focus on the wave-seabed pipeline interaction problem. In this study, a proposed finite element model is adopted to investigate the interaction between nonlinear ocean waves, a buried pipelines and a porous seabed. The numerical results indicate the importance to the effect of pipeline on the seabed response [9].

2.1 Submarine Pipeline

Pipelines are used for a number of purposes in the development of offshore hydrocarbon resources [10]. These include export (transportation) of pipelines, flowlines to transfer product from a platform to export lines, water injection or chemical injection flowlines, flowlines to transfer product between platforms, subsea manifolds and satellite wells and pipeline bundles

Mechanical design of underwater pipeline usually requires consideration of several factors. The internal pressure is due to contained fluid. If the generated stress in the pipe wall is too large, the pipeline will yield circumferentially and continued yielding will lead to thinning of pipe wall and rupture. There is also external pressure which is due to the hydrostatic and hydrodynamics effect on the pipeline. Pipeline stability depends on the geometry of the seabed and types of sand. A pipeline laid on uneven seabed does not usually conform to seabed profile but instead forms free span. Expansion stress arises from difference between pipeline operating temperature and installation temperature [11].

Pipeline routing is a major factor that can directly influence cost and feasibility of a pipeline project. For example, this may impact technical considerations such as excessive water depth or the presence of geohazards, or geopolitical reasons such as national boundaries. Furthermore, these factors generally become more pronounced when pipeline routes traverse continental slopes to the abyssal or deep ocean depths [12].

2.2 Pipeline Support and Stability Analysis

Submarine pipeline are usually just laid above or under the seabed. There are basically no pipe supports used for underwater pipelines. Some only used anchor as fixed support and others used rock dumping to ensure the pipelines are in-place. To cater for thermal expansion and hydrodynamics forces (process related), bends are sometimes intentionally introduced.

Figure 2: Secondary stabilization – concrete mattresses [13]

Pipelines resting on the seabed are subjected to fluid loading from both waves and steady currents. For regions of the seabed where damage may result from vertical or lateral movement of the pipeline it is a design requirement that the pipe weight is sufficient to ensure stability under the worst possible environmental conditions. In some circumstances, the pipeline may be allowed to move laterally provided stress (or strain) limits are not exceeded. [10]

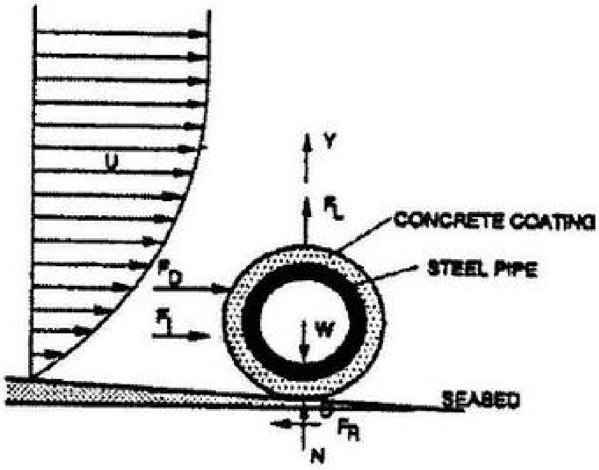


Figure 3: Free body diagram of pipeline for on-bottom stability analysis [10]

Pipeline stability analyses require the calculation of hydrodynamic loads acting on the pipeline for various shore crossing configurations. Hydrodynamic stability analyses are performed on shallow water pipelines and may include a limit state design approach in which the pipeline-soil interaction during pipeline movement and subsequent pipeline embedment is included. Optimization of concrete weight coating and discrete anchoring stabilization techniques versus trenching requirements must be performed. Pipeline stability analyses are required to ensure pipeline design; construction and installation processes are suitable for the anticipated environmental and operational conditions. Evaluation of near shore soil conditions, seasonal coastal processes and shoreline erosion/accretion processes are also often considered in the stability analyses [12].

The loads acting on the pipeline due to wave and current action are; the fluctuating drag, lift and inertia forces. In a design situation a factor of safety is required by most pipeline codes, the components of hydrodynamics forces are shown below:

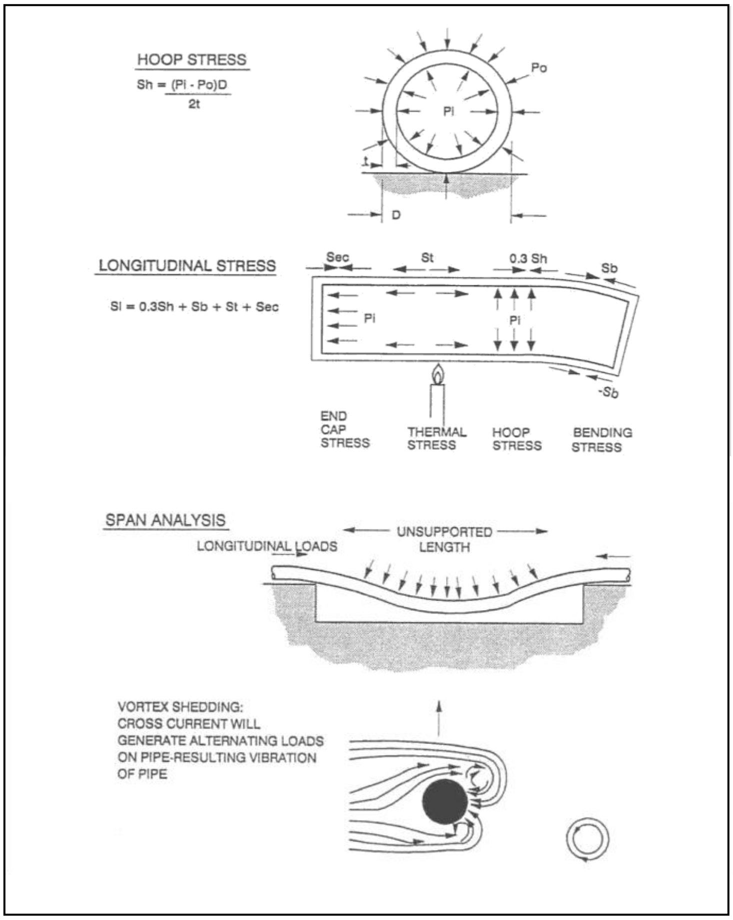


Figure 4: Flowline stresses and vortex shedding [10]

2.3 Pipeline Stress Analysis

Pipeline stress analysis is performed to determine if the pipeline stresses are acceptable (in accordance with requirements) during pipeline installation, testing and operation. The analysis performed to verify that stresses experienced are acceptable includes [10]:

- Hoop stress
- Longitudinal stress
- Span Analysis
- Stability analysis
- Expansion and buckling analysis

Pipelines do not always rest continuously in contact with the seabed. There may be spans where pipeline bridges across low points in profile. Spans can give rise to various structural problems and may need to be corrected [14].

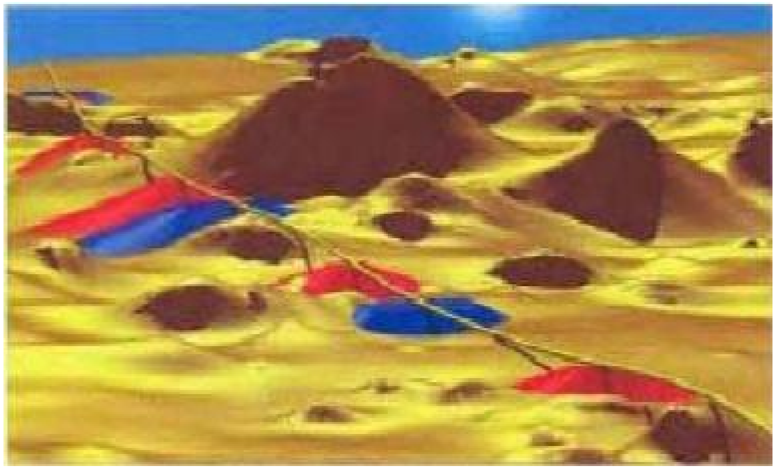


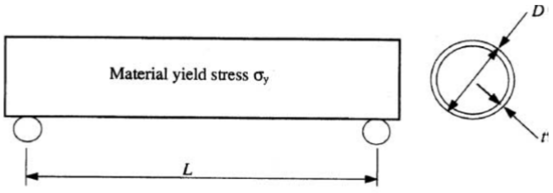
Figure 5: Free spanning pipeline on seabed [14]

The numerical simulation of unilaterally constrained structural systems is receiving increased attention, mainly due to the fact that direct solutions to the problem are unattainable. Maier and Andreuzzi [15] and Chuang and Smith [16] adopted quadratic programming for the determination of pipeline configurations bounded by a rigid seabed of irregular geometry.

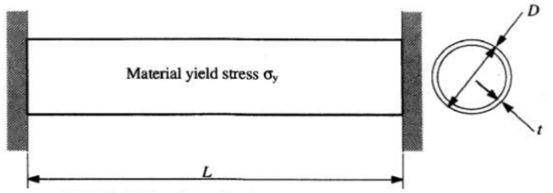
According to C.Kalliontzia, E. Andrianis, K. Spyropoulos and S. Doikas [17], the mathematical treatment of pressurized submarine pipelines, which are freely laid on sea floors, poses a considerable problem since the contact points are not known a *priori*. The geometrical irregularities of the assumed frictionless seabed profile, which may either be rigid or deformable, influence to a large extent the bending stress distribution along the pipeline.

Research has been carried out in the past, aimed mainly at providing solutions regarding the accurate prediction of pipeline configurations resting freely on seabeds. The use of a reliable FE model for design predictions could allow the engineer to study material and structural behaviors, especially in the remote regions of the structure where physical observation or measurement is not possible [18].

Preliminary tests have been carried out by Oliver [18] on simply supported (SS) and rigidly clamped pipes under quasi-static and impact loading conditions using rigid patch and wedge indentors.



