ALLOWABLE CORRODED PIPE PRESSURE ESTIMATION DUE TO INTERNAL PRESSURE AND LONGITUDINAL COMPRESSIVE STRESS

By

MOHD AFIFIE BIN HILMI

DISSERTATION REPORT

Submitted to the Mechanical Engineering Programme
in Partial Fulfilment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Mechanical Engineering)

September 2011

Universiti Teknologi PETRONAS
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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

____

(Dr. Saravanan Karuppanan)

Universiti Teknologi PETRONAS
Tronoh
Perak Darul Ridzuan

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.

Mohd Afifie Bin Hilmi

ACKNOWLEDGEMENT

In the name of Allah, The Most Gracious, The Most Merciful. Praise to Allah S.W.T by whose grace and sanction I manage to complete Final Year Project within time.

I would like to acknowledge the advice and guidance of Dr. Saravanan Karuppanan, my supervisor. Thank for his suggestion and encouragement, without his knowledge and assistance this study would not have been successful. I appreciate his support.

I would also like to thank my family members, especially for supporting and encouraging me to pursue this degree. Last but not least, all of my friends that had given ideas and moral support to me to finish this study. Without all of these encouragements, I would not have finished the degree.

ABSTRACT

The pipeline is one of the important facilities in the oil and gas industry. It was being used to transport oil and gas from one facility to other facilities. So the integrity of the pipeline is the most important aspect that had to be considered in order to avoid the unnecessary loss during the production. Due to that, certain standard codes have been to determine the remaining strength of the corroded pipeline. In this project, the corroded pipe pressure estimation due to the internal pressure and longitudinal compressive stresses has been studied. The objective of this project is to estimate the allowable corroded pressure of the corroded pipe due to the internal pressure and the longitudinal compressive stress by using the finite element analysis software. The results obtained from the finite element analysis will be compared with the available codes in literature.

The scope of study covers the integrity of the corroded pipeline due to the internal pressure and longitudinal compressive stress based on the single corrosion defect. The assessment will be carried out using the ANSYS software by generating the 3D models. The compressive stress does influence the corroded pipe failure pressure estimation. When higher longitudinal compressive stress is applied to the corroded pipe, the strength of the pipe will be decreased.From ANSYS result, it can be concluded that the difference between corroded pressure estimation by standard code and FEA is about 4% to 80% for approach 1 while for approach 2 is about 10% to 70%. The percentage of erorr in approach 1 is higher compared to approach 2 because of the safety factors that were included in the equation. These safety factors will reduce the corroded pipe pressure estimation compared to the actual one.

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LIST OF ABBREVIATIONS

P_{corr} = Allowable corroded pipe pressure of a single longitudinal corrosion defect (N/mm^2)

P_{comb} = Allowable corroded pipe pressure (internal pressure and longitudinal compressive stress) of a single longitudinal corrosion defect (N/mm^2)

D = Nominal outside diameter (mm)

d = Depth of corroded region (mm)

L = Longitudinal length of corroded region (mm)

t = Pipe wall thickness (mm)

Q = Length correction factor

f_u = Tensile strength to be used in design

c = Width of corroded region

ε_d = Factor for defining a fractile value for the corrosion depth

γ_d = Partial safety factor for corrosion depth

γ_m = Partial safety factor for longitudinal corrosion model prediction

F = Total usage factor

F_1 = Modeling factor

F_2 = Operational usage factor

H_1 = Factor to account for compressive longitudinal stress

θ = Ratio of circumferential length of corroded region to the nominal outside circumference of the pipe

σ_L = Combined nominal longitudinal stress due to external applied loads (N/mm^2).

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Oil and gas transmission pipelines are very important facilities in the oil and gas industry. The challenges to keep these pipelines safe for a long time with minimum maintenance cost had been the main problem faced by all the oil and gas companies. As in the oil and gas industry, the pipelines are always subjected to the harmful effects of the surrounding environment. One of the most common problem occurred on the pipelines is the corrosion. The corrosion problem had been the most problematic event occurred on the pipelines. This is because the corrosion will reduce the thickness of the pipe thus reducing the strength of the pipe. Eventually the pipe will be leaking and the production will be at loss. Due to that, several standard codes have been developed such as ASME B31G, Modified B31G, RSTRENG, DNV RP-F-101 and PCORRC to determine the remaining strength of the corroded pipeline so that the unnecessary maintenance can be avoided and can save some operation cost. But, these codes had their own limitation in determining the strength of the corroded pipelines. For example some code can only be used to investigate the pipe integrity under internal pressure; other stresses are not taken into account and there also uncertainties associated with the sizing of the corrosion defect and the material properties during the calculation. The standard codes is said to be conservative because the estimation of corroded pressure is lower than the actual corroded pressure. So this project will focus on the maximum allowable pressure estimation for the corroded pipe due to the internal pressure and the longitudinal compressive stress. By using the 3D model finite element analysis (FEA), the integrity of the pipelines will be investigated.

1.2 Problem Statement

In the oil and gas industry, the pipelines had been used as the transportation mechanism for oil and gas from one facility to the other facilities. This is because of the reliability of the pipelines to transport the oil and gas is very good and can be considered the safest way available. But the corrosion problem in the pipelines can affect the pipelines safety aspect. The corroded pipelines can cause several incidents such as the pipeline leakage and this will bring the loss for the oil and gas companies. Furthermore, the corroded pipelines can reduce the pipe's strength and can cause the pipe cracking, local buckling and pipe bursting. The current solution is very conservative which may result in the premature replacement of the corroded pipe and it can be costly. So, the thorough assessment and understanding is required to reduce the conservatism involved in the current assessment method.

1.3 Objective

The objective of this project is to estimate the allowable corroded pressure of the corroded pipe due to the internal pressure and the longitudinal compressive stress by using the finite element analysis software. The second objective is to compare the results obtained from the finite element analysis with those available codes in literature.

.4 Scope of Study

n this project, the integrity of the corroded pipeline due to the internal pressure and longitudinal ompressive stress based on the single corrosion defect will be investigated. The DNV RP F101 ode will be used for the strength assessment of the corroded pipelines. This is because this code an be used to assess the corroded pipe pressure due to the internal pressure and the compressive tress. The 3D models of the pipelines will be developed by varying the depth of the defect from % of pipe's thickness up to the 70% of pipe's thickness. Besides that, the longitudinal ompressive stress of the pipe will also be varied from 0MPa until -300MPa. These 3D models vill be developed by using the ANSYS software and the simulation can be carried out to get the ressure estimation for the corroded pipeline. The results that were obtained through the imulation will be compared with the DNV RP F101 code so that the percentage of the accuracy etween these two methods can be calculated. The conservatism of the code can be determined hrough this work. For this project, the materials that will be used are the carbon steel pipe X52.

CHAPTER 2

LITERATURE REVIEW

2.1 Pipeline Integrity

In recent years, the pipeline failure due to the corrosion had been the major concern in the oil and gas industry. This is because the pipeline failure can cause major loss for the oil and gas companies. For example in the US, studies showed that the internal corrosion control was the major cost item. It was estimated that the total cost of corrosion in the oil and gas production industry was $1.372 billion per year, $589 million cost was allocated only for the surface pipeline and the facility costs was about $463 million annually and another $320 million was for capital expenditures related to corrosion [1].

Usually the breakdown in the transmission of the oil and gas system can be related to the pipeline failures. For example, the corrosion protection system such as the coating has come out and exposed the pipe to the surrounding, aggressive environment, and rapid corrosion growth may lead to a corrosion failure. Other than that, this failure may happen due to the external interference, stress corrosion cracking, the internal pressure and the compressive stress [2]. Due to the seriousness of this problem, certain assessment methods were developed in order to ensure the continuity of the pipeline integrity. Studies had been conducted by the researchers and the oil and gas companies and they had come up with the various methods and some of them are empirical and some of them are semi-empirical methods. But all of these methods had the same objective which is to determine the load capacity of the corroded pipelines based on experimental tests. However, all of these methods were said to have their limitation and known to be conservative because they are dependent on material properties, pipelines geometries and defect geometry [3].

For example the ASME B31G code, is said to be conservative because this code will estimate the corroded pipe pressure lower than the actual corroded pressure of the pipe. Besides that, this code had their own limitation where is it can only be used to assess the strength of the corroded pipe line due to the internal pressure only. This code is not applicable to the pipeline that had the internal pressure and combined compressive stresses. Moreover, most of these methods are limited to internal pressure and non interacting defects.

The examples of the corrosion assessment methods available nowadays are ASME B31G, Modified B31G, RSTRENG, DNV RP-F-101 and PCORRC. Other than that, the assessment will be limited to not greater than 80% affected wall thickness and not less than 10% of the affected wall thickness. Most of the codes seem to estimate the geometry of the defects as the rectangular defect which can cause the inaccuracy of the pressure estimation. Also these codes that were used seem to be neglecting the actual size of the defect. The uncertainties in the sizing of the defects and the material properties of the defects can produce inaccuracy to the pressure estimation [6].

Figure 2.1: Illustration of irregular and rectangular defects

Based on the Figure 2.1, most codes had assumed the corrosion defect in the rectangular shape. Due to that, the pressure estimation will be underestimated because the real pressure will not be as large as the pressure for the rectangular shaped defect [6].

The computation technology is another solution for the corrosion assessment in the pipelines. Nowadays, these methods can be used to assess the corroded pipelines by taking into account their geometry and size of the corroded region. The geometry of the profile used in the simulation is obtained by the magnetic flux leakage (MFL) and ultrasonic pigs used to diagnose the oil and gas pipelines. Recently it is proven that this method can be used to measure the geometric shape of the corroded regions accurately and establish their location on the pipeline [4].

Using the computation technology method, the most critical part of the corroded pipeline segments can be revealed and also the burst and maximum allowable operating pressure (MOAP) for each segment can be computed. By using the finite element method, the structural analysis of nonlinear stress state of the pipeline segment can be developed with the consideration of the multifactor loading and all technical inspection data including the in-line inspection (ILI) data, external inspection and geophysical research. The remaining strength of the corroded pipelines can be estimated more accurately compared to the previous assessment methods [4].

Figure 2.2: Solid model of the corroded pipeline segment.

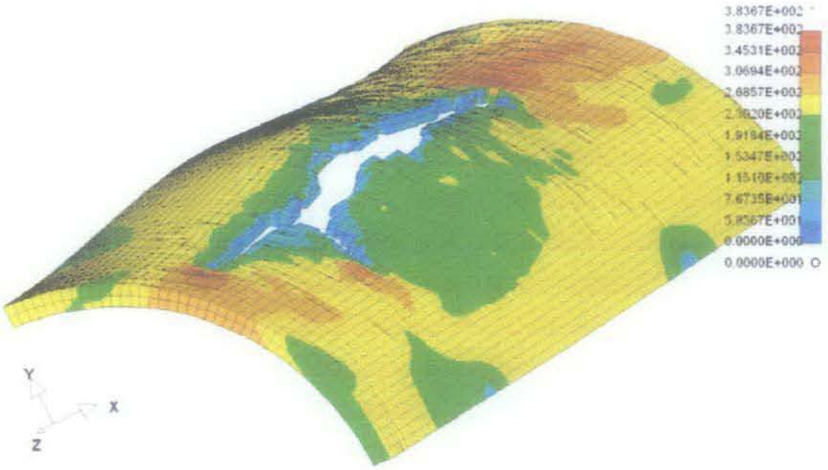

Figure 2.3: Simulation of corroded pipeline rupture. Equivalent von Mises stresses [MPa] are shown

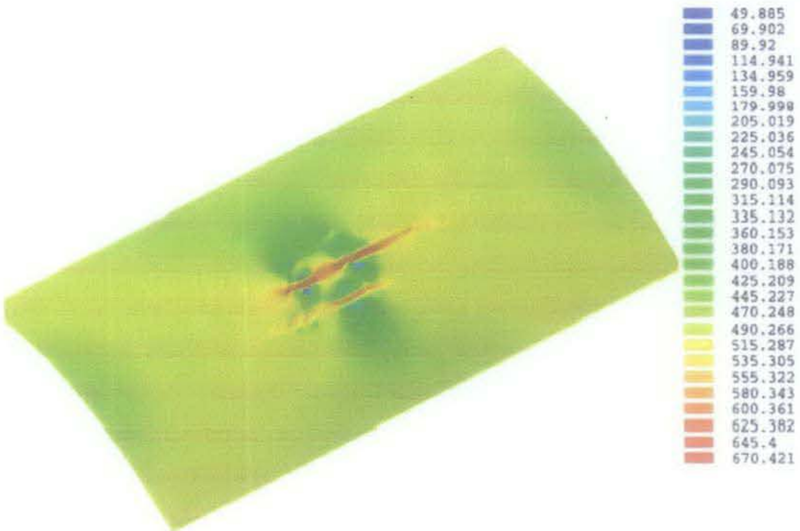

Figure 2.4: Pattern of equivalent von Mises stresses [MPa] in the corroded pipeline segment.

Figure 2.2, Figure 2.3 and Figure 2.4, show the process involved in determining the corroded pressure of pipe by using the computational method. Figure 2.2 shows the solid model of the corroded pipe before load was applied on the pipe. Figure 2.3 and Figure 2.4 show the effects after the load were applied on the pipe. The stress or the pressure on the pipe can be clearly seen and analysis can be done [4].

From the results of full-scale hydrostatic testing for rupture of the pipes having the artificial and natural corroded defects, the developed computation technology was proven to be authenticated. The result shows that the difference between the calculated and the experimental value of the burst pressure did not exceed 5% in all cases. While for the calculation of the burst pressure using the standard codes shows that the error conceded is in between 30% to 70% [4].

2.2 ANSYS Simulation Theory

Through the computation technology, the finite element analysis had become the most effective way to analyze the allowable operating pressure for the corroded pipeline. The numerical simulation can be developed using the finite element analysis software ANSYS based on the information such as the corroded defect size and shape [5].