(a) Simply supported pipe



(b) Rigidly fixed pipe

Figure 6: Longitudinal and cross-sectional view of steel tubes [18]

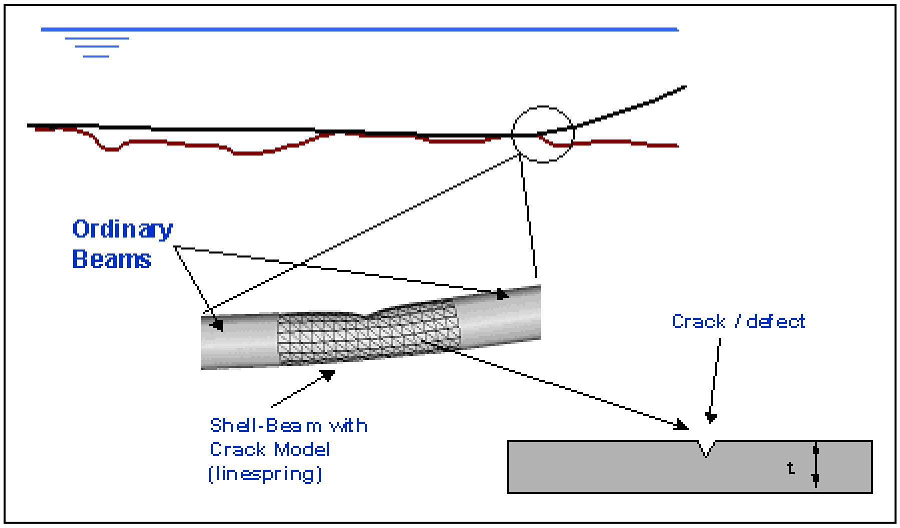


Figure 7: Result of free span analysis [19]

2.4 Seabed Topography Analysis

Technology today has developed numbers of software to investigate the condition of the seabed geometry and geotechnics. One of the infamous software used by the oil and gas company is SIMLA. SIMLA is a software used for pipeline laying and in-place analysis program. [20]

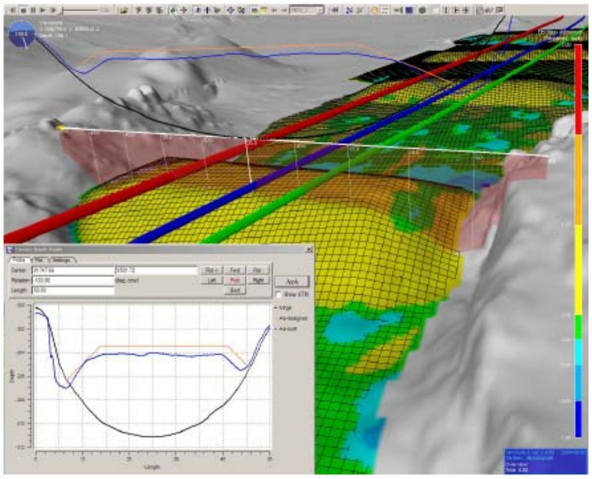


Figure 8: SIMLA with SimVis: Planning of pipe routes, trenching and rock dumping [20]

Alam M.R. and Mei C.C. [21] estimate the impact of long-period internal waves on gas pipelines. They study on the evolution of internal solitary waves and the effect of harmonic-generation in time-periodic waves travelling over random topography.

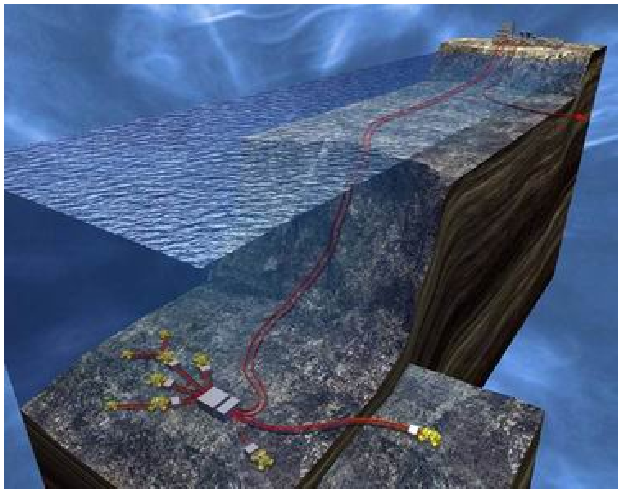


Figure 9: Underwater pipeline [21]

The irregular seabed profile is seen on the continental slope; a steep slope where the mild slope continental shelf reaches ultra deep waters as seen in figure 10. Figure 11 shows visualizations of a rough seabed topography and subsea pipeline of the Ormen Lange field (Norway) passing a rough seabed [14].

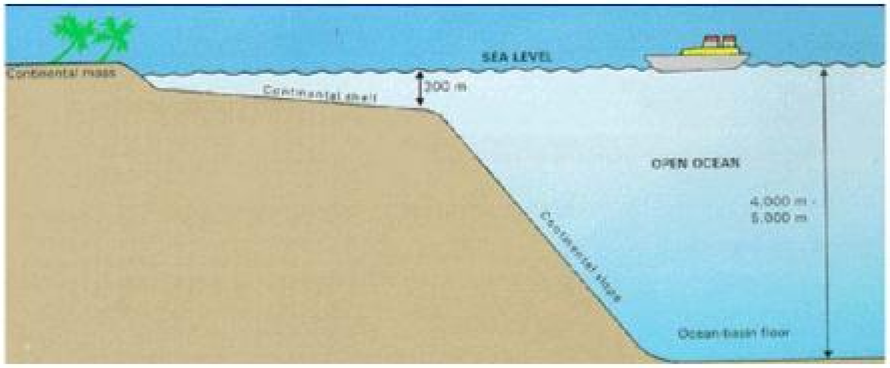


Figure 10: Continental shelf and continental slope [14]

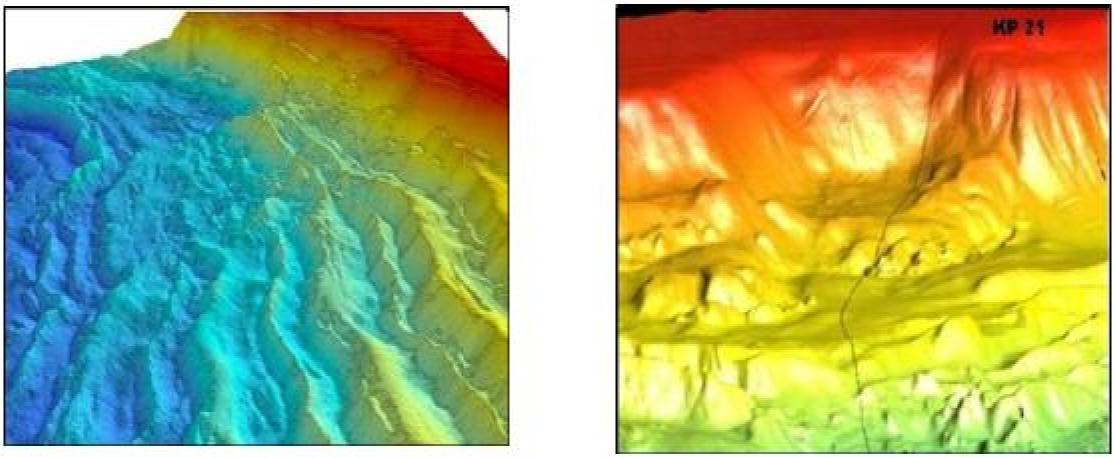


Figure 11: Subsea pipelines on rough seabed, Ormen Lange field, Norway [14]

2.5 Pressure Design of Pipeline [22]

2.5.1 Thin Wall Approximation

Consider a straight section of pipe filled with a pressurized liquid or gas. The internal pressure generates three principal stresses in the pipe wall: as illustrated in Figure 14: a hoop stress σ_r. When the ratio of the pipe diameter to its wall thickness D/t is greater than 20 the pipe may be considered to thin wall. In this case, the hoop stress is nearly constant through the wall thickness and equal to

$$\sigma_h = \frac{PD}{2t}$$

P = Design pressure, Psi
D = Outside pipe diameter, in
t = Pipe wall thickness, in

The longitudinal stress is also constant through the wall and equal to half the hoop stress

$$\sigma_l = \frac{PD}{4t}$$

The radial stress varies through the wall, from P at the inner surface of the pipe to zero on the outer surface.

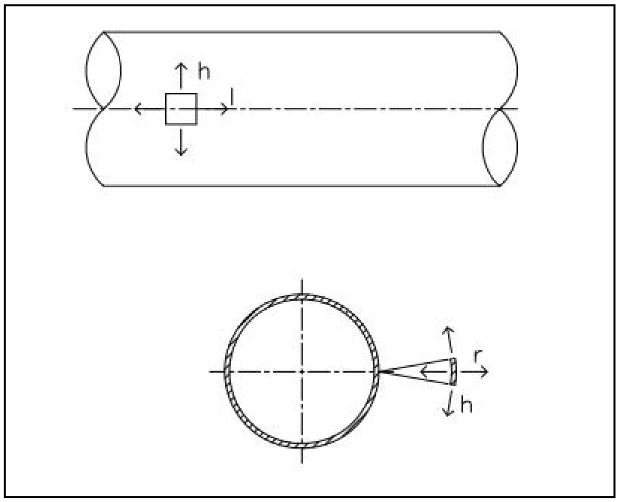


Figure 12: Hoop (h), Longitudinal (l) and Radial (r) Stress Directions

2.5.2 Pipeline design equation

For oil and gas pipelines, the thickness of the pipe wall is obtained by writing that the hoop stress, which is the largest stress in the pipe, must be limited to a certain allowable stress S. Using the thin wall approximation, this condition corresponds to

$$\frac{PD}{2t} < S$$

P = Internal design pressure, psi
D = Pipe outer diamenter, in
t = Pipe wall thickness, in
S = Allowable stress, psi

For hazardous liquid pipelines (hydrocarbon, carbon dioxide, etc.) the allowable stress is set at [ASME B31.4]:

$$S = 0.72\ S_Y E$$

0.72 = Design factor
E = Longitudinal weld joint factor, Table 1
S_y = Specified minimum yield strength,psi, Table 2

For gas pipelines, the allowable stress is [ASME B31.8]:

$$S = S_Y F E T$$

P = Design pressure, psi
D = Nominal outside diameter, in
S_Y = Specified minimum yield stress,psi, Table 2 (commonly referred to as SMYS in the pipeline industry)
F = Design factor, Table 3

E = Weld joint factor, Table 1

T = Temperature derating factor, Table 4

Table 1: Examples of Longitudinal Weld Joint Factors E [ASME B31.8]

Material	Pipe Class	E
ASTM A 53,A106	Seamless	1.0
ASTM A 53	ERW	1.0
ASTM A 53	Furnace Butt Welded	0.6
ASTM A 134	Electric Fusion Arc Welded	0.8
ASTM A 135	Electric Resistance Welded (ERW)	1.0
API 5L	Seamless	1.0
API 5L	Submerged Arc Welded or ERW	1.0
API 5L	Furnace Butt Welded	0.6

Table 2: Examples of Yield and Ultimate Stress [ASME II Part D]

Temperature (°F)	A 106 Gr.B S_Y (ksi)	A 106 Gr.B S_u (ksi)	A 312 T.304 S_Y (ksi)	A 312 T.304 S_Y (ksi)
100	35.0	60	30.0	75.0
200	31.9	60	25.0	71.0
300	31.0	60	22.5	66.0
400	30.0	60	20.7	64.4
500	28.3	60	19.4	63.5

Table 3: Location Design Factor F [ASME B31.8]

Location	**F**
Class 1 Div.1: Deserts, farm land, sparsely populated, etc	0.8
Class 1 Div.2: Class 1, with line tested to 110% design	0.72
Class 2: Industrial areas, town fringes, ranch, etc.	0.6
Class 3: Suburban housing, shipping centers, etc.	0.5
Class 4: Multistory buildings, heavy traffic, etc.	0.4

Note : Lowe location design factors apply at crossing, compressor station, etc. The pipeline designer must refer to codes and regulations for the applicable location design factor.