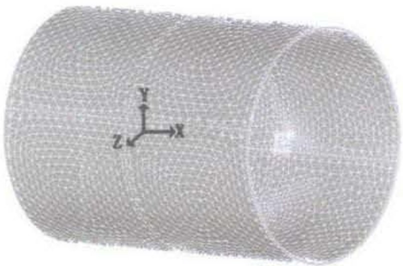

Figure 2.5: Uniform Pipeline Meshing

Figure 2.5 show the example of the meshing process on the pipe. Based on the studies, in order to accurately simulate the influence of corroded defects to piping pressure, the SOLID95 element had been used to assess the corroded defects. The simulation model is developed according to the actual size with the grid refinement conducted in the defect region and the model will be meshed [5].

The internal pressure and the symmetrical displacement constraints were applied on the corroded pipeline model. The simulation results are shown in Figure 2.6 and Figure 2.7 [5].

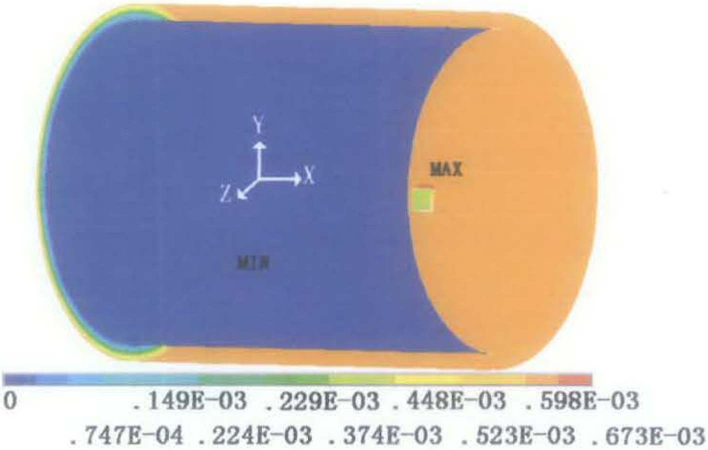

Figure 2.6: Pipeline Displacement

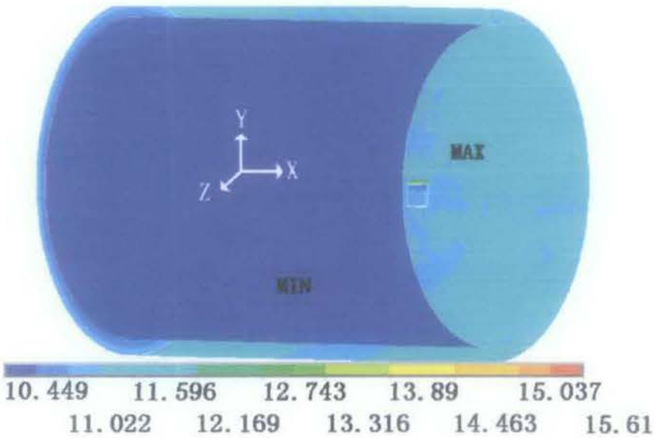

Figure 2.7: Pipeline Stress

Based on Figure 2.6, it shows that the center of the corroded pipeline experienced the highest deformation effect while the other areas stay the same. Figure 2.7 shows that the stress applied on the corroded pipeline which is at internal area of the pipe is more obvious compared to the other area because of the corroded defect [5].

‍2.3 Standard Code

The DNV RP-F101 code is used in assessing the pipelines that contained the corrosion defects. This is because this code can be used to access the corrosion defects subjected to internal pressure loading only and the internal pressure loading combined with longitudinal compressive stresses. In this standard assessment, it consists of two different approaches [6].

These two approaches had their differences in the safety philosophy. For the first approach, based on the calibrated safety factor the allowable operating pressure for the corroded pipelines can be determined. The first approach will take some information into consideration such as the natural spread in material properties and wall thickness as part of their calculation. Other than that, the internal pressure variations, sizing of the defect and the specification of the material properties are also specifically considered [6].

Table 2.1: Partial Safety Factor, γ_m

Inspection Method	Safety Class		
	Low	Normal	High
Relative (MFL)	0.79	0.74	0.70
Absolute (UT)	0.82	0.77	0.72

Table 2.1 shows that the safety class for the safety factor of the model. The safety class is based on the reading recorded by using the relative measurement which is the Magnetic Flux Leakage (MFL) and the absolute measurement which is the Ultrasonic Testing [6].

Table 2.2: Partial safety factor, γ_d and Fractile value, ε_d

Inspection Sizing Accuracy StD(d/t)	ε_d	Safety Class		
		Low	Normal	High
Exact 0.00	0.00	1.00	1.00	1.00
0.04	0.00	1.16	1.16	1.16
0.08	1.00	1.20	1.28	1.32
0.16	2.00	1.20	1.38	1.58

Table 2.2 shows the safety factor for corrosion depth γ_d with different classes and the fractile value, ε_d. The measurement is recorded with different inspection sizing accuracy [6].

The second approach is based on the ASD (Allowable Stress Design) format. The allowable operating pressure for the corroded pipelines can be calculated by multiplying the failure pressure with the original design factor. The uncertainties regarding the size of the corrosion defect is left to the judgment of the user [6].

CHAPTER 3

METHODOLOGY

3.1 Project Flowchart

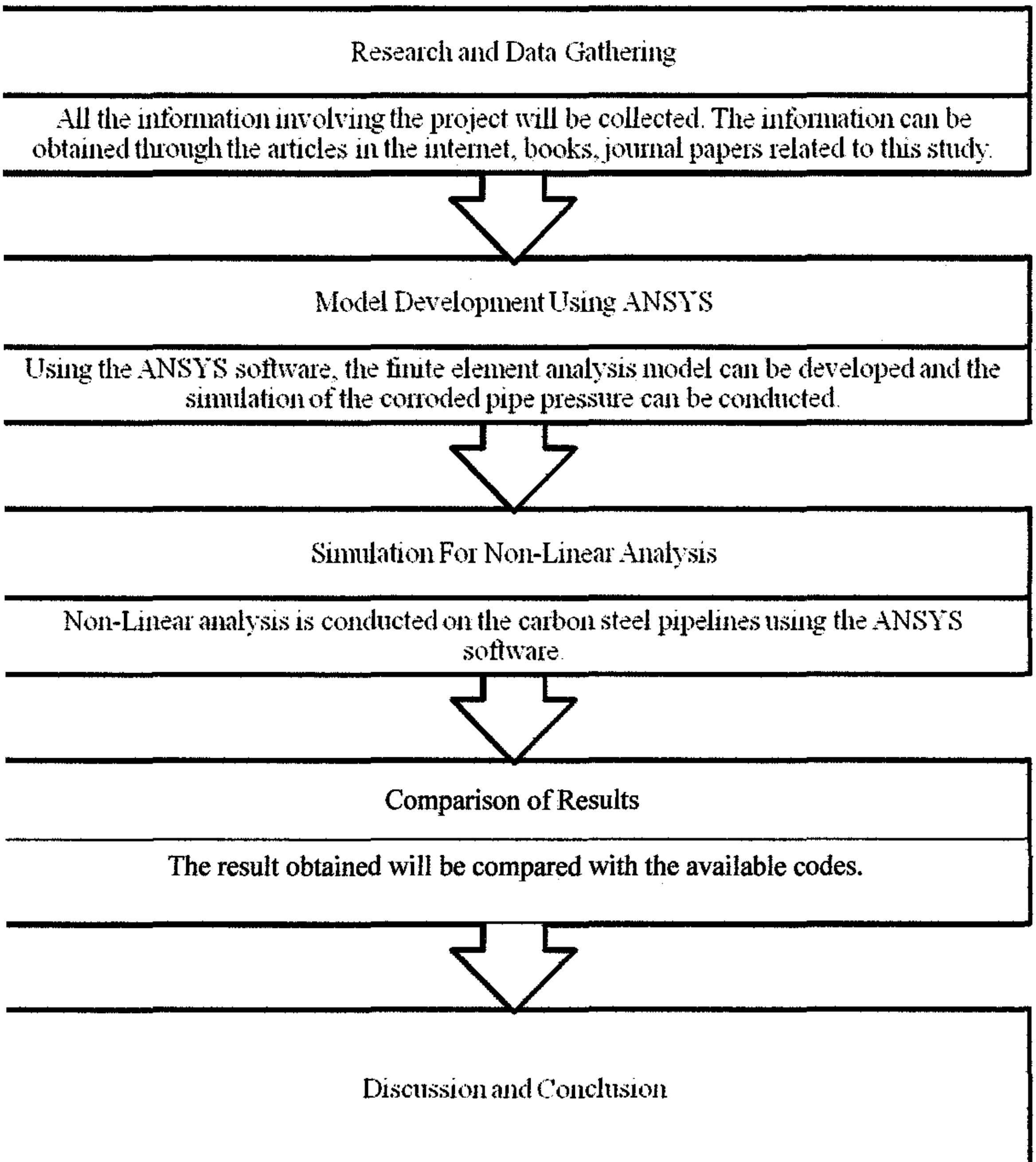

Figure 3.1: Project Flowchart

'igure 3.1 shows the flow process of the project from the beginning until finish. The process itarts with the research and data gathering. After that the finite element model will be developed)y using ANSYS. When the model is already done, the non-linear analyses are conducted on the)ipe model using ANSYS. Then, the results will be compared with the standard code. Lastly, the)roject will be concluded based on the objective of the project.

ł.2 Research and Data Gathering

[he first step in conducting this project is to gather all the information involved in this project hrough all sort of resources such as articles, book, journal papers and the thesis related to this tudy. After gathering the information, next step is to understand all the useful correlation or ɜquation available in this study. The code that will be used is the DNV RP-F101. Then the finite ɜlement analysis (FEA) model will be developed using the ANSYS software. The result obtained vill be compared and the conservatism involved will be analyzed.

ł.2.1 DNV-RP-F101

'he DNV RP-F101 code will be used for the assessment of the pipeline with single corrosion lefect. This code provides the complete guidance for the pipeline under the internal pressure and he longitudinal compressive stress.

(a) Calibrated Safety Factor Method

The first approach in the DNV RP-F101 code used to obtain the allowable corroded pressure is the calibrated safety factor method (internal pressure and the longitudinal compressive stress):

Step 1: Determine the value of the longitudinal compressive stress. This is to know the existence of the compressive stress.

Step 2: Calculate the corroded pipe pressure due to the internal pressure and combined longitudinal compressive stress.

$$pcorr = \gamma m \frac{2tfu}{(D-t)} \frac{(1 - \gamma d\left(\frac{d}{t}\right)*)}{[1 - \frac{\gamma d\left(\frac{d}{t}\right)*}{Q}]} \times H1$$

where

$$H1 = \frac{1 + \frac{\sigma L}{\zeta fu}\frac{1}{Ar}}{1 - \frac{\gamma m}{2\zeta Ar}\frac{(1 - \delta d\left(\frac{d}{t}\right)*)}{(1 - \frac{\gamma d\left(\frac{d}{t}\right)*}{Q})}}$$

$$\left(\frac{d}{t}\right)* = \left(\frac{d}{t}\right)means + \varepsilon dStD[\frac{d}{t}]$$

$$Q = \sqrt{1 + 0.31(\frac{L}{\sqrt{Dt}})^2}$$

(b) Allowable Stress Approach

The second approach used to obtain the allowable corroded pressure is the allowable stress approach method (internal pressure and the longitudinal compressive stress):

Step 1: Determine the value of the longitudinal compressive stress. This is to know the existence of the compressive stress.

Step 2: Determine whether it is necessary to consider the effect of longitudinal compressive stress. The longitudinal compressive stress can be excluded if the $\sigma_L > \sigma_1$.

where

$$\sigma 1 = -0.5 fu \frac{(1 - \frac{d}{t})}{(1 - \frac{d}{tQ})}$$

If $\sigma_L > \sigma_1$, step 4 can be ignored.

Step 3: Calculate the corroded pressure under the internal pressure only.

$$pcomb = \frac{2tfu}{(D-t)} \frac{(1 - \left(\frac{d}{t}\right))}{[1 - \frac{\left(\frac{d}{t}\right)}{Q}]}$$

Step 4: Calculate the corroded pipe pressure due to the internal pressure and combined longitudinal compressive stress.

$$pcomb = \frac{2tfu}{(D-t)} \frac{(1 - \left(\frac{d}{t}\right))}{[1 - \frac{\left(\frac{d}{t}\right)}{Q}]} \times H1$$

where

$$H1 = \frac{1 + \frac{\sigma L}{fu} \frac{1}{Ar}}{1 - \frac{1}{2Ar} \frac{(1 - \left(\frac{d}{t}\right))}{(1 - \frac{\left(\frac{d}{t}\right)}{Q})}}$$

$$Ar = (1 - \frac{d}{t}\theta)$$

$$\theta = \frac{c}{\pi D}$$

Step 5: Calculate the safe working pressure for the corroded pipe.

$$pcorr = F \times pcomb$$

.3 Model Development Using ANSYS

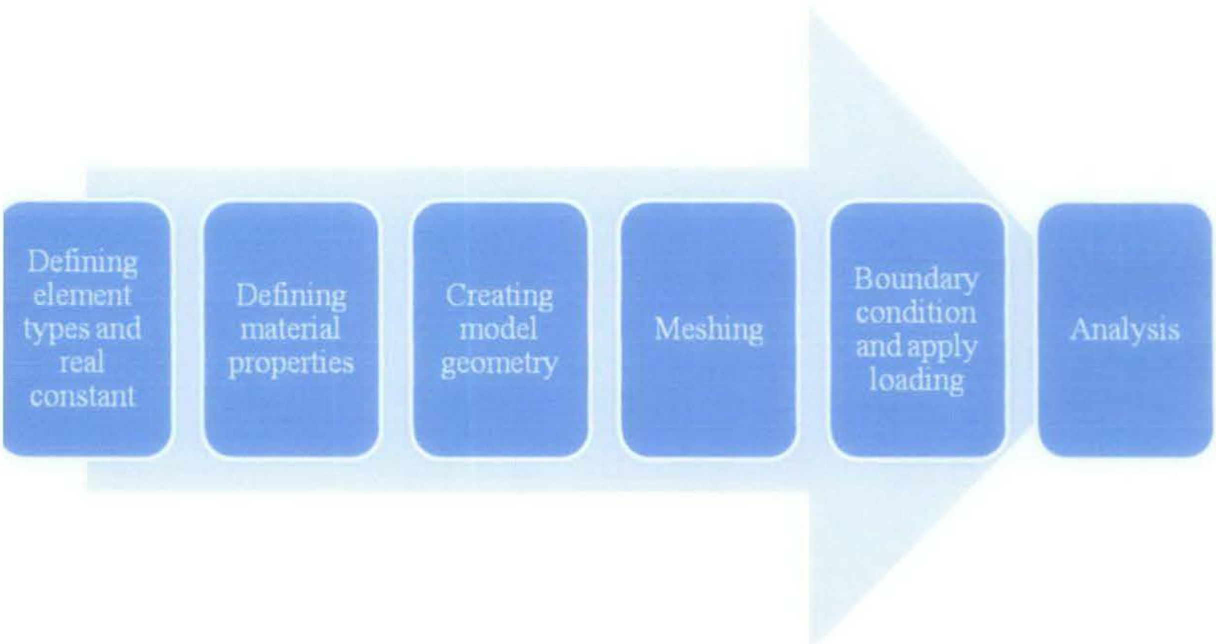

Figure 3.2: Flow Process in Developing Finite Element Model

'igure 3.2 shows the process to develop the finite element model using ANSYS. In this project, he finite element models are developed by using the ANSYS program. The model that was leveloped will be using the real dimension and specification that was being used nowadays. The ›urpose of this analysis is to determine the corroded pipe pressure using the computational nethod.