Table 4: Temperature Derating Factor [B31.8]

Temperature (ºF)	**T**
250 or less	1.0
300	0.967
350	0.933
400	0.9
450	0.867

2.5.3 Lame's formula

Without the thin wall approximation, the more general form of the three principal stresses in a closed cylinder subject to internal pressure P is given by Lame's formula.

$$\sigma_t = P\frac{r_i^2}{r_0^2 - r_i^2}\left(1 + \frac{r_0^2}{r^2}\right)$$

$$\sigma_r = P\frac{r_i^2}{r_0^2 - r_i^2}\left(1 - \frac{r_0^2}{r^2}\right)$$

$$\sigma_l = P\frac{r_i^2}{r_0^2 - r_i^2}$$

σ_t = Tangential (hoop) stress, psi

σ_r = Radial stress, psi

σ_l = Longitudinal (axial) stress, psi

r_i = Inner pipe radius, in

r_0 = Outer pipe radius, in

r = Radial distance of a point in the pipe wall, in

2.5.4 Allowable stress

The allowable stress for pipelines is 72% S_y and does not depend on the material's ultimate strength. The allowable stress for power and process plant piping systems is

$$S(T) = \min.\ \{ S_Y(T) / SF_Y ;\ S_U(T) / SF_U \}$$

S(T) = Allowable stress at design temperature T, psi

SF_y = Safety factor applied to yield stress

SF_u = Safety factor applied to ultimate strength

S_y (T) = Minimum specified yield stress at design temperature T,psi

S_u(T) = Minimum specified ultimate strength at design temperature T, psi

For carbon steel pipe in ASME B31.3 applications;

$$\mathbf{S(T) = min.\{2\ S_Y\ (T\ )\ /\ 3;S_U\ (T\ )\ /\ 3\}}$$

Where the values of yield stress S_y or ultimate strength S_u at design temperature are larger than at room temperature, the room temperature values are used. Some values of allowable stress are listed in Table 5.

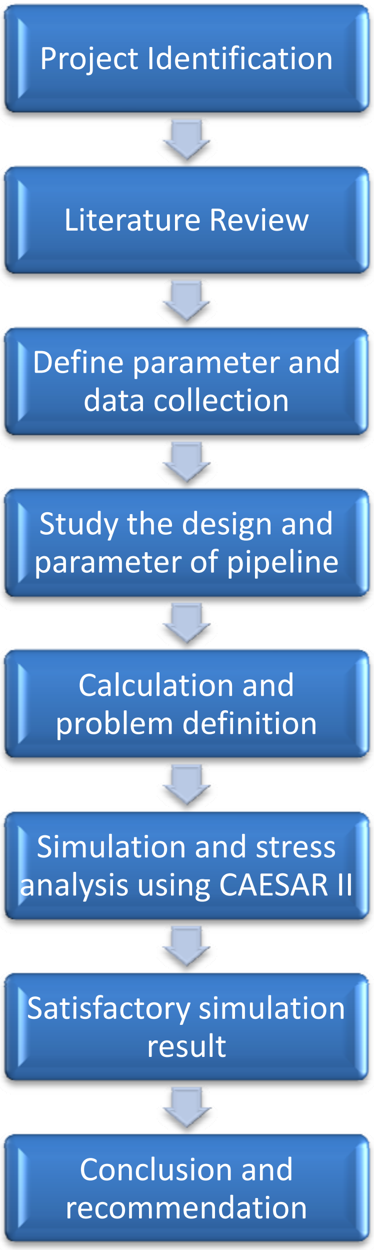
Table 5: ASME B31.3 Allowable Stress

Material	100ºF	200ºF	300ºF	400ºF	500ºF
A 106 Gr.B	20.0	20.0	20.0	20.0	18.9
API 5L X52	22.0	22.0	22.0	22.0	-
A 312 Type 304	20.0	20.0	20.0	18.7	17.5
B 241 6061 T6	12.7	12.7	10.6	5.6	-

CHAPTER 3: METHODOLOGY

3.1 Project Flow Process

The author had read some journals and articles to enhance the understanding on irregular seabed topography and also stress analysis imposed on pipelines. In order to complete the project according to the given time frame, the author had planned on the project flow process as follows:



3.2 Material Selection

Generally, carbon steels are used for subsea pipelines. API-5L “Specification for Line Pipe” (2000) is used for standard specifications. API-5L covers Grade B to Grade X80 steels with Outside Diameter (OD) ranging from 4.5 to 80 inch. Table 1 shows tensile strength properties according to API-5L. Generally the most common steel grade used for deepwater subsea pipelines is X65, regarding its cost-effectiveness and adequate welding technology [14]. Thus, for this project, pipe material used is API 5L X65.

Table 6: Tensile strength properties (API 5L, 2000) [14]

Grade	Yield Strength Min. (Psi)	Yield Strength Max. (Psi)	Ultimate Tensile Strength Min. (Psi)	Ultimate Tensile Strength Max. (Psi)	Elongation in 2 in. min. (%)
B	35,000	65,000	60,000	110,000	a
X42	42,000	72,000	60,000	110,000	a
X46	46,000	76,000	63,000	110,000	a
X52	52,000	77,000	66,000	110,000	a
X56	56,000	79,000	71,000	110,000	a
X60	60,000	82,000	75,000	110,000	a
X65	65,000	87,000	77,000	110,000	a
X70	70,000	90,000	82,000	110,000	a
X80	80,000	100,000	90,000	120,000	a

The minimum elongation in 2 in. (50.8 mm) shall be that determined by the following equation:

U.S. Customary Unit Equation

$$e = 625{,}000\,\frac{A^{0.2}}{U^{0.9}}$$

SI Unit Equation

$$e = 1{,}944 \frac{A^{0.2}}{U^{0.9}}$$

where;

e = minimum elongation in 2 in. (50.8 mm) in percent rounded to the nearest percent.

A = applicable tensile test specimen area, as follows:

a. For both sizes of round bar specimens, 0.20 in.^{2} (130 mm^2);
b. For full section specimens, the smaller of (i) 0.75 in.^{2} (485 mm^2) and (ii) the cross-sectional area of the test specimen, calculated using specified outside diameter of the pipe and the specified wall thickness of the pipe, rounded to the nearest 0.01 in.^{2} (10 mm^2); and
c. For strip specimens, the smaller of (i) 0.75 in.^{2} (485 mm^2) and (ii) the cross-sectional area of the test specimen, calculated using the specified width of the test specimen and the specified wall thickness of the pipe, rounded to the nearest 0.01 in.^{2} (10 mm^2).

U = specified minimum ultimate tensile strength in Psi (Mpa).

By using higher grade steels, the required wall thickness is reduced. Therefore, the cost of pipeline per meter is slightly reduced. Higher grade steels result in a lighter pipeline, thus the tension is lower. This factor is very important in deep waters, where required tension can be a limiting factor.

3.3 Line Pipe Specification

Table 2 below shows the physical information regarding the pipe geometry, steel material strength and all other information required to define the necessary input for stress analysis.

Table 7: Pipeline specifications

Line Pipe Diameter = 10" (DN 250)	**Parameter values**
Pipe Inside diameter ID, DN 250	230.19 mm
Pipe Structural wall thickness, DN 250	21.43 mm
Pipe Outside diameter, OD	273.05 mm
Yield Strength	448 MPa
Tensile Strength	500 – 750 MPa
Allowable Stress	25,700 Psi
Elasticity modulus	2.95E7 Psi
Poisson's Ratio	0.292

3.4 Design Condition

Design Pressure, P1 = 120 bar(g)

Hydrotest Pressure, HP = 150 bar(g)

Max. Design Temperature, T1 = 82 ºC

Min. Design Temperature, T2 = 5 ºC

Installation temperature, $T_{ambient}$ = 21 ºC

Fluid Density = 790 Kg/m^3

Drag coefficient, C_D = 0.7

Added mass coefficient, C_a = 0.85

Lift coefficient, C_l = 0.9

3.5 Load Cases

The pipeline system is analyzed for various load cases listed below, in accordance with the Pipeline Design Code DEP 31.40.10.19/ISO 14692/ASME B 31.3

Table 8: Load cases

Load Case	Description	Case Type	Remarks
1	WNC	SUS	Dead weight of installed system
2	W	SUS	Dead weight of installed system with content
3	WW	SUS	Dead weight of installed system with water filled
4	W+P1	SUS	Sustain condition at design pressure without thermal effect
5	W+T1+P1	OPE	Sustain condition at design pressure & design temperature with thermal effect
6	W+T2+P1	OPE	Sustain condition at design pressure & minimum design temperature with thermal effect
7	WW+HP	HYD	Hydrotest condition
8	L8=L5-L4	EXP	Expansion due to maximum design temperature T1
9	L9=L6-L4	EXP	Expansion due to minimum design temperature T2

Legend:

WW	Pipeline filled with water
W	Pipeline with fluid weight
WNC	Pipeline with no contents
P1	Design pressure of the pipeline
HP	Hydrotest pressure
T1	Design temperature of the pipeline (buried/aboveground)
T2	Minimum design temperature (buried/aboveground)

3.6 Applicable Codes, Standards and Specifications

Following codes and standards, with the requirements in these design criteria, shall form the basis for stress analysis. The International System of units (SI) shall be used for all unit measurement.

Code and Standard:

ASME B31.3	: Process piping
API 5L	: Specification for Line Pipes

3.7 Steps of the Analysis

Figure below shows the step by step procedures to complete the analysis from starting point until the end where all the results are generated.