.3.1 Defining element types and real constant

ı the ANSYS program, there will be over than 100 elements that can be chosen to be used as the ement for the finite element model. The elements are usually chosen based on the material that ill be used in the project and the meshing types that will be used to get the accurate results for ie analysis.

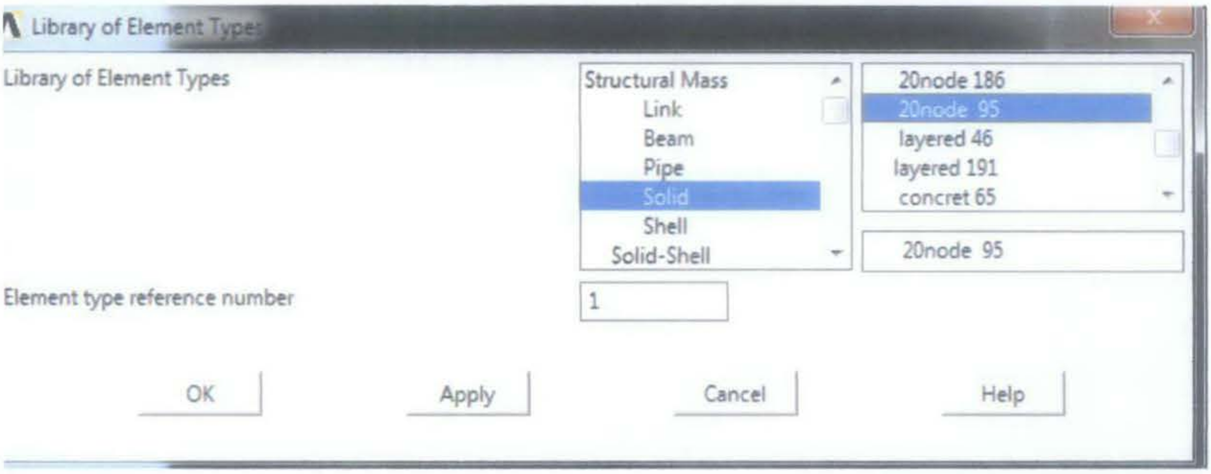

Figure 3.3: Defining the element types of model

igure 3.3 shows the library of element types. The element types must be defined first in order ır the simulation to take place. In this project, for the pipe steel X52, the element that will be sed is the SOLID95. SOLID95 is the solid brick 20node 95, that will give the nice rectangle ieshing and more accurate results for the analysis.

.3.2 Defining material properties

he material properties must be defined first before the analysis is conducted. Providing correct ıaterial properties is very important in getting correct finite element analysis (FEA) results from NSYS. The linear and nonlinear property that must be filled is based on the material that was sed in the project. For linear properties, the Young's modulus and poisson's ratio value is ıserted.

Table 3.1: Material properties of steel X52

Material	Young's modulus (GPa)	Poisson's ratio	Yield stress (MPa)	UTS (MPa)
Steel X52	210	0.3	358	455

'able 3.1 shows the value of Young's modulus and poisson's ratio for the pipe steel X52 that ill be used in this project.

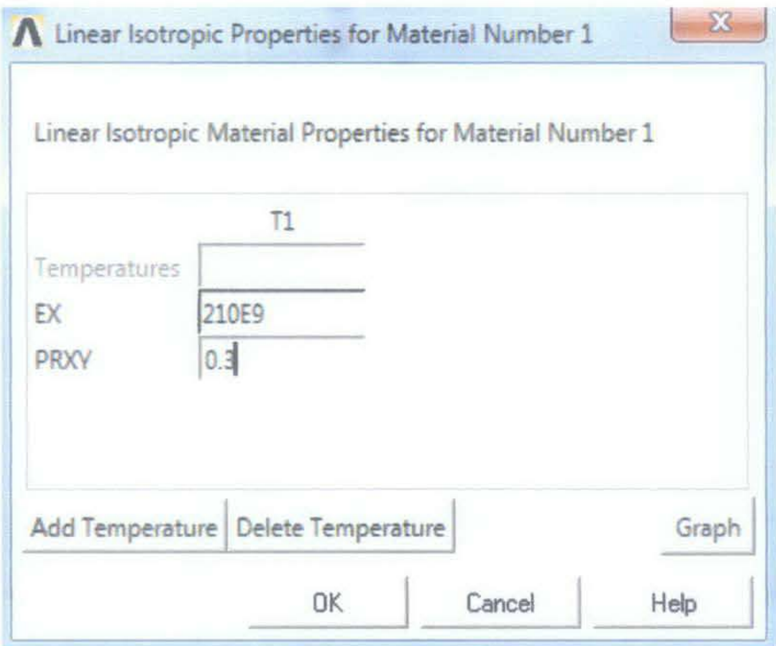

Figure 3.4: Defining linear properties of model

'igure 3.4 shows the linear isotropic material properties for the pipe. The EX is the Young's iodulus of the pipe and PRXY is the poisson's ratio of the pipe.

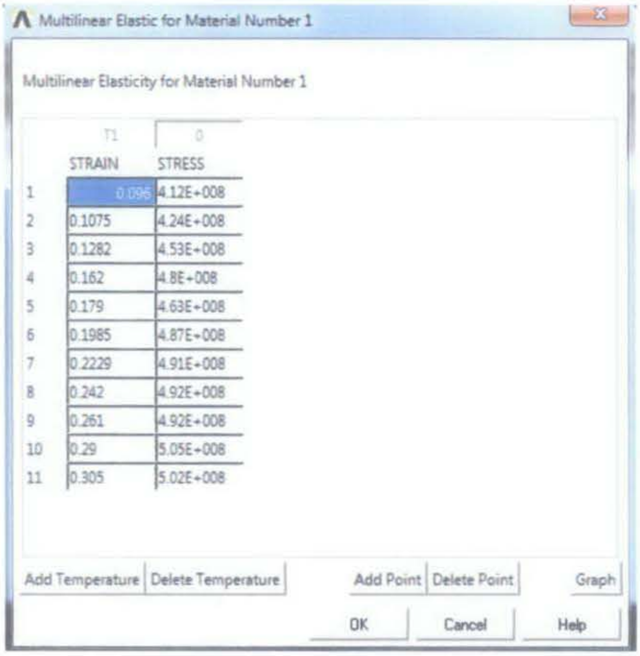

Figure 3.5: Defining nonlinear properties of model

igure 3.5 shows the nonlinear properties of the pipe X52 where the engineering stress and strain alue of the material is inserted.

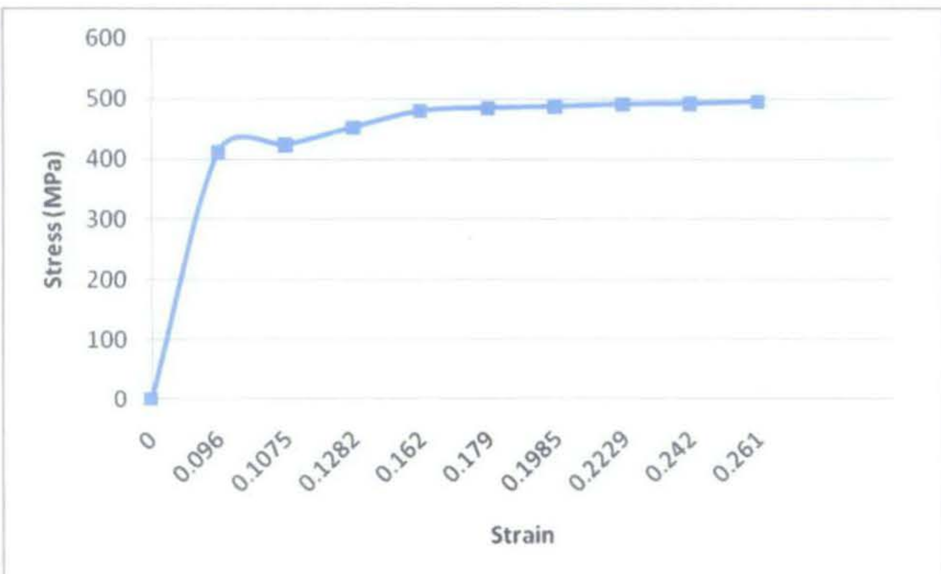

Figure 3.6: Engineering stress and strain graph for X52

igure 3.6 shows the engineering stress vs strain graph based on the nonlinear properties for pipe eel X52. From this graph the ultimate tensile strength of the pipe can also be observed.

.3.3 Creating model geometry

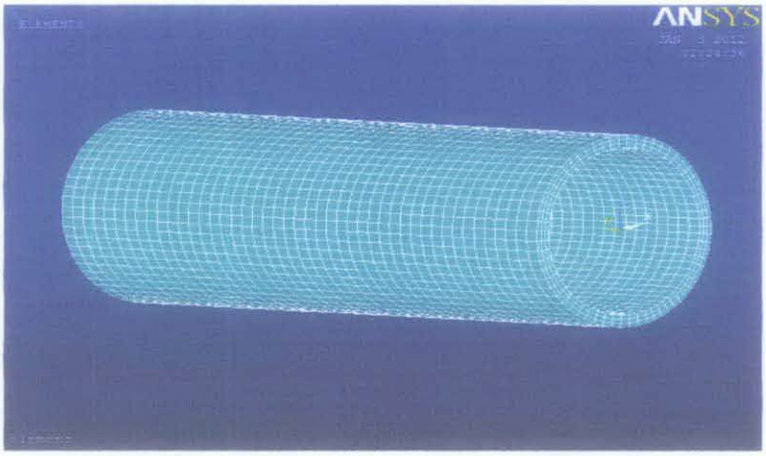

Figure 3.7: Full meshed pipe model

'o obtain solid 3D model, first the model is created in the 2-dimensional area. The model was eveloped using the correct dimension for the real pipe so that the analysis will produce accurate ɜsults. In this project, the 3-dimensional model of the pipe is developed by creating the ɜctangle area for the 2D segment. Then this 2D segment will be extruded along the axis by 180 egrees to produce the semi cylinder. The defect area is created by subtracting some volume to roduce the defect area. The full and quarter of the pipe model with the defect is shown in Figure .7 and Figure 3.8.

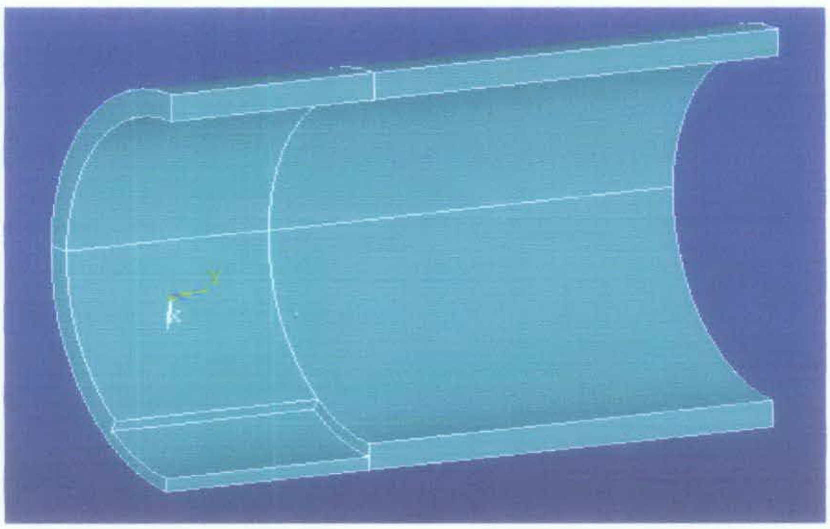

Figure 3.8: Quarter pipe model with 50% defect depth

.3.4 Meshing

Ieshing process is one of the most important step in engineering simulation. In meshing rocess, the model will be divided into many cells and some point will be represented by nodes. oo many cells will produce a longer time for the analysis while too few cells will produce an ıaccurate results. So, the model must be meshed efficiently so that the simulation can be run ıcessfully. Different physics requires different meshing approaches. Figure 3.9 shows the state f the pipe model after being meshed.

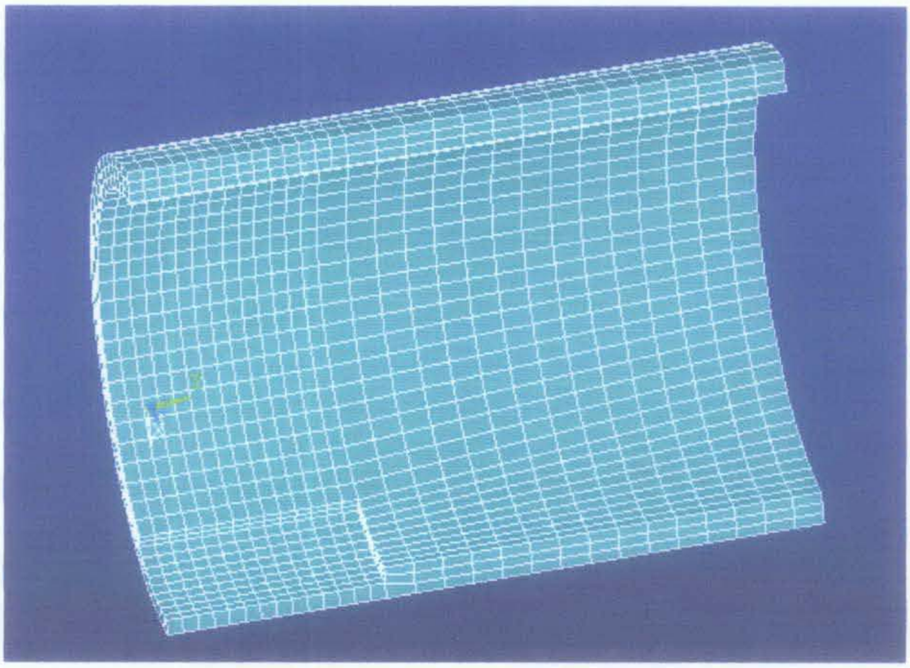

Figure 3.9: Meshed pipe model

3.5 Boundary condition and load application

ı this analysis, only quarter of the pipe model is created since the pipe can be assumed ʼmmetrical. The symmetric boundary condition is applied on the pipe as the mark for the pipe ı be symmetrical. In this project, there will be two main pressures applied on the pipe which are ıe internal pressure and the longitudinal compressive stress.

Symmetric boundary condition

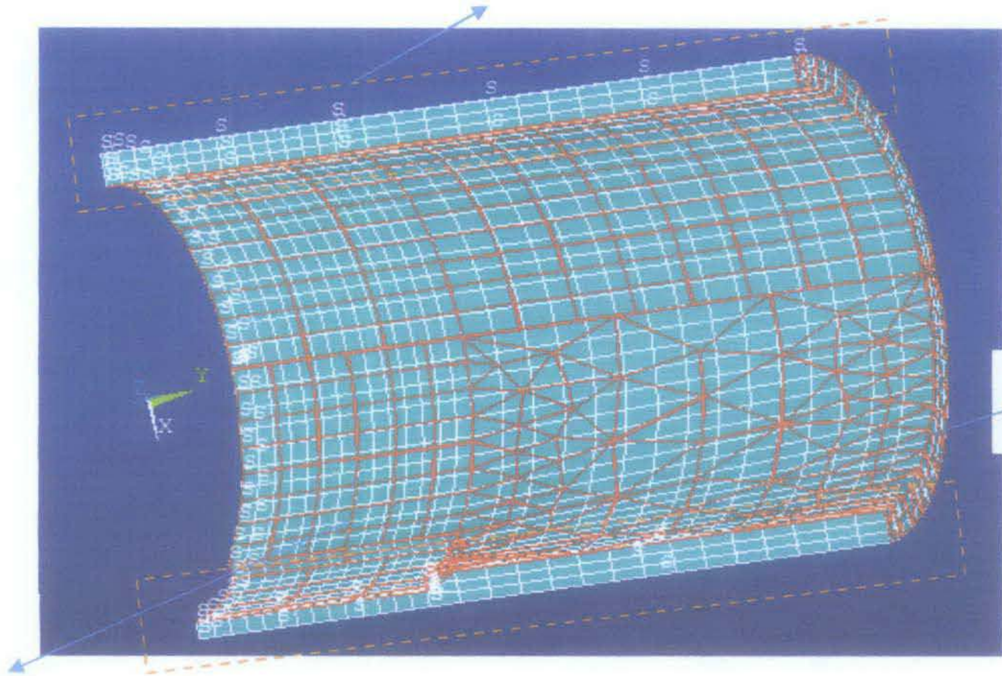

Figure 3.10: Internal load and longitudinal compressive stress applied on pipe model

gure 3.10 shows that the internal load combined with the longitudinal compressive stress are pplied on the pipe model. This is to estimate the remaining strength of the pipe. On the model me boundary conditions were applied on the model. For example the constraints and the mmetric condition are set to the model.

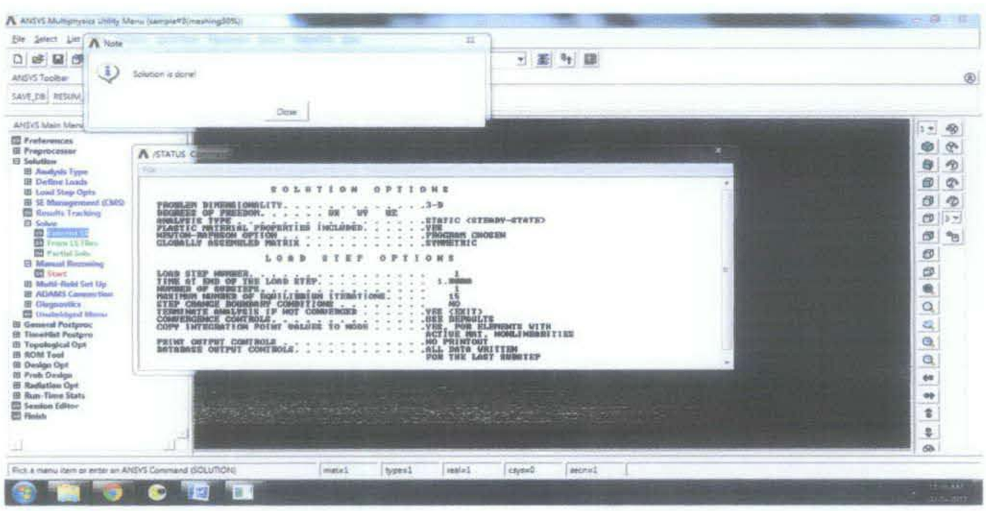

Figure 3.11: Model solved

fter all the conditions and loads were set on the pipe model, the simulation of the model can be arted. Figure 3.11 shows that the simulation for the pipe model is successfully conducted.

3.6 Analysis

fter the load were applied on the pipe model, the stress distribution on the pipe can be sualized. The area which has the biggest load also can be seen and the different load at the fferent nodes can also be viewed.

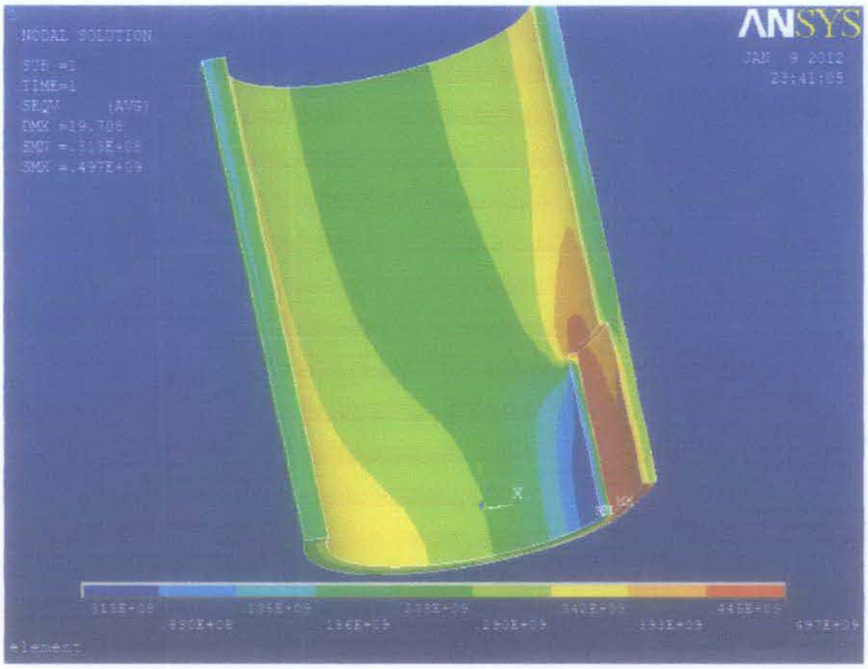

Figure 3.12: Contour plot of Von Mises Stress distribution along the pipe

igure 3.12 shows the stress distribution on the pipe model after the simulation is successfully nducted. This nodal solution tells that the stress is high on the defect region compared to the her area around the pipe. The Figure 3.13 shows the element solution for the pipe and every des that was present on the model.

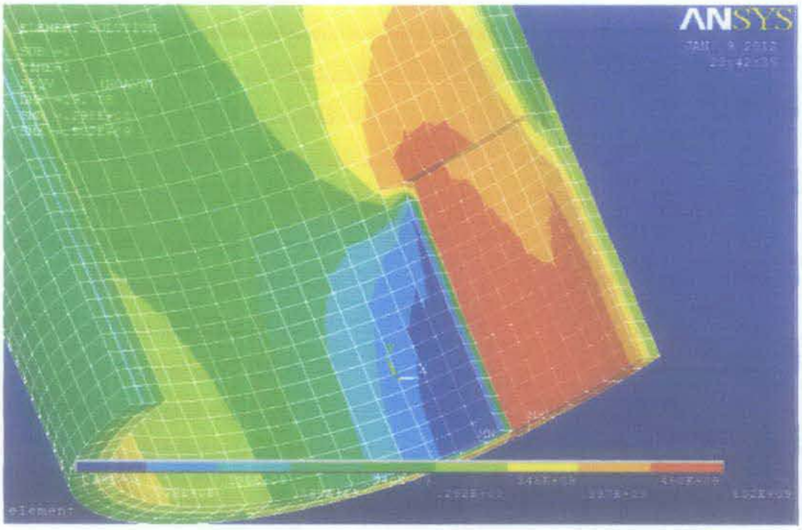

Figure 3.13: Stress at the nodes

5 Comparison of Results

Table 3.2: The analysis matrix

Compressive stress (MPa)	*d/t*	Failure Pressure (MPa) Approach 1 (Pcorr)	Approach 2 (Pcorr)	FEA (Nonlinear)
0	0.2			
	0.4			
	0.5			
	0.6			
	0.7			
-100	0.2			
	0.4			
	0.5			
	0.6			
	0.7			
-200	0.2			
	0.4			
	0.5			
	0.6			
	0.7			
-300	0.2			
	0.4			
	0.5			
	0.6			
	0.7			

able 3.2 shows the table for the analysis to compare the results from the standard code with the sults from ANSYS. In this project, the longitudinal compressive stress will be varied from 0 Pa until -300 MPa. The defect depth will also be varied. The calculation result for the approach calibrated safety factor method and approach 2- allowable stress method will be recorded in e table and will be compared with the finite element analysis results.

6 Project Duration

order to effectively monitor the progress of this project, a Gantt chart has been constructed. he Gantt chart is included in Appendix A.

7 Tool Required

ie software required in this project are:

(1) Microsoft Office
(2) ANSYS

CHAPTER 4

RESULTS AND DISCUSSION

1 Empirical Results

ıe calculation for the approach 1-calibrated safety factor method and approach 2- allowable ress method is conducted by varying depth of defect and the longitudinal compressive stress. ıe parameters of pipe steel X52 that will be used in the calculation is all stated in Table 4.1.

Table 4.1: Parameters used in this project

ırameter	Value
utside diameter of pipe, D (mm)	219.0
ıickness of pipe, t (mm)	14.5
ltimate tensile strength of pipe, fu (MPa)	455.1
ǝngth of corroded region, L (mm)	200
'idth of corroded region, c (mm)	100
ırtial safety factor for model, γ_m	0.74
ırtial safety factor for corrosion depth, γ_d	1
'actile value for corrosion depth, ε_d	1
atio of circumferential length of corroded region, □	0.145
epth of corroded region, d (mm)	7.25
sage factor for longitudinal stress, ζ	0.85
otal usage factor, F	0.648

1.1 Calibrated Safety Factor Method

ıe calibrated safety factor method is the first approach in DNV RP-F101 code that was used to ›tain the allowable corroded pressure. The assessment included the internal pressure and the ngitudinal compressive stress.

ep 1: Determine the value of the longitudinal compressive stress. This is to know the existence ᶠthe compressive stress. For example the longitudinal compressive stress is -200 MPa.

$$\sigma_L = -200 \text{ MPa}$$

ep 2: Calculate the corroded pipe pressure due to the internal pressure and combined ngitudinal compressive stress.

$$:omb = \gamma_m \frac{2tf_u}{(D-t)} \frac{\left(1-\gamma_d\left(\frac{d}{t}\right)^*\right)}{\left[1-\frac{\gamma_d\left(\frac{d}{t}\right)^*}{Q}\right]} \times H_1$$

nd the length correction factor, Q:

$$= \sqrt{1 + 0.31\left(\frac{L}{\sqrt{Dt}}\right)^2}$$

$$= \sqrt{1 + 0.31\left(\frac{200}{\sqrt{(219)(14.5)}}\right)^2}$$

$$= 2.215$$

nd factor to account for compressive longitudinal stress, H_l using the -200 MPa for ›mpressive stress:

$$1 = \frac{1 + \frac{\sigma L}{\zeta fu} \frac{1}{Ar}}{1 - \frac{\gamma m}{2\zeta Ar} \frac{\left(1 - \delta d \left(\frac{d}{t}\right) *\right)}{\left(1 - \frac{\gamma d \left(\frac{d}{t}\right) *}{Q}\right)}}$$

$$r = (1 - \frac{d}{t}\theta)$$

$$= \frac{c}{\pi D}$$

$$= \frac{100}{\pi(219)}$$

=0.145

$$= (1 - \frac{7.25}{14.5}(0.145))$$

= 0.9275

here,

$$\left(\frac{d}{t}\right) * = \left(\frac{d}{t}\right) measure + \varepsilon dStD[\frac{d}{t}]$$

$$= 0.5 + (1)(0)$$

$$= 0.5$$

ıerefore,

$$1 = \frac{1 + \frac{(-200 \times 10^6)}{(0.85)(455.1 \times 10^6)} \frac{1}{0.9275}}{1 - \frac{0.74}{2(0.85)(0.9275)} \frac{(1 - (1)(0.5))}{(1 - \frac{(1)(0.5)}{2.215})}}$$