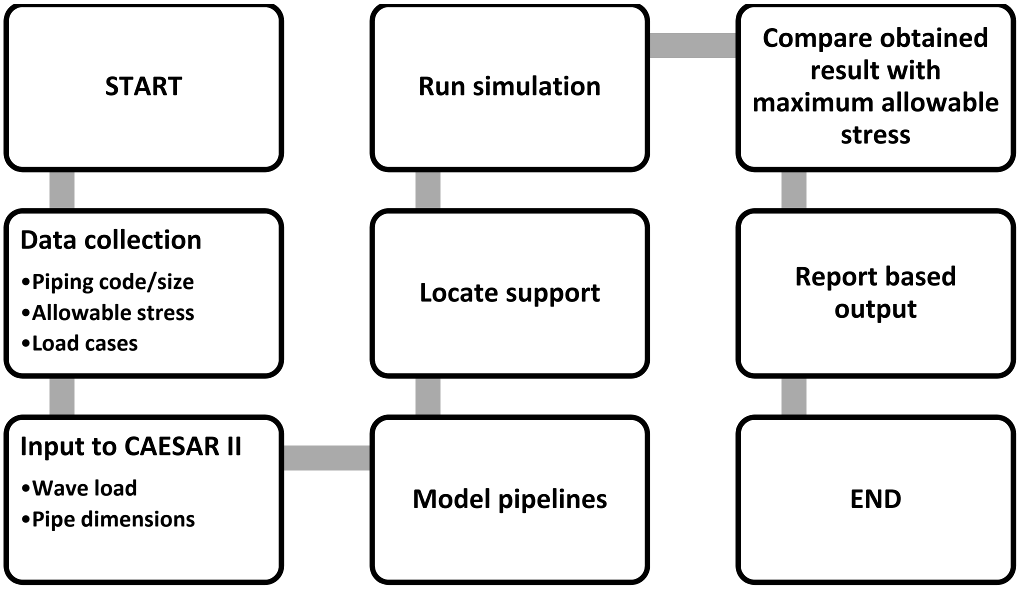


Figure 13: Analysis steps

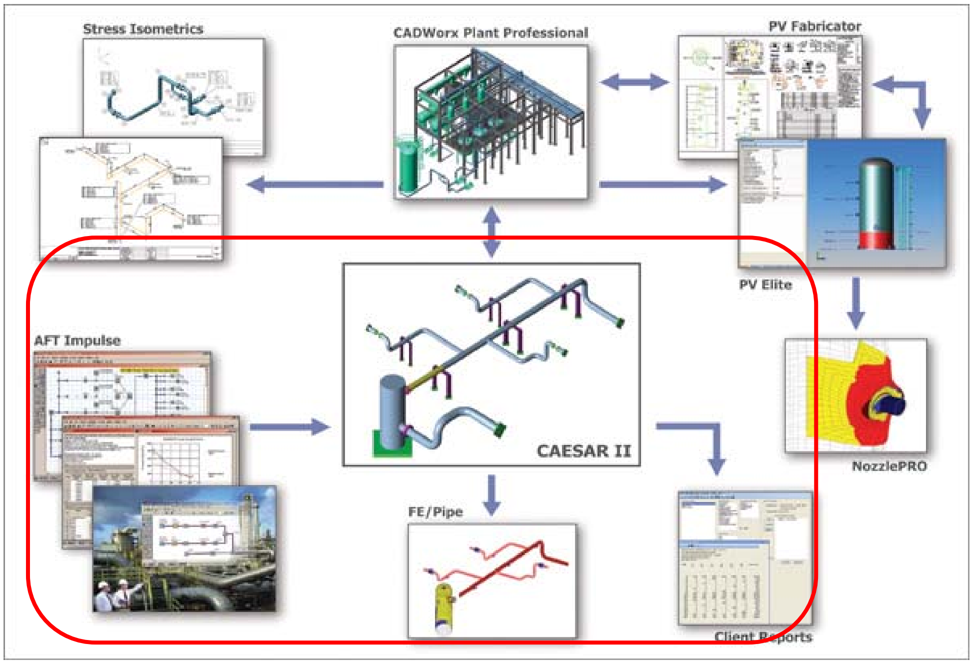


Figure 14: CAESAR II workflow

3.8 Project Gantt Chart

Table 9: FYP 1 Gantt Chart

No	**Detail/Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Selection of Project Topic	■	■						Mid-semester break							
2	Project Identification and Planning		■	■												
3	Preliminary Research Work		■	■	■	■	■									
4	Submission of Preliminary Report						●									
5	Project Work:						■	■		■	■					
	- Further research and study						■	■								
	- Literature review							■		■						
6	Seminar (compulsory)										●					
7	Project work continues:										■	■	■	■	■	■
	- Defining project constraints and criteria to be evaluated										■	■	■	■		
	- Developing the analysis technique												■	■	■	■
9	Submission of Draft Report														●	
10	Submission of Final Report															●

● Milestone

■ Process

Table 10: FYP 2 Gantt Chart

No	**Detail/Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
11	Project Work Continues	▨	▨	▨	▨	▨	▨	▨	Mid-semester break								
	• Data gathering for analysis	▨	▨	▨	▨												
	• Start pipeline modelling				▨	▨	▨	▨									
	• Verifying results						▨	▨									
12	Submission of Progress Report									●							
13	Project Work Continues:									▨	▨	▨	▨	▨			
	• Results of analysis										▨	▨	▨				
14	Pre-EDX												●				
15	Submission of Draft Report													●			
16	Submission of Dissertation (Soft Bound)														●		
17	Submission of Technical Paper														●		
18	Oral Presentation															●	
19	Submission of Project Dissertation (Hard Bound)																●

● Milestone

▨ Process

CHAPTER 4: RESULT AND DISCUSSION

4.1 Stress Analysis Result

The stresses, displacements, forces and moments for the system analyzed are found to be within code allowable limits. The maximum stresses (refer Appendix A) and maximum displacement from the analysis results are tabulated below.

4.2 Maximum Stresses

(a) Table 11: Hydro Test Load Case

LOAD CASES:	NODE NO	CALCULATED STRESS (PSI)	ALLOWABLE STRESS (PSI)	STRESS RATIO (%)
CASE 7 (HYD) WW+HP	120	12959.4	27500	47.1

During hydro test, the stress of the pipeline is subjected up to 12959.4 Psi at node 120. Hydrostatic testing is used to determine and verify pipeline integrity. Generally, pipelines are hydrotested by filling the test section of pipe with water and pumping the pressure up to a value that is higher than maximum allowable operating pressure (MAOP).

(b) Table 12: Operating Load Case

LOAD CASES:	NODE NO	CALCULATED STRESS (PSI)	ALLOWABLE STRESS (PSI)	STRESS RATIO (%)
CASE 5 (OPE) W+T1+P1	120	13371.9	27500	48.62
CASE 6 (OPE) W+T2+P1	130	16701.6	27500	60.73

Compared to all the applied load cases on the underwater pipeline, operating load case 6 gives the maximum value of stress which 16701.6 Psi with stress ratio of 60.73 percent. Pipelines are loaded by operating conditions; basically, internal pressure and temperature. The stress distribution is at maximum during operation of the pipeline due to the increasing temperature. These lead to the expansion of the pipeline which later creates stress upon certain areas such as the joints.

(c) Table 13: Sustained Load Case

LOAD CASES:	NODE NO	CALCULATED STRESS (PSI)	ALLOWABLE STRESS (PSI)	STRESS RATIO (%)
CASE 1 (SUS) WNC	120	6155.5	27500	24
CASE 2 (SUS) W	120	7698.8	27500	30
CASE 3 (SUS) WW	120	8084.6	27500	31.5
CASE 4 (SUS) W+P1	120	12356.7	27500	48.1

Sustained loads consist of internal pressure and dead-weight. Dead weight is from the weight of pipes, fittings and components. Internal design or operating pressure causes uniform circumferential stresses in the pipe wall, based on which a pipe thickness is determined. Additionally, internal pressure gives rise to axial stresses in the pipe wall. A pipe's dead-weight causes it to bend between supports and nozzles, producing axial stresses in the pipe wall. In the stress analysis, node 120 gives the highest value of stress for all sustained load cases. Case 4 is the highest amongst other that reads stress of 12356.7 Psi with ratio nearly 50 %.

(d) Table 14: Expansion Load Case

LOAD CASES:	NODE NO	CALCULATED STRESS (PSI)	ALLOWABLE STRESS (PSI)	STRESS RATIO (%)
CASE 8 (EXP) L8=L5-L4	9050	3046.4	55262.9	5.5
CASE 9 (EXP) L9=L6-L4	9050	758.9	55262.9	1.4

Expansion loads refer to the cyclic thermal expansion and contraction of pipe. When the pipeline is restrained in the directions it thermally deforms, such constraint on free thermal deformation generates cyclic thermal stress range, the system is susceptible to failure by fatigue. To avoid fatigue failure, pipeline system should be made flexible. Table shows the least pipe stress generated at support node 9050.

4.3 Maximum displacement

Table 15: Maximum displacement

LOAD CASES:	NODE NO	DX mm	DY mm	DZ mm
CASE 1 (OPE) WNC	28	0.0035	0.0426	0.0000
CASE 1 (OPE) W+T1+P1	150	0.0636	-0.0000	1.5788
CASE 1 (OPE) W+T1+P1	190	0.7282	-0.7663	5.6254

Subsea pipeline are loaded by internal pressure, by longitudinal displacement restrictions caused by support or soil interaction and by temperature differential. Above table represents random selection of nodes with maximum displacement. The displacements are higher during operations (refer Appendix B).

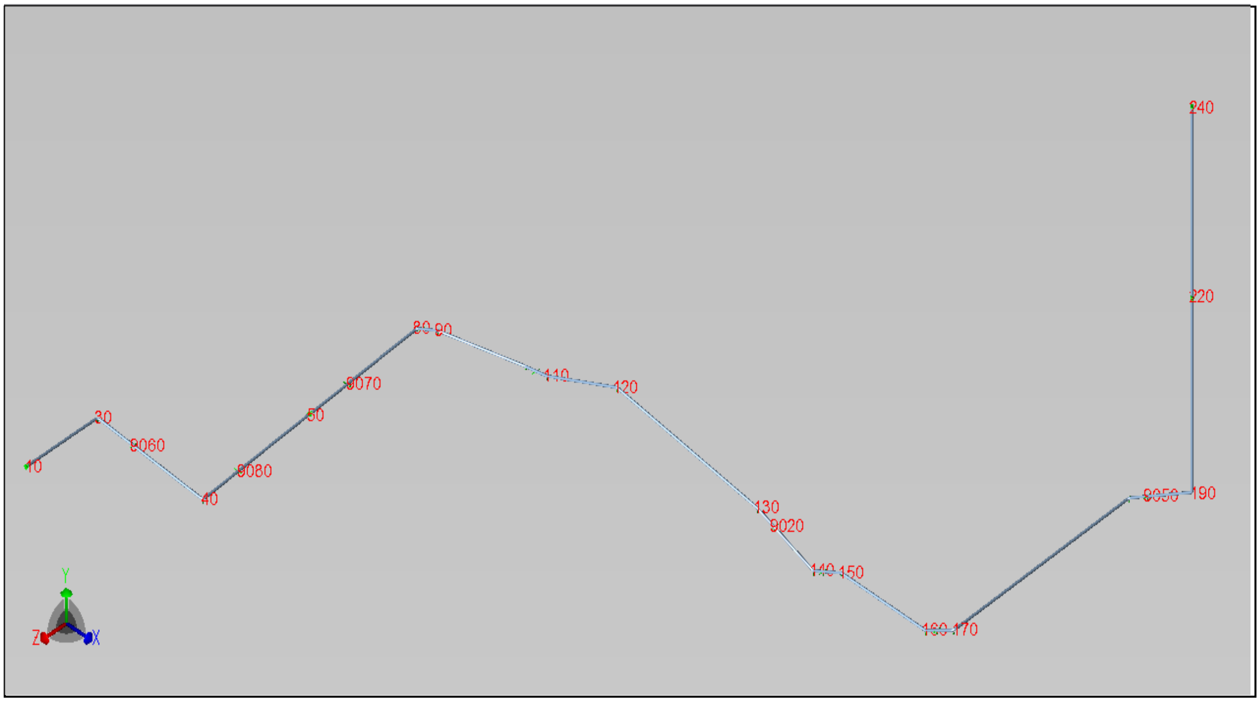


Figure 15: Pipeline routing using CAESAR II (with node numbers)

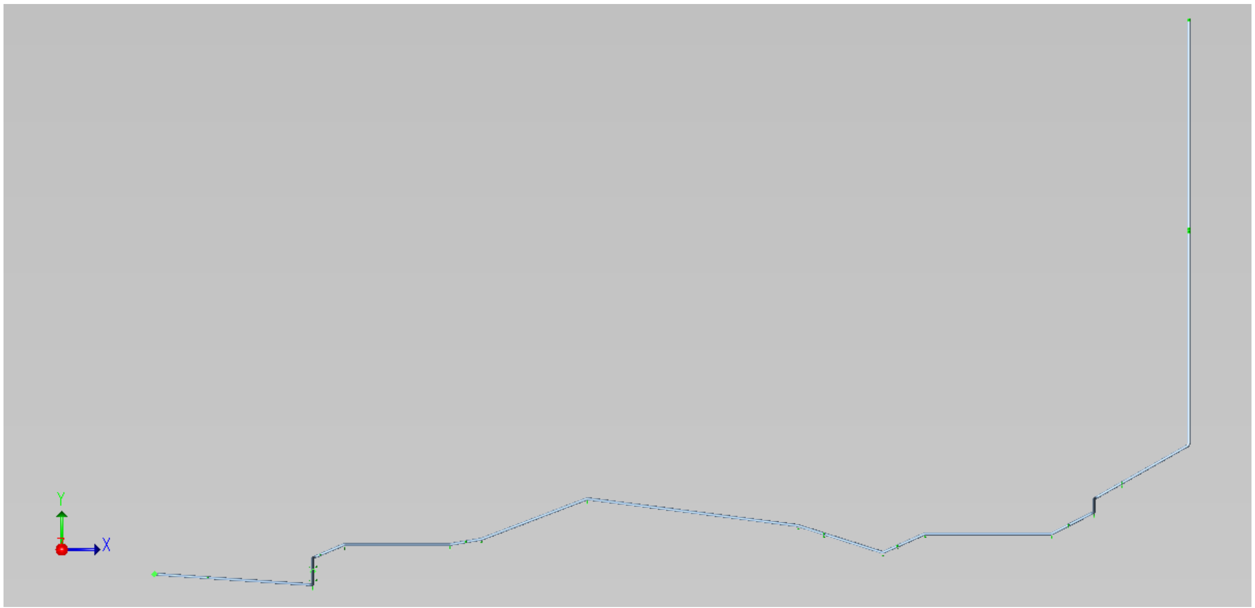
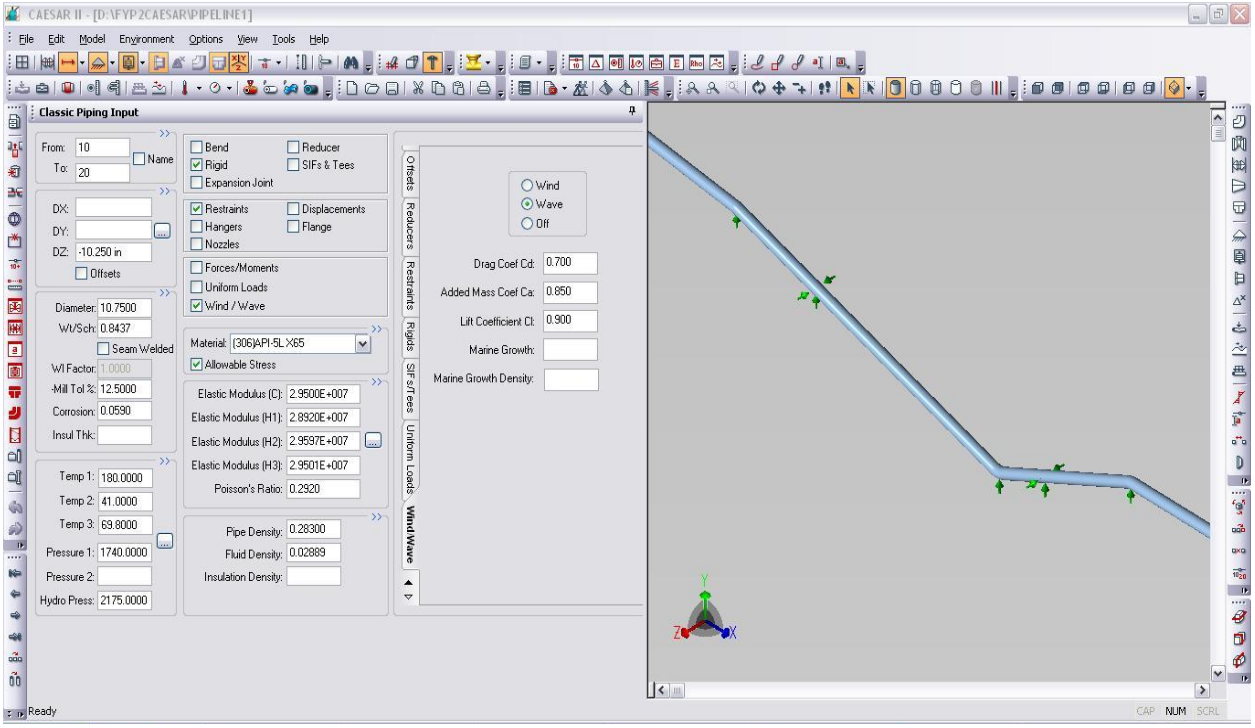


Figure 16: Front view of the pipeline routing



CAESAR II - [D:\FYP2CAESAR\PIPELINE1]

Classic Piping Input

From: 10
To: 20
☐ Name
DX:
DY:
DZ: -10.250 in
☐ Offsets
Diameter: 10.7500
Wt/Sch: 0.8437
☐ Seam Welded
WI Factor: 1.0000
-Mill Tol %: 12.5000
Corrosion: 0.0590
Insul Thk:
Temp 1: 180.0000
Temp 2: 41.0000
Temp 3: 69.8000
Pressure 1: 1740.0000
Pressure 2:
Hydro Press: 2175.0000

☐ Bend
☐ Reducer
☑ Rigid
☐ SIFs & Tees
☐ Expansion Joint
☑ Restraints
☐ Displacements
☐ Hangers
☐ Flange
☐ Nozzles
☐ Forces/Moments
☐ Uniform Loads
☑ Wind / Wave
Material: (306)API-5L X65
☑ Allowable Stress
Elastic Modulus (C): 2.9500E+007
Elastic Modulus (H1): 2.8920E+007
Elastic Modulus (H2): 2.9597E+007
Elastic Modulus (H3): 2.9501E+007
Poisson's Ratio: 0.2920
Pipe Density: 0.28300
Fluid Density: 0.02889
Insulation Density:

○ Wind
● Wave
○ Off
Drag Coef Cd: 0.700
Added Mass Coef Ca: 0.850
Lift Coefficient Cl: 0.900
Marine Growth:
Marine Growth Density:

Figure 17: CAESAR II interface of pipeline modeling

4.4 Seabed Topography Cases

There are three (3) cases of the seabed geometry and topography. Each of these cases concentrates on a specific loading scenario and has different type of free span.

4.4.1 Case 1:

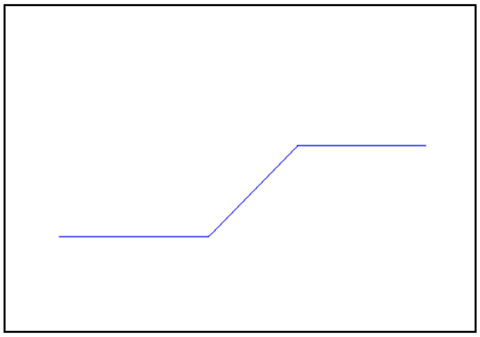


Figure 18: Slide-down shaped topography

Offshore oil and gas pipelines are being subjected to deeper water depths, more extreme environmental conditions and harsher operating requirements than ever before. Thus, free spanning pipelines are becoming more common and are often unavoidable during pipeline installation. For case 1, free spans are induced by elevated obstructions. Loads are more focused at node 80 (refer figure 19), hence the stress distribution is higher at that point of the pipeline. Fixed support which is an anchor and guide support is located along node 40 to 90 to sustain the pipe from buckling or fatigue failure.

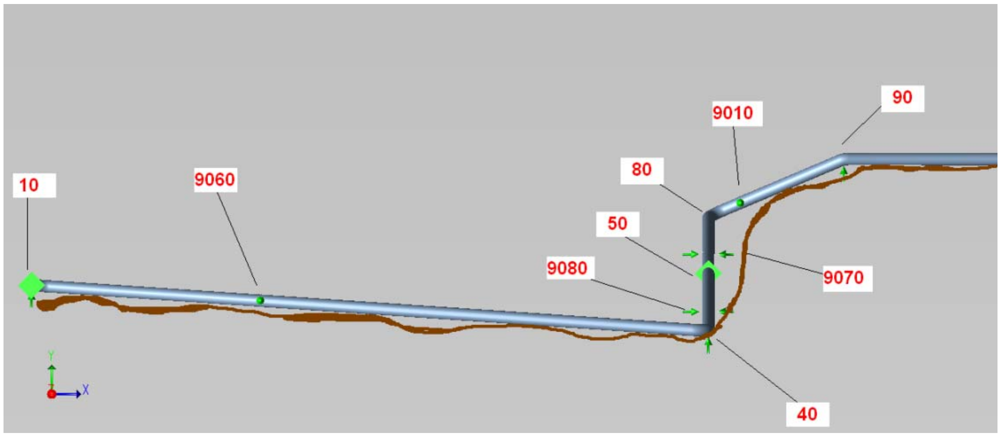


Figure 19: Slide-down shaped topography applied on the pipeline routing (Brown line indicates the seabed topography)

4.4.2 Case 2

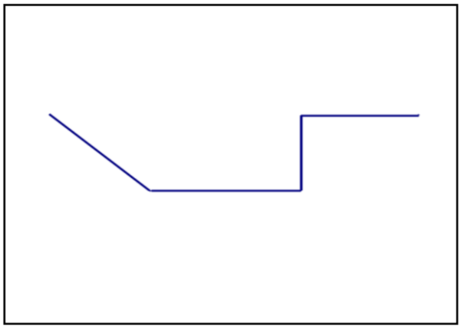


Figure 20: Stair-case shaped topography

Case 2 is basically the same conditions with case 1, only the stress distribution is higher at 90 degree shaped of seabed. This is due to the hanging pipeline in between the corner of the 90 degree seabed (refer figure 21). Without suitable type of support, the pipeline at the point may buckle and later will cause fatigue failure. Guide support is located in the middle between node 140 and node 150 to ensure the pipeline can withstand load subjected to it. Higher stress results were obtained at node 150 which means critical point of the pipeline.