= 0.635

ıe corroded pipe pressure is:

$$orr = \gamma m \frac{2tfu}{(D-t)} \frac{(1 - \gamma d \left(\frac{d}{t}\right) *)}{[1 - \frac{\gamma d \left(\frac{d}{t}\right) *}{Q}]} \times H1$$

$$= (0.74) \frac{2(14.5)(455.1)}{(219 - 14.5)} \frac{(1 - (1)0.5)}{[1 - \frac{(1)0.5}{2.215}]} \times 0.635$$

= 19.58 MPa

1.2 Allowable Stress Method

llowable stress method is the second approach in DNV RP-F101 code that was used to obtain e allowable corroded pressure. The assesment included the internal pressure and the ngitudinal compressive stress.

ep 1: Determine the value of the longitudinal compressive stress. This is to know the existence the compressive stress. For example the longitudinal compressive stress is -200 MPa.

$$\sigma_L = -200 \text{ MPa}$$

ep 2: Determine whether it is necessary to consider the effect of longitudinal compressive ress. The longitudinal compressive stress can be excluded if $\sigma_L > \sigma_1$.

here

$$1 = -0.5fu \frac{(1-\frac{d}{t})}{(1-\frac{d}{tQ})}$$

$$= (-0.5 * 455.1) \frac{(1-\frac{7.25}{14.5})}{(1-\frac{7.25}{(14.5 \times 2.215)})}$$

$$= -146.95 \text{ MPa}$$

$< \sigma_1$

herefore step 4 cannot be ignored.

tep 3: Calculate the corroded pressure under the internal pressure only.

$$\text{press} = \frac{2tfu}{(D-t)} \frac{\left(1-\left(\frac{d}{t}\right)\right)}{\left[1-\frac{\left(\frac{d}{t}\right)}{Q}\right]}$$

$$= \frac{(2 \times 14.5 \times 455.1)}{(219-14.5)} \frac{\left(1-\left(\frac{7.25}{14.5}\right)\right)}{\left[1-\frac{\left(\frac{7.25}{14.5}\right)}{2.215}\right]}$$

= 41.68 MPa

ep 4: Calculate the corroded pipe pressure due to the internal pressure and combined ngitudinal compressive stress.

$$\text{omb} = \frac{2tfu}{(D-t)} \frac{\left(1-\left(\frac{d}{t}\right)\right)}{\left[1-\frac{\left(\frac{d}{t}\right)}{Q}\right]} \times H1$$

ıere,

$$1 = \frac{1 + \frac{\sigma L}{fu}\frac{1}{Ar}}{1 - \frac{1}{2Ar}\frac{\left(1-\left(\frac{d}{t}\right)\right)}{\left(1-\frac{\left(\frac{d}{t}\right)}{Q}\right)}}$$

$$= \frac{1 + \frac{(-200)}{455.1}\frac{1}{0.9275}}{1 - \frac{1}{(2 * 0.9275)}\frac{(1 - \left(\frac{7.25}{14.5}\right))}{(1 - \frac{\left(\frac{7.25}{14.5}\right)}{2.215})}}$$

= 0.76

ıe combined pressure is:

$:omb = 41.68\ MPa \times 0.76\ MPa$

= 31.68 MPa

ep 5 : Calculate the safe working pressure for the corroded pipe.

$:orr = F \times pcomb$

ıe total usage factor, *F* = 0.648

ıerefore,

$:orr = 0.648 \times 31.68\ MPa$

$= 20.53\ MPa$

2 Overall Result Summary

Table 4.2:Overall Result Summary

		Failure Pressure (MPa)		
Compressive stress (MPa)	d/t	Approach 1 (MPa)	Approach 2 (MPa)	FEA
0	0	47.76	41.82	80.00
	0.2	42.00	36.78	67.10
	0.4	34.97	30.62	50.00
	0.5	30.84	27.01	40.30
	0.6	26.20	22.94	33.00
	0.7	20.95	18.34	22.00
-100	0	47.52	41.82	78.30
	0.2	41.98	36.78	66.70
	0.4	34.27	30.62	48.30
	0.5	29.97	27.01	39.10
	0.6	24.15	22.94	31.90
	0.7	18.21	18.34	20.50
-200	0	40.85	41.82	75.60
	0.2	32.41	36.78	65.40
	0.4	23.84	26.72	47.20
	0.5	19.58	21.80	37.30
	0.6	15.39	17.01	29.20
	0.7	11.29	12.40	18.00
-300	0	18.98	28.51	68.40
	0.2	13.95	21.58	57.20
	0.4	9.34	15.04	41.00
	0.5	7.25	11.98	33.00
	0.6	5.34	9.11	23.20
	0.7	3.64	6.46	15.00

ıble 4.2 shows the overall result summary of the project. The corroded pressure estimation ːtween the standard code and the ANSYS is recorded in this table. From this table, it can be ɪncluded that the difference between corroded pressure estimation by standard code and FEA ; for approach 1 is about 4% to 80% while for approach 2 is about 10% to 70%.

3 Discussion

gure 4.1 and 4.2, show the graphs of Pcorr/Pintact vs *d/t* for longitudinal compressive stress of 00 MPa and -300 MPa. The graphs show that the corroded pressure or the remaining strength ' the pipe will be less if the depth of the defect is increasing. Finite element analysis show the west corroded pipe pressure compared to the DNV RP F101 codes. For the approach 2 in gure 4.1, the corroded pressure is higher than the corroded pressure for approah 1.

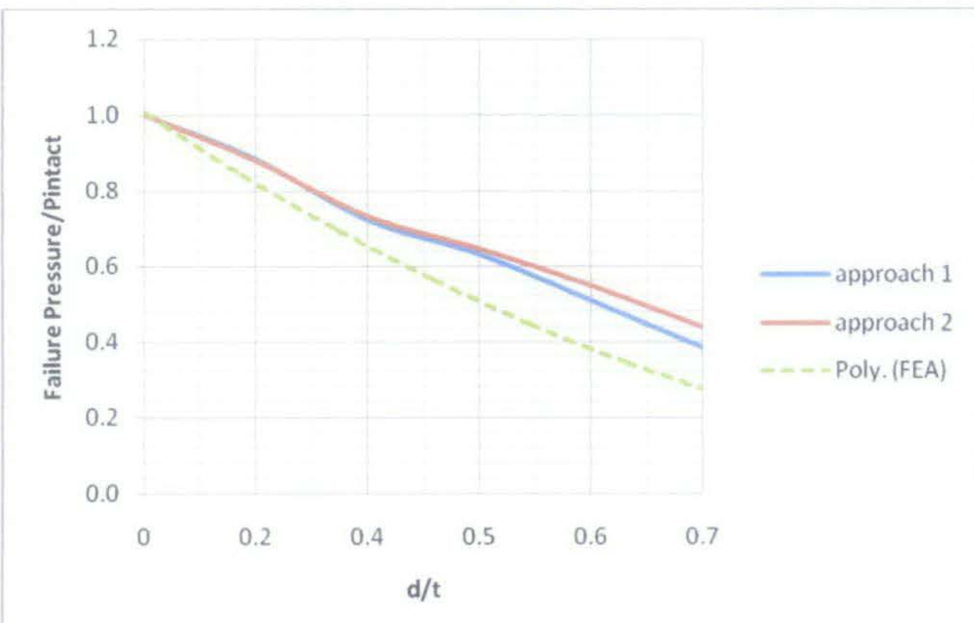

Figure 4.1: Graph of $P_{corr/}P_{intact}$ vs *d/t* for σ_L= -100 MPa

Figure 4.2, it can be seen that the lowest corroded pressure is recorded in approach 1 ɪmpared to approach 2 and the finite element analysis. This explain that, when the compressive ːess is increasing, the corroded pressure will be decrease quickly compared to the approach 2. ıis is because approach 1 had the safety factors that will make the corroded pressure estimation ːcome lower.

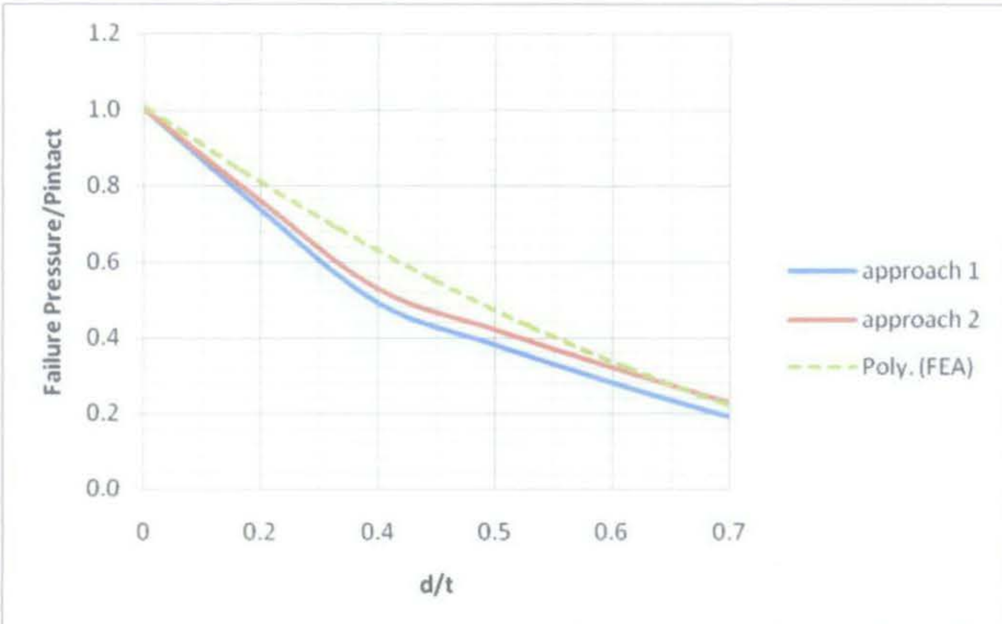

Figure 4.2: Graph of P_{corr}/P_{intact} vs d/t for σ_L = -300 MPa

gure 4.3 and 4.4, show the graphs of corroded pressure vs the longitudinal compressive stress r d/t = 0.4 and d/t = 0.6. From this graph, it can be concluded that the corroded pressure or the maining strength of the pipe will be less when bigger compressive stress is applied on the pipe. ie depth of the defect is also a factor for how much the corroded pressure had on the pipe.

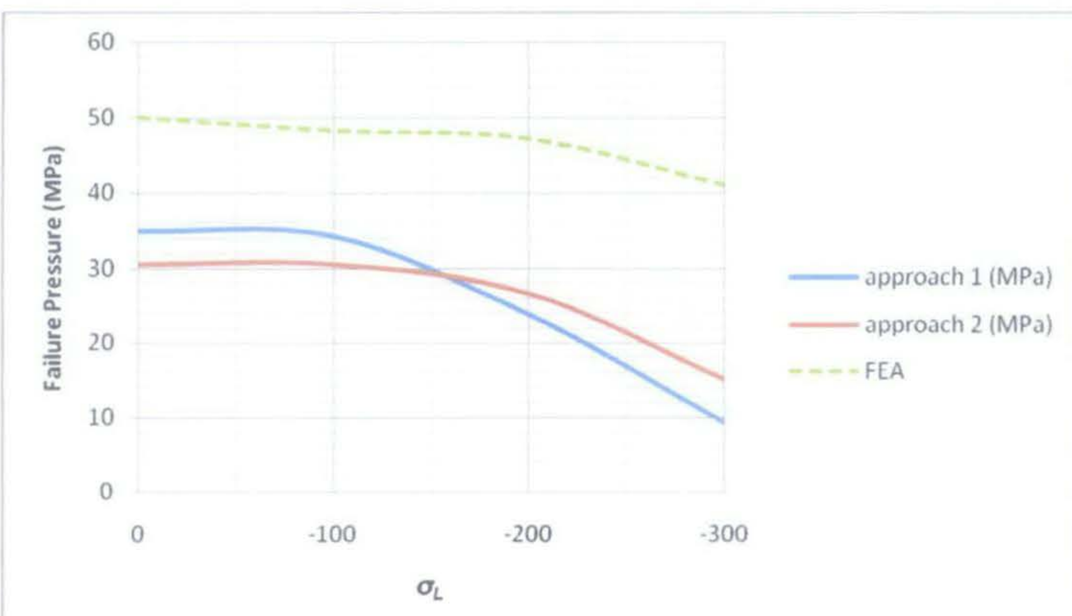

Figure 4.3: Graph of corroded pressure vs σ_L for d/t = 0.4

om Figure 4.3, the corroded pipe pressure for approach 1 shows the clear decreasing pattern hen the longitudinal compressive stress reached -100 MPa. Before that the corroded pipe essure is in steady state until it reach -100 MPa. The corroded pressure determined using proach 2 only starts to decrease when the compressive stress is at -180 MPa. This shows that approach 2 the longitudinal compressive stress will take affect when the stress is about -180 Pa. When the depth of defect is increasing, the compressive stress will take effect faster which below -100 MPa. It can be seen in Figure 4.4, the graph starting to drop when σ_L = -80MPa for proach 1 and σ_L = -100MPa for approach 2.