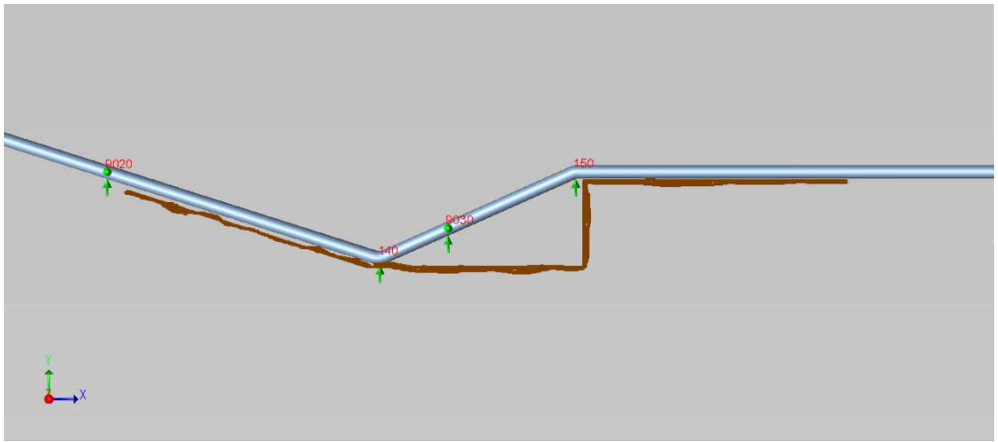


Figure 21: Stair-case shaped topography applied on the pipeline routing (Brown line indicates the seabed topography)

4.4.3 Case 3

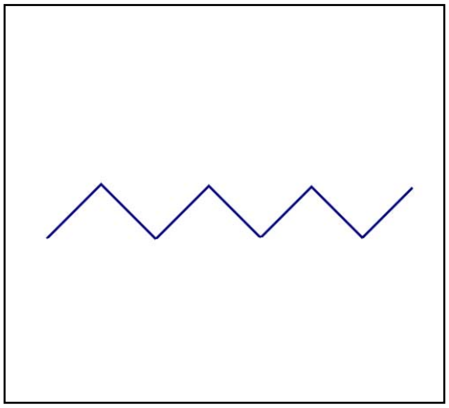


Figure 22: Wavy shaped topography

The gap between the pipeline and seafloor will affect the free stream velocity of the current passing around the free spanning pipe. This gap can also limit the amount of deflection that may occur due to static and dynamic loading. In general, as pipe tension increases, the maximum allowable span length increases. The stresses on the free span due to static loading are not affected significantly by the increase in pipe tension. For case 3, no support is located along node 150 to 160. The humps of the seabed in a way creates a +Y rest support to the pipeline. The stress distribution is stable along the pipeline due to uniform load subjected.

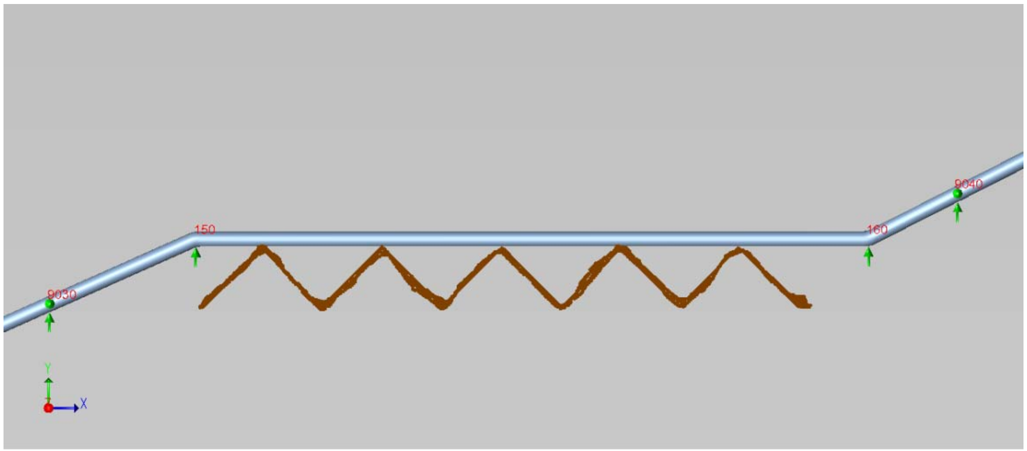
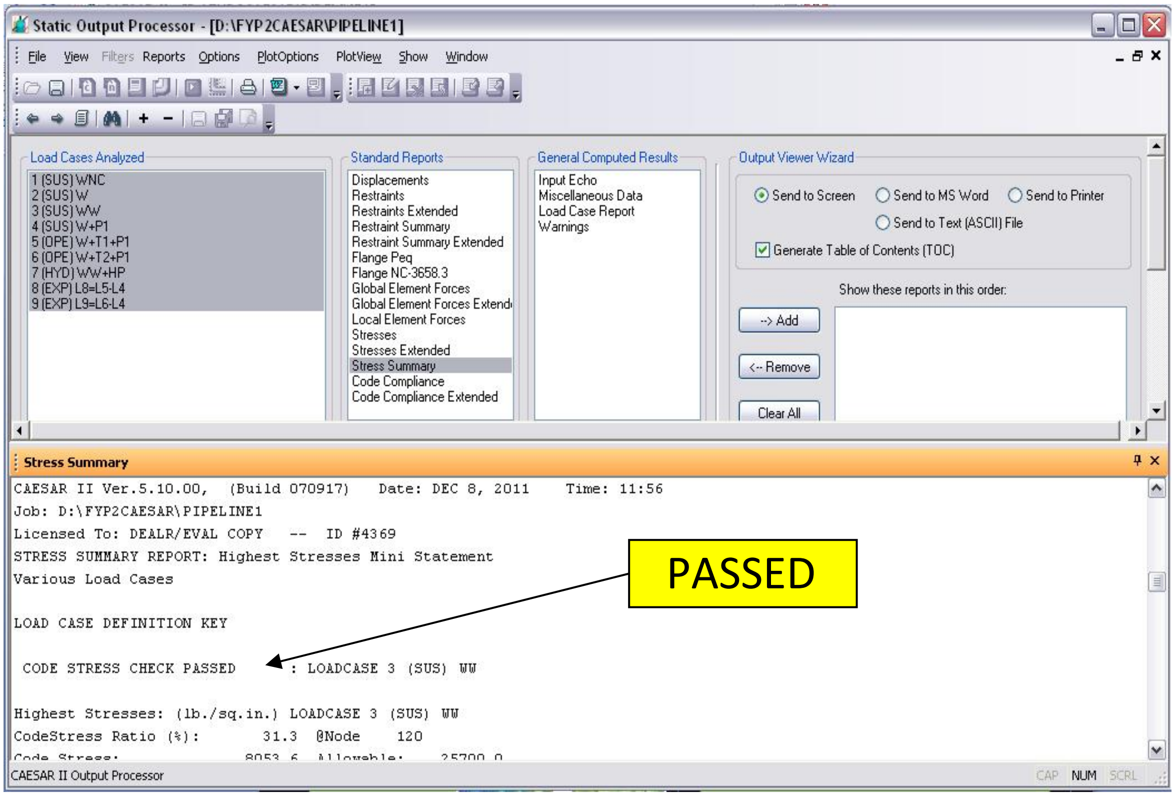


Figure 23: Wavy shaped topography applied on the pipeline routing (Brown line indicates the seabed topography

4.5 Stress Summary Result



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Job: D:\FYP2CAESAR\PIPELINE1
Licensed To: DEALR/EVAL COPY   --  ID #4369
STRESS SUMMARY REPORT: Highest Stresses Mini Statement
Various Load Cases

LOAD CASE DEFINITION KEY

 CODE STRESS CHECK PASSED       : LOADCASE 3 (SUS) WW

Highest Stresses: (lb./sq.in.) LOADCASE 3 (SUS) WW
CodeStress Ratio (%):       31.3  @Node    120
Code Stress:              8053.6  Allowable:    25700.0
```

Figure 24: Stress summary result

The pipeline met all the criteria and passed all the analysis. With suitable type of support attached to the pipeline, it can withstand the maximum possible load subjected. The material used for the pipeline has the best strength to make the lifetime of the pipeline last longer. Appendix A shows the maximum calculated stress for all load cases and appendix B shows the displacement of each node in the pipeline.

4.6 Support Location

The pipeline is laid on the seabed and fully constrained. There are one anchor block at the connecting point or tie in point between the pipeline and the riser. Only three types of supports that is used in this pipeline which are resting (+Y), guide with 3mm gap and limit stop. Support type and support location is listed in the table below and support shall be designed considering the loading.

Table 16: Support types

No.	Node	Type of support	Description
1	10	ANC	Anchored at flange (tie-in point)
2	30	+Y	Rest support
3	9060	Guide, Lim	Guide with 3mm gap and limit stop
4	40	+Y	Rest support
5	9080	+Y, guide	Rest support, guide with 3mm gap
6	9070	+Y, guide	Rest support, guide with 3mm gap
7	80	+Y	Rest support
8	9010	Guide	Guide with 3mm gap
9	90	+Y	Rest support
10	100	+Y	Rest support
11	9000	Guide	Guide with 3mm gap
12	110	+Y	Rest support
13	120	+Y, Lim	Rest support and limit stop
14	139	+Y, Lim	Rest support and limit stop
15	9020	+Y, Guide	Rest support, guide with 3mm gap
16	149	+Y	Rest support
17	9030	+Y, Guide	Rest support, guide with 3mm gap
18	150	+Y	Rest support
19	160	+Y	Rest support
20	9040	+Y, Guide	Rest support, guide with 3mm gap
21	170	+Y	Rest support

22	180	+Y, Lim	Rest support and limit stop
23	9050	+Y, Guide	Rest support, guide with 3mm gap

4.7 Distances between Nodes

Table 17: Distance between nodes

Node from	Node to	Distance (m)
10	30	10
30	9060	5
9060	40	15
40	9080	5
9080	50	10
70	9070	5
9070	80	10
80	9010	1
9010	90	2
90	100	10
100	9000	1.25
9000	110	1.25
110	120	10
120	130	20
130	9020	2
9020	140	6
140	9030	1.5
9030	150	2.5
150	160	12
160	170	4
170	180	20
180	190	9
190	240	40

CHAPTER 5: CONCLUSION

This report has covered the pipeline modeling and performed pipe stress analysis. Analytical solutions were developed using pipe stress analysis software, CAESAR II version 5.10 to generate stress distributions along the underwater pipeline of 250mm diameter. The design code compliance was verified for the subsea pipeline laying on irregular seabed geometry under ocean current loads.

It is concluded from the stress analysis result that the system is within design envelope and stress are acceptable under operating/design conditions. With the recommended support system, stresses are kept low within code allowable limits. The pipe stress analysis of underwater pipeline with DN250 has successfully been analyzed using CAESAR II. The X65 Carbon Steel pipeline has maximum strength that is able to withstand the highest value of current load.

The maximum allowable stress along the pipeline was calculated to be 27500 Psi. The maximum stress on the pipeline were up to 16701.6 Psi located at node 130 with 60.73 % stress ratio. While, the maximum displacement can be seen at node 9030 (refer appendix B of page B11) of 3 inches in +Z direction, 0.0129 inches in +Y direction and 0.2797 inches and +X direction. Node 9030 is a means of guide support. It is not laid on the seabed due to the gap of free spanning (refer case 2). All of the nodes have higher displacements during load case 5 and 6 which is the operating conditions compared to other load cases.

The stress analysis result was compared using manual template calculation to validate the value. This result should only be used as a guide in determining the most practical and reasonable maximum allowable stress for a given case.

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```
LISTING OF STATIC LOAD CASES FOR THIS ANALYSIS


1 (SUS) WNC
2 (SUS) W
3 (SUS) WW
4 (SUS) W+P1
5 (OPE) W+T1+P1
6 (OPE) W+T2+P1
7 (HYD) WW+HP
8 (EXP) L8=L5-L4
9 (EXP) L9=L6-L4
```