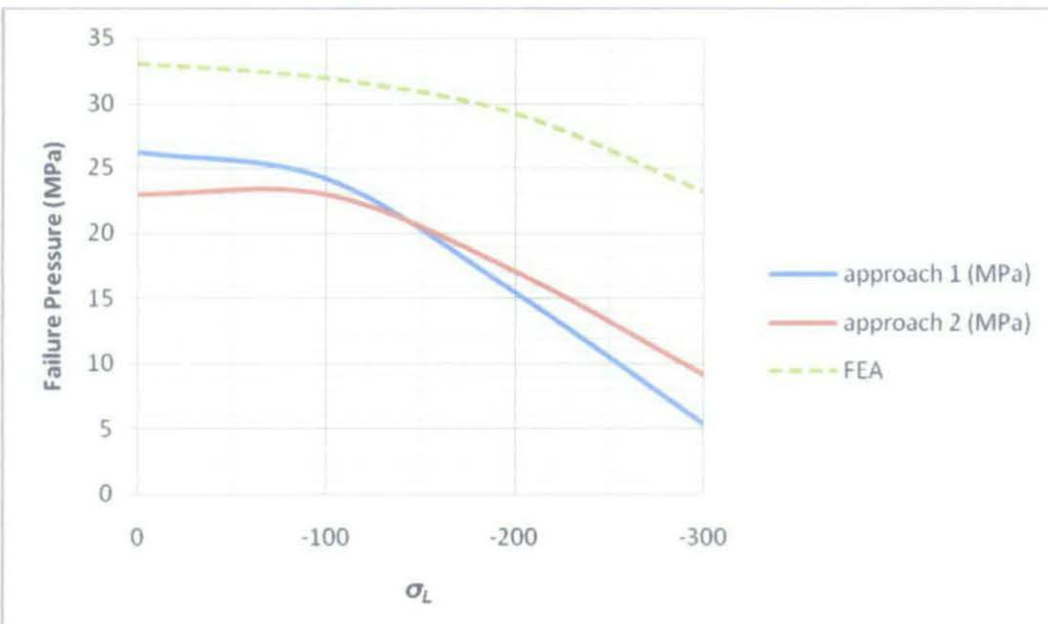

Figure 4.4: Graph of corroded pressure vs σ_L for d/t = 0.6

gure 4.5 and 4.6 show the graphs of corroded pressure vs d/t for approach 1 and approach 2 ith all the longitudinal compressive stress applied in this project. From these graphs, it can be en that the σ_L = 0MPa had the highest value estimation for the corroded pipe pressure mpared to the others longitudinal compressive stress. This prove that the remaining strength of e pipe will be higher if there is no longitudinal compressive stress compared to the pipe that d the longitudinal compressive stress.

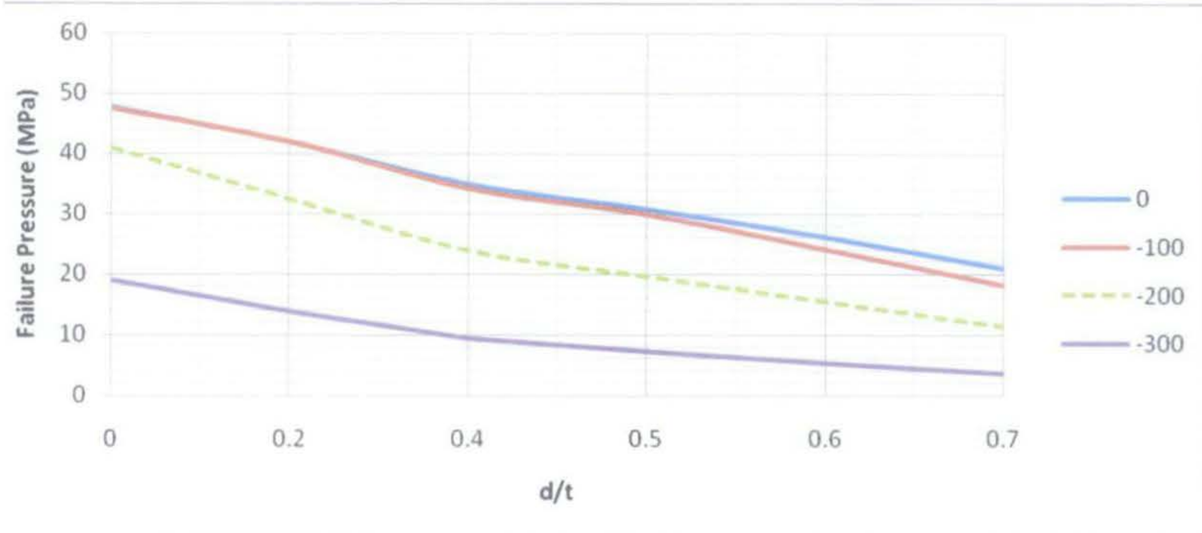

Figure 4.5: Graph of corroded pressure vs *d/t* for approach 1

ıt from Figure 4.6, the graph of corroded pipe pressure estimation for σ_L = -100 MPa is the me with the graph of σ_L = 0 MPa. This is because the longitudinal compressive stress effect is nored due to the condition stated for approach 2. Basically only the internal pressure is nsidered in this analysis while the longitudinal compressive stress will give little or no effect the pipe. The cut- off point for the graph below is when the compressive stress is about -110 Pa.

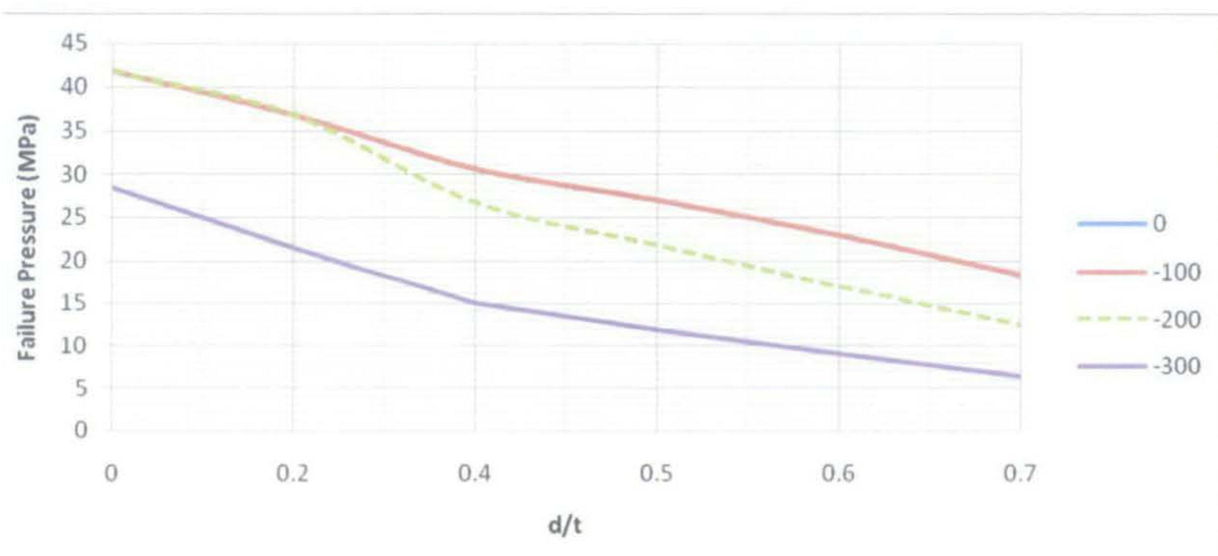

Figure 4.5: Graph of corroded pressure vs *d/t* for approach 2

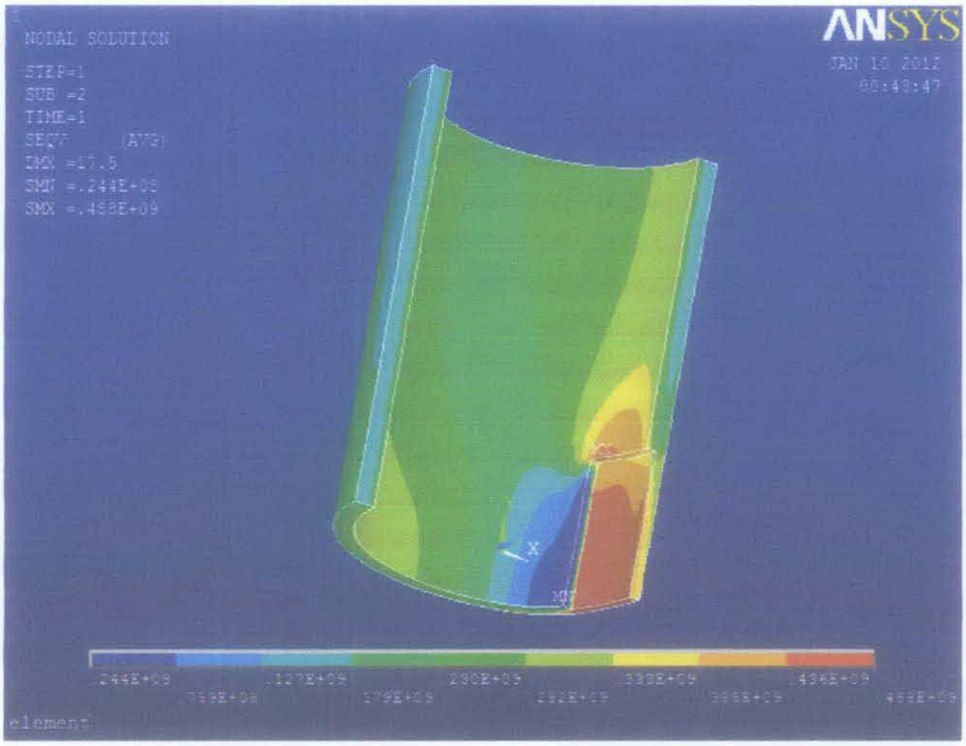

Figure 4.7: Nodal solution of Von Misses Stress Distribution for $d/t = 0.5$ (Internal view)

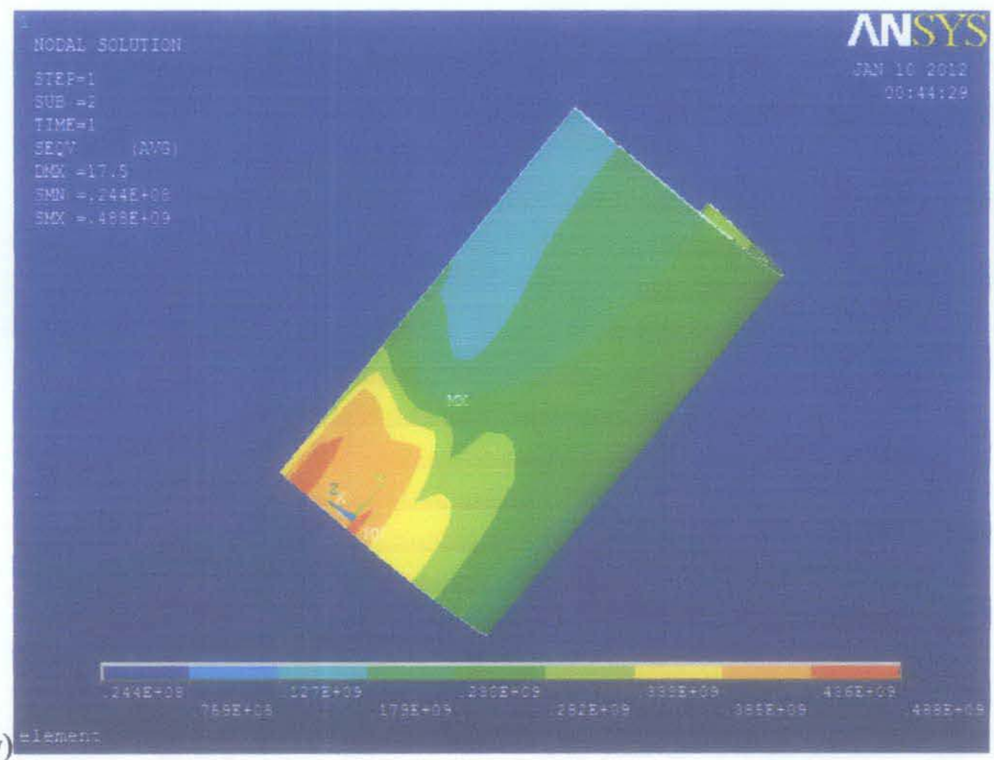

Figure 4.8: Nodal solution of Von Misses Stress Distribution for $d/t = 0.5$ (External View)

gure 4.7 and 4.8 show the nodal solution of the pipe model for $d/t = 0.5$ with $\sigma_L = -300$ MPa. In is project, there are two methods used in order to determine or estimate the pressure for the ırroded pipe. Between these two methods only one of them is used as the comparison with the ındard code. This first method used to estimate the pressure for the corroded pipe is the one ›int method. The pressure for the corroded pipe can be estimated by checking on the nodes at e inner surface of the pipe model. The pressure at that surface had to be equal to the ultimate nsile strength of the pipe steel X52 which is 455.1 MPa. The pipe model in Figure 4.8 had the ırroded pipe pressure about 33 MPa.

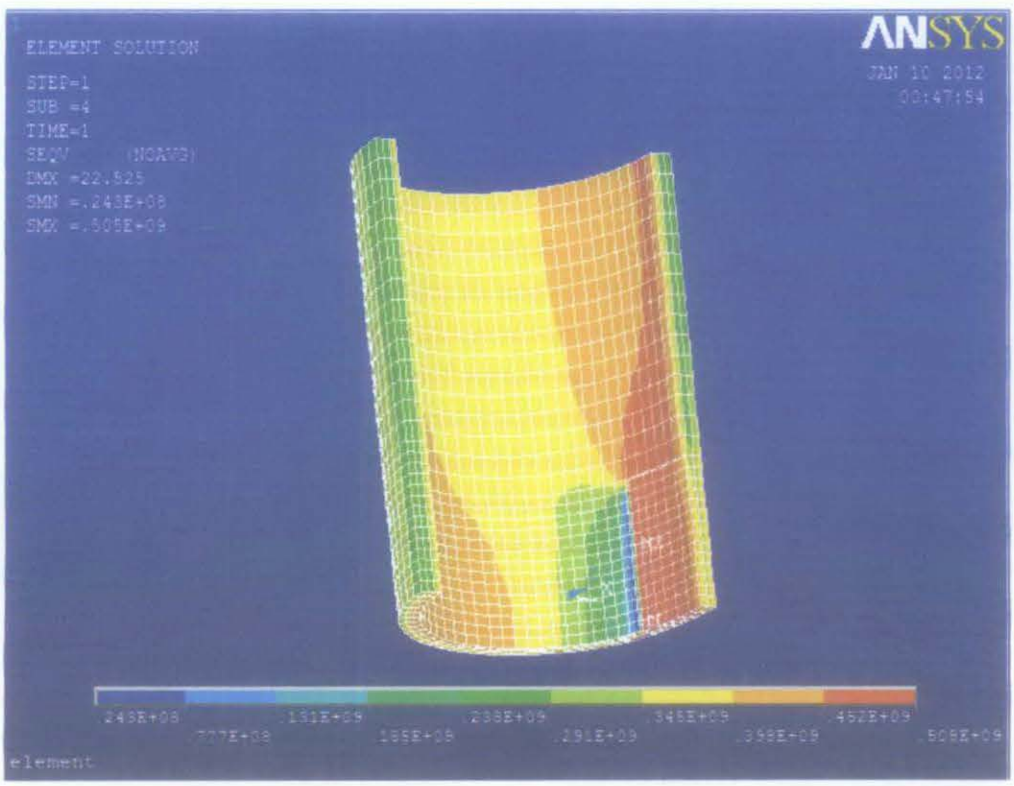

Figure 4.9: Element solution of Von Misses Stress Distribution for d/t=0.2;σ_L= -200 MPa

gure 4.9 and 4.10 show the element solution of the pipe model for $d/t = 0.2$ with $\sigma_L = -200$ Pa. The second method used to estimate the pressure for the corroded pipe is the entire gament method. This method will take time to get the corroded pipe pressure compared with e first method.

ıe corroded pipe pressure can be estimated provided the stopping criterion is achieved which is hen the Von-Mises stress reaches the ultimate tensile stress across the entire ligament of the pe. Figure 4.10 shows the effect of the longitudinal compressive stress on the defect region.

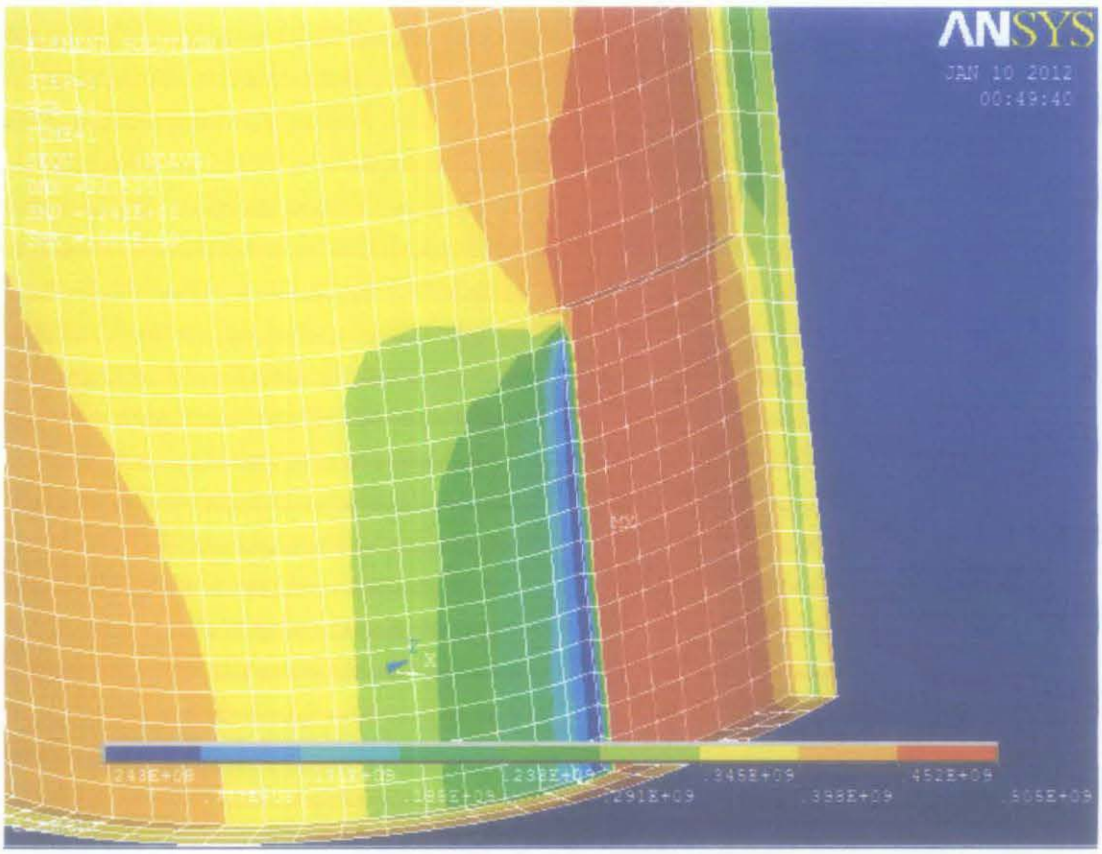

Figure 4.10: Focus view on the effect of compressive stress to the defect area

'om the nodal solution of the Von-Misses Stress Distribution, it clearly can be seen that the ress distribution at the defect with the lower depth will have a higher pressure distribution. The maining strength of the corroded pipe with low depth of defect is higher compared to the ırroded pipe with high depth of defect. For the d/t = 0.2 the corroded pressure is about 65.4 Pa while for d/t = 0.7 the corroded pressure is about 18 MPa. This is for longitudinal ımpressive stress equal to -200 MPa.

gure 4.11 and 4.12, show the graphs of corroded pressure vs *d/t* for approach 1 and approach 2 ith all the longitudinal compressive stress applied in this project. From these graphs, it can be en that the σ_L= -300 MPa had the highest value estimation using FEA to pressure estimation ing the code compared to the others longitudinal compressive stress. This explain that, when mpressive stress is at -300 MPa, the corroded pressure for the code is dropping drastically mpared to the other compressive stress.

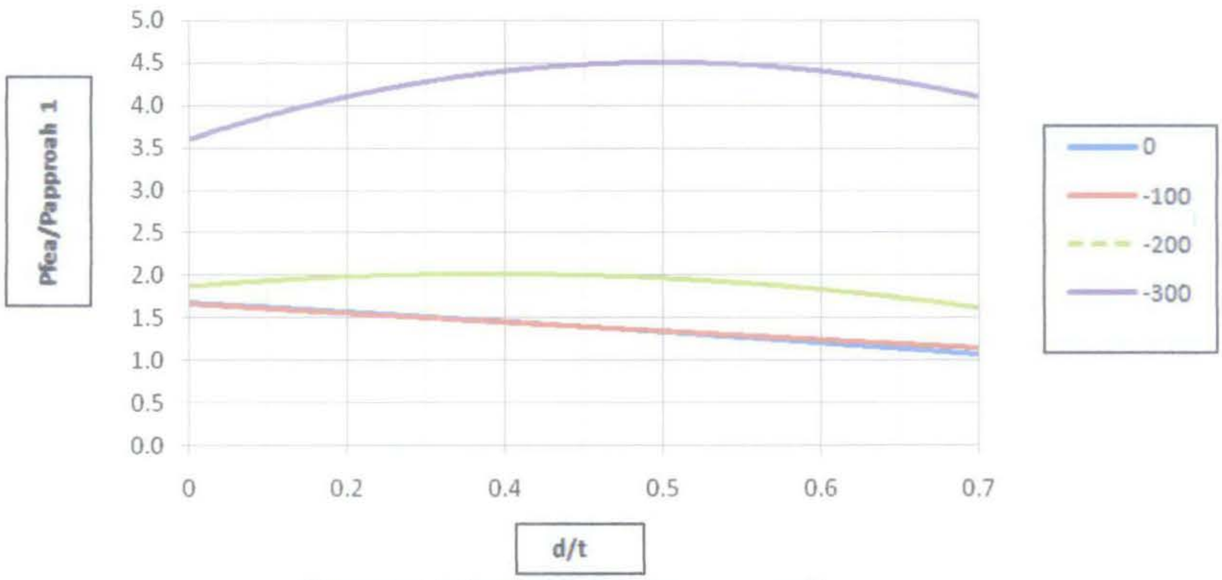

Figure 4.11: Graph of $P_{FEA}/P_{approach1}$ vs *d/t*

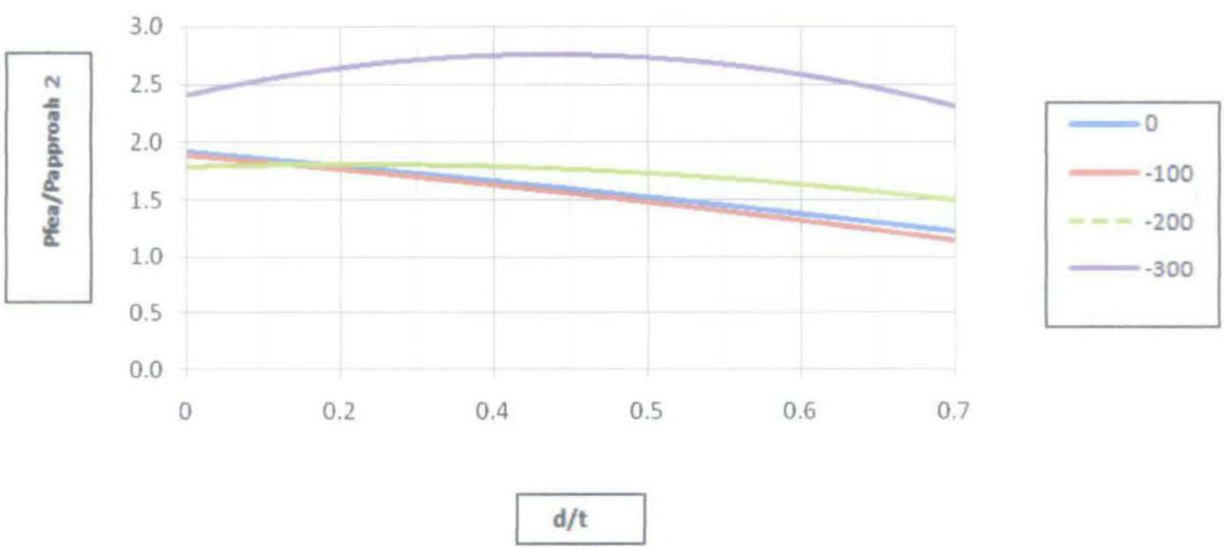

Figure 4.12: Graph of $P_{FEA}/P_{approach2}$ vs *d/t*

gure 4.12, the graph of corroded pipe pressure estimation for the σ_L= -300 MPa had same uation with the approach 1. But the compressive stress for -100 MPa showed the lowest ratio mpared to the others.

ree of Freedom and Number of Elements

Table 4.3: Table of Number of Elements and degree of freedom

Compressive stress (MPa)	d/t	Number of Elements	DOF
0	0	900	25
	0.2	2787	27
	0.4	2773	24
	0.5	2788	19
	0.6	2675	21
	0.7	2703	29
-100	0	900	23
	0.2	2787	23
	0.4	2773	21
	0.5	2788	19
	0.6	2675	18
	0.7	2703	16
-200	0	900	17
	0.2	2787	22
	0.4	2773	20
	0.5	2788	19
	0.6	2675	15
	0.7	2703	13
-300	0	900	16
	0.2	2787	15
	0.4	2773	14
	0.5	2788	14
	0.6	2675	10
	0.7	2703	8

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

. Conclusion

r the oil and gas industry, the pipelines integrity is a very important aspect in order to ıximize the profit from the production. The standard codes available today are considered to be ı conservative to be used. This is because some codes is said to be estimating the corroded ;ssure lower than the actual corroded pressure. Besides that the codes have some limitations :h as neglecting the actual size of the defect and some code only can be used for the internal ;ssure, while the other stresses are not taken into account. Because of these limitations, the ;ssure estimation for the corroded pipeline seems to be inaccurately estimated. This will lead the unnecessary maintenances and premature replacement of the pipelines.

erefore, the Finite Element Analysis (FEA) is developed to encounter this problem. The FEA ılysis can accurately estimate the failure pressure of the corroded pipeline by using the ISYS software. Through result analysis from ANSYS software, it can be concluded that the ference between corroded pressure estimation by standard code and FEA is about 4% to 80% approach 1 while for approach 2 is about 10% to 70%. The percentage of erorr in approach 1 higher compared to approach 2 because of the safety factors that were included in the ıation. These safety factors will make the corroded pipe pressure estimation become lower npared to the actual one. The compressive stress will also be a factor that affects the corroded ıe estimation. When higher longitudinal compressive stress is applied to the corroded pipe, the ɜngth of the pipe will decrease.

; Recommendations

ere are some suggestions that can be carried out for future study in estimating the corroded ›e pressure:

1. Conduct the study on the curved pipe. In the pipelines transmission, there are curved pipes and the pressure applied to the curved pipe is different compared to the straight pipe. So the corroded pipe pressure for the curved pipe seems to be interesting topic for investigation in the future.
2. Conduct at least two different computation methods as the comparison to the standard codes. Besides ANSYS, other computation method such as SOLIDWORK can be used to estimate the corroded pipe pressure.