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STRESS SUMMARY REPORT: Highest Stresses Mini Statement
Various Load Cases


LOAD CASE DEFINITION KEY

CASE 1 (SUS) WNC
CASE 2 (SUS) W
CASE 3 (SUS) WW
CASE 4 (SUS) W+P1
CASE 5 (OPE) W+T1+P1
CASE 6 (OPE) W+T2+P1
CASE 7 (HYD) WW+HP
CASE 8 (EXP) L8=L5-L4
CASE 9 (EXP) L9=L6-L4


Piping Code: B31.3      = B31.3 -2006, May 31, 2007


 CODE STRESS CHECK PASSED      : LOADCASE 1 (SUS) WNC

Highest Stresses: (lb./sq.in.) LOADCASE 1 (SUS) WNC
CodeStress Ratio (%):       24.0  @Node    120
Code Stress:              6155.5  Allowable:    25700.0
Axial Stress:              286.2  @Node    200
Bending Stress:           6143.2  @Node    120
Torsion Stress:           1851.6  @Node    180
Hoop Stress:                 0.0  @Node     20
3D Max Intensity:         6239.1  @Node    120

 CODE STRESS CHECK PASSED      : LOADCASE 2 (SUS) W

Highest Stresses: (lb./sq.in.) LOADCASE 2 (SUS) W
CodeStress Ratio (%):       30.0  @Node    120
Code Stress:              7698.8  Allowable:    25700.0
Axial Stress:              358.0  @Node    200
Bending Stress:           7683.5  @Node    120
Torsion Stress:           2315.9  @Node    180
Hoop Stress:                 0.0  @Node     20
3D Max Intensity:         7803.7  @Node    120

 CODE STRESS CHECK PASSED      : LOADCASE 3 (SUS) WW

Highest Stresses: (lb./sq.in.) LOADCASE 3 (SUS) WW
CodeStress Ratio (%):       31.5  @Node    120
Code Stress:              8084.6  Allowable:    25700.0
Axial Stress:              375.9  @Node    200
Bending Stress:           8068.5  @Node    120
Torsion Stress:           2431.9  @Node    180
Hoop Stress:                 0.0  @Node     20
3D Max Intensity:         8194.8  @Node    120

 CODE STRESS CHECK PASSED      : LOADCASE 4 (SUS) W+P1

Highest Stresses: (lb./sq.in.) LOADCASE 4 (SUS) W+P1
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Licensed To: DEALR/EVAL COPY -- ID #4369

STRESS SUMMARY REPORT: Highest Stresses Mini Statement
Various Load Cases

```
CodeStress Ratio (%):       48.1  @Node    120
Code Stress:             12356.7  Allowable:    25700.0
Axial Stress:             5046.5  @Node    200
Bending Stress:           7683.5  @Node    120
Torsion Stress:           2315.9  @Node    180
Hoop Stress:             10178.6  @Node     28
3D Max Intensity:        14269.8  @Node    180

 NO CODE STRESS CHECK PROCESSED: LOADCASE 5 (OPE) W+T1+P1

Highest Stresses: (lb./sq.in.) LOADCASE 5 (OPE) W+T1+P1
OPE Stress Ratio (%):        0.0  @Node    120
OPE  Stress:             13371.9  Allowable:        0.0
Axial Stress:             4571.5  @Node    200
Bending Stress:           9037.3  @Node    120
Torsion Stress:           2206.3  @Node    180
Hoop Stress:              9345.1  @Node     28
3D Max Intensity:        14761.2  @Node    120

 NO CODE STRESS CHECK PROCESSED: LOADCASE 6 (OPE) W+T2+P1

Highest Stresses: (lb./sq.in.) LOADCASE 6 (OPE) W+T2+P1
OPE Stress Ratio (%):        0.0  @Node    130
OPE  Stress:             16701.6  Allowable:        0.0
Axial Stress:             9393.4  @Node    120
Bending Stress:           7378.4  @Node    120
Torsion Stress:           2187.1  @Node    180
Hoop Stress:              9345.1  @Node     28
3D Max Intensity:        18320.2  @Node    130

 NO CODE STRESS CHECK PROCESSED: LOADCASE 7 (HYD) WW+HP

Highest Stresses: (lb./sq.in.) LOADCASE 7 (HYD) WW+HP
CodeStress Ratio (%):        0.0  @Node    120
Code Stress:             12959.4  Allowable:        0.0
Axial Stress:             5695.0  @Node    200
Bending Stress:           7631.2  @Node    120
Torsion Stress:           2300.1  @Node    180
Hoop Stress:             11681.4  @Node     28
3D Max Intensity:        16083.4  @Node    180

 CODE STRESS CHECK PASSED      : LOADCASE 8 (EXP) L8=L5-L4

Highest Stresses: (lb./sq.in.) LOADCASE 8 (EXP) L8=L5-L4
CodeStress Ratio (%):        5.5  @Node   9050
Code Stress:              3046.4  Allowable:    55262.9
Axial Stress:              516.2  @Node    128
Bending Stress:           3046.3  @Node   9050
Torsion Stress:            184.4  @Node     80
Hoop Stress:                 0.0  @Node     20
3D Max Intensity:         3257.9  @Node   9050
```

CAESAR II Ver.5.10.00, (Build 070917) Date: DEC 29, 2011 Time: 10:53
Job: D:\FYP2CAESAR\PIPELINE1
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STRESS SUMMARY REPORT: Highest Stresses Mini Statement
Various Load Cases

```
 CODE STRESS CHECK PASSED      : LOADCASE 9 (EXP) L9=L6-L4

Highest Stresses: (lb./sq.in.) LOADCASE 9 (EXP) L9=L6-L4
CodeStress Ratio (%):        1.4  @Node   9050
Code Stress:               758.9  Allowable:    55262.9
Axial Stress:             5133.5  @Node    128
Bending Stress:            758.9  @Node   9050
Torsion Stress:             26.2  @Node    168
Hoop Stress:                 0.0  @Node     20
3D Max Intensity:         5765.9  @Node    130
```

```
LISTING OF STATIC LOAD CASES FOR THIS ANALYSIS


1 (SUS) WNC
2 (SUS) W
3 (SUS) WW
4 (SUS) W+P1
5 (OPE) W+T1+P1
6 (OPE) W+T2+P1
7 (HYD) WW+HP
8 (EXP) L8=L5-L4
9 (EXP) L9=L6-L4
```

CAESAR II Ver.5.10.00, (Build 070917) Date: DEC 28, 2011 Time: 10:53
Job: D:\FYP2CAESAR\PIPELINE1
Licensed To: DEALR/EVAL COPY -- ID #4369

DISPLACEMENTS REPORT: Nodal Movements
CASE 5 (OPE) W+T1+P1

NODE	DX in.	DY in.	DZ in.	RX deg.	RY deg.	RZ deg.
10	-0.0000	-0.0000	0.0000	-0.0000	0.0000	-0.0000
20	-0.0000	-0.0000	-0.0071	-0.0002	0.0000	-0.0001
28	-0.1270	0.0523	-0.2708	0.0836	0.0290	-0.2668
29	-0.1307	0.0468	-0.2809	0.0824	0.0291	-0.2766
30	-0.1291	-0.0000	-0.2903	0.0793	0.0292	-0.2934
38	0.2559	-0.1039	-0.6550	0.0558	0.0403	0.3421
39	0.2622	-0.0363	-0.6660	0.0544	0.0415	0.3401
40	0.2540	-0.0000	-0.6761	0.0489	0.0425	0.3362
50	-0.4521	-0.6018	-1.1306	0.1140	0.0474	0.1777
60	-0.4605	-0.5814	-1.1377	0.1142	0.0474	0.1777
61	-0.4605	-0.5814	-1.1377	0.1142	0.0474	0.1777
70	-0.4690	-0.5610	-1.1449	0.1144	0.0474	0.1777
78	-0.8662	0.0004	-1.5014	-0.0211	0.0081	0.0155
79	-0.8652	-0.0015	-1.5101	-0.0306	0.0048	0.0098
80	-0.8593	-0.0000	-1.5163	-0.0386	0.0030	0.0006
88	-0.7778	0.0043	-1.5564	-0.0945	-0.0138	-0.0295
89	-0.7749	0.0029	-1.5575	-0.0964	-0.0143	-0.0324
90	-0.7722	-0.0000	-1.5577	-0.0985	-0.0150	-0.0357
98	-0.4429	-0.0065	-1.3936	-0.2237	-0.0525	0.1114
99	-0.4411	-0.0038	-1.3923	-0.2251	-0.0530	0.1090
100	-0.4400	-0.0000	-1.3914	-0.2264	-0.0533	0.1064
108	-0.3936	0.2097	-1.3603	-0.2900	-0.0651	0.1059
109	-0.3932	0.2126	-1.3603	-0.2908	-0.0652	0.1071
110	-0.3930	0.2155	-1.3610	-0.2916	-0.0652	0.1083
118	-0.4127	1.0814	-1.8101	-0.5188	-0.1088	-0.1060
119	-0.4084	1.0747	-1.8113	-0.5209	-0.1088	-0.1324
120	-0.4059	1.0654	-1.8041	-0.5230	-0.1092	-0.1596
128	-0.0033	-0.0066	1.0245	-0.9615	-0.1085	0.1560
129	-0.0018	-0.0031	1.0309	-0.9622	-0.1086	0.1495
130	0.0000	-0.0000	1.0393	-0.9630	-0.1087	0.1430
138	0.2366	0.0005	3.3662	-1.1375	-0.0880	-0.0062
139	0.2403	-0.0005	3.3879	-1.1405	-0.0878	-0.0049
140	0.2440	-0.0000	3.3706	-1.1437	-0.0867	-0.0038
148	0.3661	0.0058	2.2215	-1.2292	-0.0858	-0.0557
149	0.3692	0.0034	2.2052	-1.2312	-0.0848	-0.0631
150	0.3717	-0.0000	2.2027	-1.2330	-0.0842	-0.0708
158	0.6960	-0.0172	2.7200	-1.4919	-0.0369	0.1361
159	0.6975	-0.0086	2.7115	-1.4939	-0.0355	0.1349
160	0.6969	-0.0000	2.6818	-1.4963	-0.0338	0.1334
168	0.6317	0.3719	0.8193	-1.5786	-0.0161	0.1321
169	0.6277	0.2785	0.6825	-1.5886	-0.0096	0.1294
170	0.6261	-0.0000	0.6073	-1.6021	-0.0044	0.1267
178	-1.9952	-0.3466	-0.0770	1.3538	0.3843	0.0339
179	-2.0651	-0.1024	-0.0494	1.3006	0.4044	0.0265
180	-2.0914	-0.0000	-0.0000	1.2527	0.4312	0.0123
188	-1.4795	-0.5409	0.0029	0.3659	0.3951	-0.1640
189	-1.4599	-0.5530	-0.0019	0.3407	0.3995	-0.1632
190	-1.4369	-0.5535	0.0264	0.3049	0.4004	-0.1627