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APPENDIX A

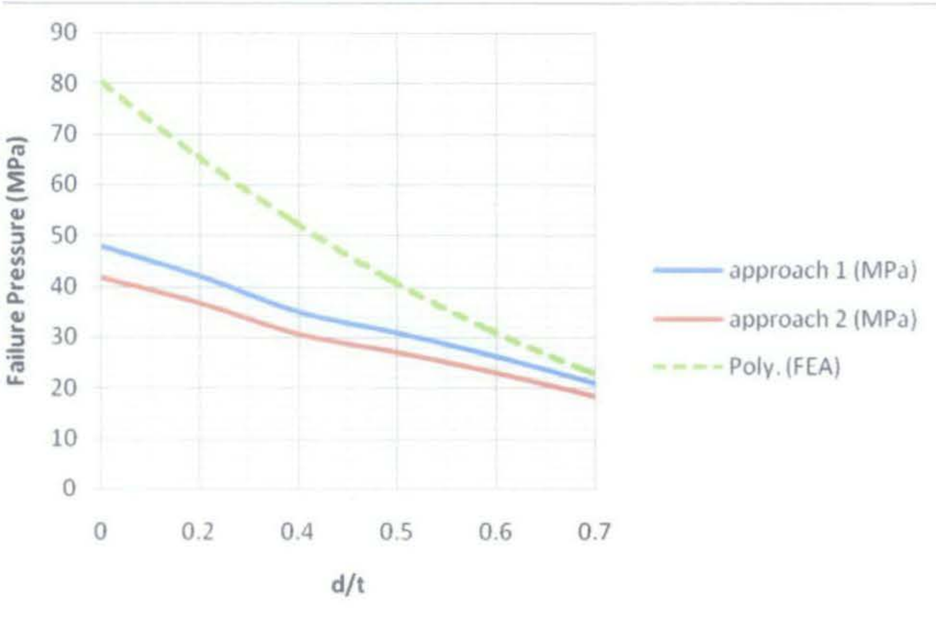
Timelines for FYP 1

/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection														
about the topic selected														
:s on the standard code ble for the project														
re the extended proposal														
e analysis on the standard using the excel														
on the different parameter tion using the excel														
re the Interim Draft Report														

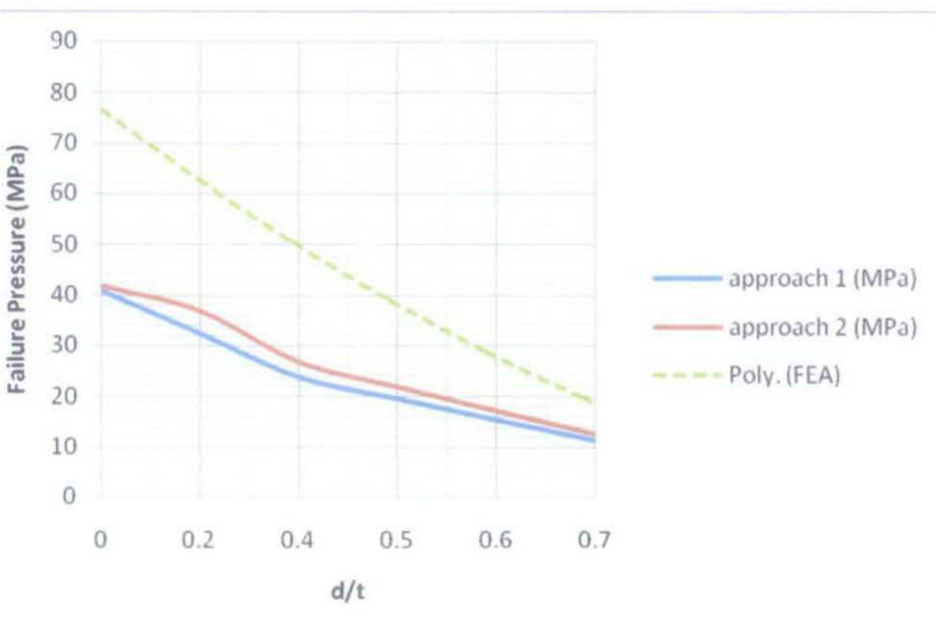
Timelines for FYP 2

/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
nue doing the project														
ruct graph and do analysis														
working on FEA model														
re the progress report														
nue working on FEA model														
re the technical paper														
up all the project work														

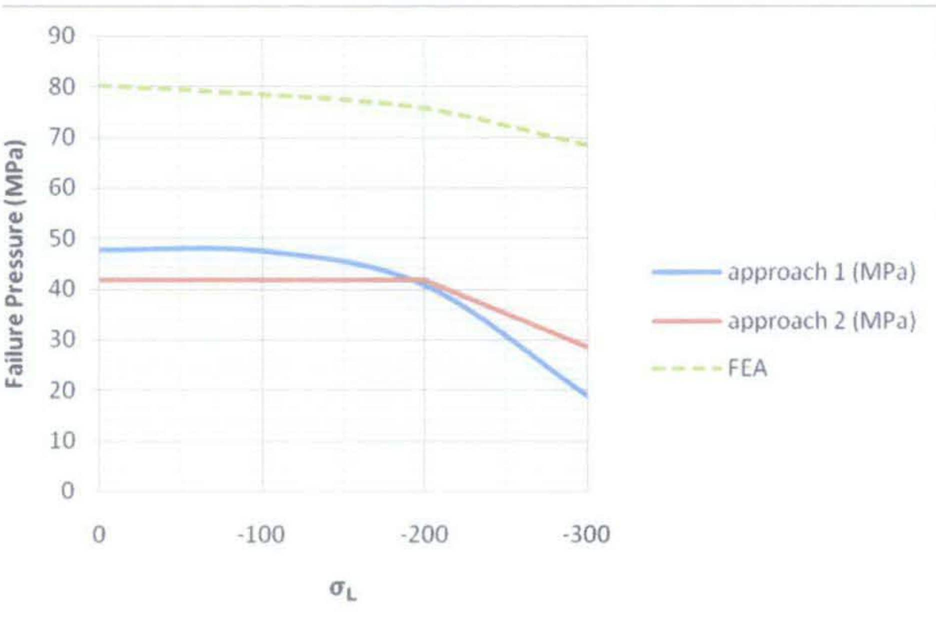
r σ_L = -100 MPa



r σ_L = -200 MPa

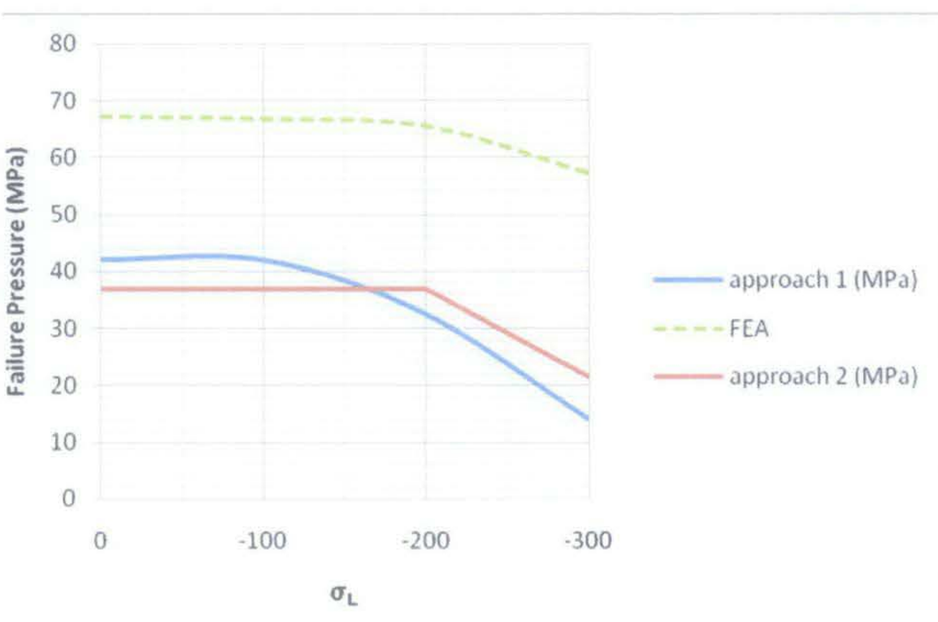


= 0



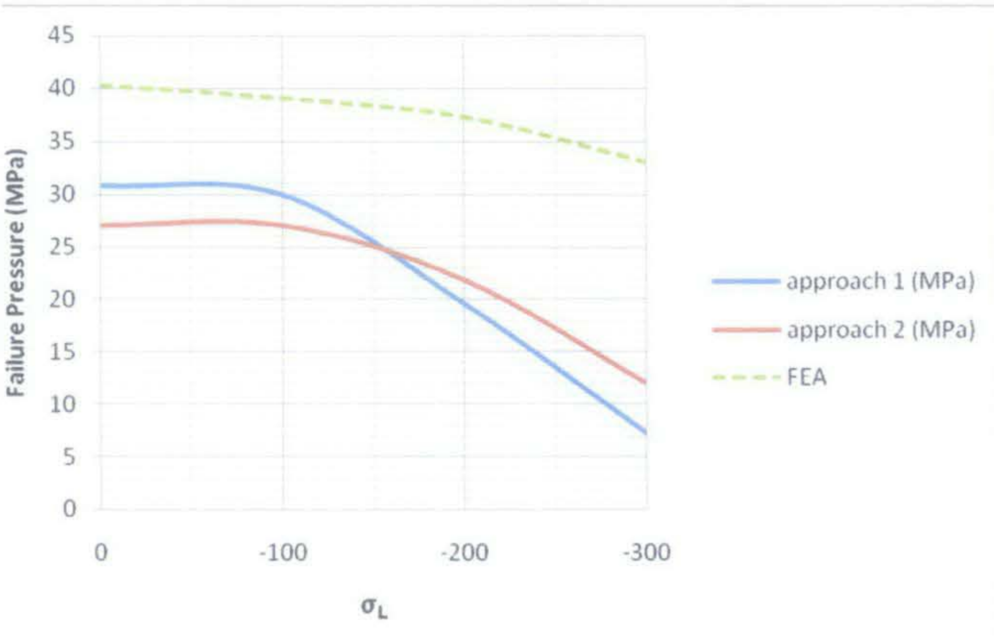
Failure Pressure (MPa)
90
80
70
60
50
40
30
20
10
0
0
-100
-200
-300
σ_L
approach 1 (MPa)
approach 2 (MPa)
FEA

= 0.2



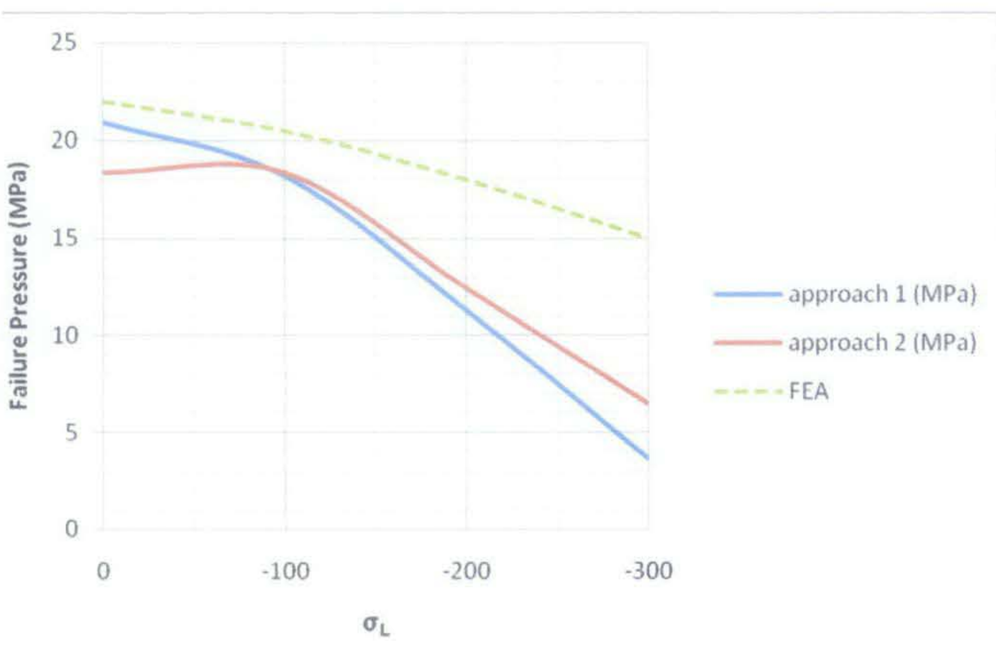
Failure Pressure (MPa)
80
70
60
50
40
30
20
10
0
0
-100
-200
-300
σ_L
approach 1 (MPa)
FEA
approach 2 (MPa)

= 0.5



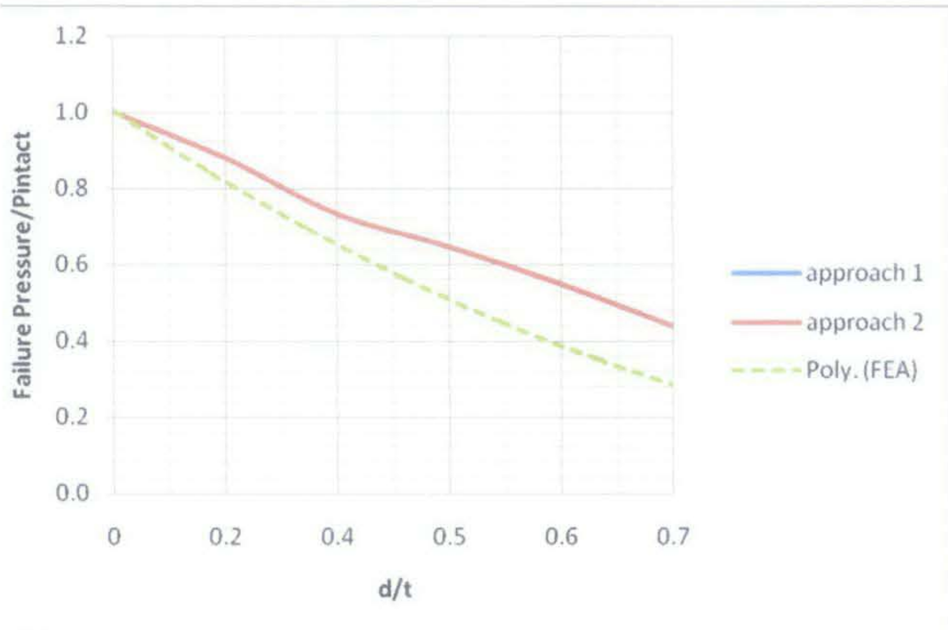
45
40
35
30
25
20
15
10
5
0
Failure Pressure (MPa)
0
-100
-200
-300
σL
approach 1 (MPa)
approach 2 (MPa)
FEA

= 0.7



25
20
15
10
5
0
Failure Pressure (MPa)
0
-100
-200
-300
σL
approach 1 (MPa)
approach 2 (MPa)
FEA

r σL = 0 MPa



r σL = -200 MPa