CAESAR II Ver.5.10.00, (Build 070917) Date: DEC 28, 2011 Time: 10:53
Job: D:\FYP2CAESAR\PIPELINE1
Licensed To: DEALR/EVAL COPY -- ID #4369

DISPLACEMENTS REPORT: Nodal Movements
CASE 5 (OPE) W+T1+P1

NODE	DX in.	DY in.	DZ in.	RX deg.	RY deg.	RZ deg.
200	-0.0000	-0.0071	0.0000	-0.0001	0.0001	-0.0001
210	-0.0000	-0.0000	0.0000	-0.0000	0.0000	-0.0000
220	0.0000	0.0071	-0.0000	-0.0000	0.0000	-0.0000
230	0.0000	0.5371	-0.0000	-0.0000	0.0000	-0.0000
240	0.0000	0.5443	-0.0000	-0.0000	0.0000	-0.0000
9000	-0.4168	0.1039	-1.3762	-0.2580	-0.0593	0.0949
9010	-0.8491	0.0037	-1.5212	-0.0465	0.0006	-0.0042
9020	0.1011	0.0910	1.7289	-1.0165	-0.1032	0.0149
9030	0.2797	0.0129	3.0000	-1.1719	-0.0867	-0.0040
9040	0.6699	0.1552	1.9187	-1.5306	-0.0268	0.1292
9050	-2.0070	-0.0000	0.2930	0.9871	0.4602	-0.0740
9060	-0.0606	-0.8949	-0.4017	0.0714	0.0302	-0.1887
9070	-0.6641	-0.0000	-1.2372	0.1031	0.0386	0.1220
9080	0.0213	-0.0000	-0.8053	-0.0999	0.0487	0.2858

DISPLACEMENTS REPORT: Nodal Movements
CASE 6 (OPE) W+T2+P1

NODE	DX in.	DY in.	DZ in.	RX deg.	RY deg.	RZ deg.
10	0.0000	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000
20	0.0000	-0.0000	0.0018	-0.0002	-0.0000	-0.0001
28	0.0374	0.0519	0.0677	0.0841	-0.0093	-0.2694
29	0.0370	0.0466	0.0699	0.0830	-0.0094	-0.2792
30	0.0323	-0.0000	0.0713	0.0800	-0.0094	-0.2961
38	-0.0728	-0.1039	0.1671	0.0597	-0.0226	0.3389
39	-0.0708	-0.0363	0.1718	0.0583	-0.0238	0.3370
40	-0.0706	-0.0000	0.1761	0.0528	-0.0251	0.3331
50	0.0214	-0.5982	0.2264	0.1180	-0.0326	0.1818
60	0.0272	-0.5771	0.2282	0.1182	-0.0326	0.1817
61	0.0272	-0.5771	0.2282	0.1182	-0.0326	0.1817
70	0.0330	-0.5559	0.2300	0.1184	-0.0326	0.1817
78	0.1981	-0.0014	0.3779	-0.0087	-0.0141	0.0323
79	0.1985	-0.0019	0.3801	-0.0162	-0.0130	0.0277
80	0.1960	-0.0000	0.3812	-0.0233	-0.0108	0.0198
88	0.1740	0.0027	0.3653	-0.0659	-0.0091	-0.0090
89	0.1736	0.0016	0.3647	-0.0676	-0.0084	-0.0120
90	0.1732	-0.0000	0.3649	-0.0694	-0.0079	-0.0152
98	0.1062	-0.0012	0.3841	-0.1720	0.0063	0.0421
99	0.1057	-0.0009	0.3836	-0.1737	0.0065	0.0372
100	0.1051	-0.0000	0.3825	-0.1752	0.0068	0.0323
108	0.0841	0.0026	0.2979	-0.2412	0.0073	-0.0060
109	0.0839	0.0024	0.2964	-0.2421	0.0075	-0.0056
110	0.0837	0.0022	0.2943	-0.2431	0.0078	-0.0052
118	-0.0011	0.0219	-0.6442	-0.4720	-0.0054	-0.1517
119	0.0007	0.0117	-0.6511	-0.4742	-0.0050	-0.1732
120	0.0000	-0.0000	-0.6507	-0.4763	-0.0050	-0.1953
128	-0.0023	-0.0105	0.6274	-0.9202	-0.0108	0.2284
129	-0.0014	-0.0052	0.6314	-0.9210	-0.0111	0.2209
130	-0.0000	-0.0000	0.6373	-0.9219	-0.0114	0.2130
138	-0.0127	0.1453	2.4401	-1.1019	-0.0173	-0.0322
139	-0.0140	0.1424	2.4548	-1.1051	-0.0185	-0.0321
140	-0.0142	0.1393	2.4320	-1.1084	-0.0187	-0.0322
148	0.0124	0.0095	1.1684	-1.1999	-0.0382	-0.0814
149	0.0133	0.0050	1.1502	-1.2018	-0.0383	-0.0880
150	0.0133	-0.0000	1.1454	-1.2036	-0.0387	-0.0948
158	-0.0677	-0.0182	1.6133	-1.4698	-0.0786	0.1557
159	-0.0694	-0.0087	1.6075	-1.4718	-0.0792	0.1551
160	-0.0733	-0.0000	1.5809	-1.4739	-0.0794	0.1542
168	-0.2913	0.3683	-0.0925	-1.5617	-0.1050	0.1567
169	-0.2984	0.2758	-0.2092	-1.5704	-0.1058	0.1529
170	-0.2862	-0.0000	-0.2680	-1.5837	-0.1083	0.1491
178	-0.2045	-0.3343	-0.1183	1.3298	0.2327	0.0389
179	-0.2509	-0.0965	-0.0733	1.2742	0.2577	0.0316
180	-0.2747	-0.0000	-0.0000	1.2238	0.2894	0.0174
188	-0.4237	0.1283	0.5300	0.3160	0.3044	0.0503
189	-0.4291	0.1319	0.5292	0.2896	0.3105	0.0413
190	-0.4342	0.1319	0.5538	0.2528	0.3126	0.0314
200	-0.0000	0.0018	0.0000	-0.0001	0.0001	-0.0001

DISPLACEMENTS REPORT: Nodal Movements
CASE 6 (OPE) W+T2+P1

NODE	DX in.	DY in.	DZ in.	RX deg.	RY deg.	RZ deg.
210	-0.0000	-0.0000	0.0000	-0.0000	0.0000	-0.0000
220	0.0000	-0.0018	-0.0000	-0.0000	0.0000	-0.0000
230	0.0000	-0.1393	-0.0000	-0.0000	0.0000	-0.0000
240	0.0000	-0.1411	-0.0000	-0.0000	0.0000	-0.0000
9000	0.0931	0.0103	0.3433	-0.2081	0.0071	-0.0012
9010	0.1916	0.0033	0.3811	-0.0293	-0.0105	0.0154
9020	0.0439	0.1948	1.1514	-0.9766	-0.0126	0.0418
9030	-0.0102	0.1069	2.0184	-1.1389	-0.0250	-0.0351
9040	-0.1637	0.1524	0.8850	-1.5108	-0.0900	0.1532
9050	-0.2958	-0.0000	0.4762	0.9506	0.3357	0.0029
9060	-0.0606	-0.8941	0.0882	0.0735	-0.0118	-0.1921
9070	0.0953	-0.0000	0.3119	0.1044	-0.0290	0.1298
9080	-0.0650	-0.0000	0.2084	-0.0953	-0.0302	0.2844

APPENDIX C: Maximum allowable pressure and temperature ratings

Maximum Allowable Pressure *(kPa)*											
Nominal Size *(mm)*	Schedule no.		Wall Thickness *(mm)*	Temperature (^{o}C)							
				-29 - 38	205	260	350	370	400	430[1]	450
				Maximum Allowable Stress *(kPa)*							
				137800	137800	130221	117130	115752	89570	74412	59943
250		20	6.35	5698	5698	5388	4844	4789	3707	3080	2480
		30	7.8	7028	7028	6642	5974	5905	4568	3796	3059
	STD	40	9.27	8385	8385	7923	7131	7048	5450	4527	3652
	XS	60	12.7	11596	11596	10955	9853	9736	7538	6263	5043
		80	15.09	13863	13863	13098	11781	11644	9012	7483	6028
		100	18.26	16922	16922	15992	14386	14214	10996	9136	7359
		120	21.44	20036	20036	18934	17032	16825	13022	10817	8716
	XXS	140	25.4	23998	23998	16474	20394	20153	15599	12960	10438
		160	28.58	27229	27229	25734	23143	22875	17700	14703	11844

APPENDIX D: The density of some common liquids can be found in the table below:

Liquid	Temperature - t - (^oC)	Density - ρ - (kg/m^3)
Crude oil, 48^o API	60^{o}F	790
Crude oil, 40^o API	60^{o}F	825
Crude oil, 35.6^o API	60^{o}F	847
Crude oil, 32.6^o API	60^{o}F	862
Crude oil,alifornia	60^{o}F	915
Crude oil, Mexican	60^{o}F	973
Crude oil, Texas	60^{o}F	873
Diesel fuel oil 20 to 60	15	820 - 950
Fuel oil	60^{o}F	890
Gasoline, natural	60^{o}F	711
Gasoline, Vehicle	60^{o}F	737
Gas oils	60^{o}F	890
Kerosene	60^{o}F	820.1
Oil of resin	20	940
Oil of turpentine	20	870

Liquid	Temperature - *t* - *(°C)*	Density - *ρ* - *(kg/m³)*
Petroleum Ether	20	640
Petrol, natural	60°F	711
Petrol, Vehicle	60°F	737
Sea water	25	1025
Sodium Hydroxide (caustic soda)	15	1250
Water - pure	4	1000

1 kg/m^3 = 0.001 g/cm^3 = 0.0005780 oz/in^3 = 0.16036 oz/gal (Imperial) = 0.1335 oz/gal (U.S.) = 0.0624 lb/ft^3 = 0.000036127 lb/in^3 = 1.6856 lb/yd^3 = 0.010022 lb/gal (Imperial) = 0.008345 lb/gal (U.S) = 0.0007525 ton/yd^3