Finite Element Analysis of Corroded Pipelines

By

ISMAIL BIN ISMAYATIM

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

____
(Dr. Saravanan Karuppanan)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ISMAIL BIN ISMAYATIM

ABSTRACT

The objective of this project is to assess the integrity of corroded pipelines due to pitting type of corrosion defects. The scope of this project will be the finite element analysis of corroded pipelines on pitting type of corrosion defects and its modelling. This project was focused on the offshore pipeline. The type of pitting considered was on the single type of pitting. This project considered only the internal pressure as the loading. The software used to model the pipeline is CATIA and the software used to do the analysis is named ANSYS. The results of FE modelling were compared to the results of available codes used by the industries. The results from the available codes were referred as the empirical results. There were 2 codes used in this project namely DNV RP F101 and ASME B31G. As a result from this project, the integrity of corroded pipeline as well as prediction of remaining strength of corroded pipeline will be obtained. The successful outcome of this project will be a great helping guidance for industrial application towards assessing the integrity of corroded pipeline subjected to internal pressure only.

ACKNOWLEDGEMENTS

I want to thank God for all His blessing; most of all, I want to give thanks for His amazing love that knows no boundaries and endures forever. Through the experience of life, I have learnt and am still learning that I am strong when I am on his shoulders. I want to thank Him for all his wonderful thoughts of me and for raising me up to so much more than I can be.

I want to express my greatest gratitude to my supervisor, Dr. Saravanan Karuppanan for his generosity, kindness and guidance throughout the project. It is not just the guidance that he gave, but he ensured that I got proper understanding and exercising to carry out my responsibilities. He did not reprimand me when I made mistakes, but was always gracious towards me. I can honestly say that I have benefited lots under his supervision.

Last but not least, my greatest gratitude goes to those who have assisted me directly or indirectly starting from the beginning of the project. Your utmost cooperation is highly appreciated and may God repay your kindness.

Thank you.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Predicting the failure of damaged oil and gas pipeline has become an essential art for the determination of design tolerance. A pipeline may experience significant internal and external corrosion defects by chemical and environmental effects that reduce its strength and resistance to fatigue, local buckling, leakage and bursting [1]. Finite Element Modelling has become a reliable engineering method to determine the fail pressure of corroded pipe.

1.2 Problem Statement

Integrity assessment of corroded pipeline is very vital in oil and gas industry. Better understanding is required to reduce the conservatism involved in the current assessment method. Previous research found out that finite element analysis has become a reliable engineering approach towards achieving actual results. In this project, finite element analysis will be implemented and also will be compared with the available codes [2]. This comparison is a common practice in engineering world of oil and gas.

1.3 Objective and Scope of Study

The scope of study of this project is failure predictions which include the study of remaining strength of corroded offshore pipeline by using finite element analysis software (ANSYS). The focus of the study is towards oil and gas offshore pipeline used to transport gas and crude oil. The ASME B31G and DNV-RP-F101 are the standards followed in order to standardize the results obtained.

There are several types of loading related to offshore pipeline such as internal pressure, axial and/or bending loads and cyclic loads. This project is mainly focused on the case of internal pressure loading only which is discussed broadly in DNV RP F101. This project was carried out by powerful finite element analysis software called ANSYS.

There are various types of corrosion being identified in this engineering world. Therefore for the modelling purposes only 1 type of defect has been chosen throughout the project and this particular project will be focus on "**pitting type of corrosion defect**". The main objectives of this project are:

1. To assess the integrity of corroded pipeline due to **pitting** types of corrosion defects
2. To model the corroded pipeline by using finite element software package
3. To identify the factors that influence the failure prediction of corroded pipeline
4. To compare the results obtained with the available codes

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The study is focused on the oil and gas offshore pipeline. Studies have shown that integrity assessment of corroded pipeline is essential to minimize the design cost and to improve the design tolerance. Nowadays, industries are striving to have the best design and to minimize as much as possible the operational cost [1].

2.2 Pipe stress analysis

Pipeline process are typically checked by pipeline engineers to verify that the routing, nozzle loads, hangers, and supports are properly placed and selected such that the allowable pipe stress is not exceeded under different situation such as sustain, operating, hydro test etc as per the ASME or any other legislative code and local government standards. Checking is usually done with the assistance of a finite element pipe stress analysis program such as Caesar II and ABAQUS [3]. In this project software called ANSYS is used.

Stress analysis is an engineering discipline that determines the stress in materials and structures subjected to static or dynamic forces or loads. Alternately, in linear elastic systems, strain can be used in place of stress.

The aim of the analysis is usually to determine whether the element or collection of elements, usually referred to as a structure, can safely withstand the specified forces. This is achieved when the determined stress from the applied force(s) is less than the ultimate tensile strength, ultimate compressive strength or fatigue strength the material is known to be able to withstand, though ordinarily a factor of safety is applied in design [1].

The factor of safety is a design requirement for the structure based on the uncertainty in loads, material strength (yield and ultimate), and consequences of failure. Often a separate factor of safety is applied to the yield strength and to the ultimate strength. The factor of safety on yield strength is to prevent detrimental deformations and the factor of safety on ultimate strength is to prevent collapse. The factor of safety is used to calculate the maximum allowable stress [1].

Factor of Safety = Ultimate Tensile Strength/Maximum allowable stress

A key part of analysis involves determining the type of loads acting on a structure, including tension, compression, shear, torsion, bending, or combinations of such loads. A stress analysis can also be made by actually applying the force(s) to an existing element or structure and then determining the resulting stress using sensors, but in this case the process would more properly be known as testing (destructive or non-destructive). In this case special equipment, such as a wind tunnel, or various hydraulic mechanisms, or simply weights is used to apply the static or dynamic loading.

When forces are applied, or expected to be applied, repeatedly, nearly all materials will rupture or fail at a lower stress than they would otherwise. The analysis to determine stresses under these cyclic loading conditions is termed fatigue analysis and is most often applied to aerodynamic structural systems.

2.3 Strength of material

In materials science, the strength of a material refers to the material's ability to withstand an applied stress without failure. Yield strength refers to the point on the engineering stress-strain curve (as opposed to true stress-strain curve) beyond which the material begins deformation that cannot be reversed upon removal of the loading. Ultimate strength refers to the point on the engineering stress-strain curve corresponding to the maximum stress. The applied stress may be tensile, compressive, or shear.

A material's strength is dependent on its microstructure. The engineering processes to which a material is subjected can alter this microstructure. The variety of strengthening mechanisms that alter the strength of a material includes work hardening, solid solution strengthening, precipitation hardening and grain boundary strengthening and can be quantified and qualitatively explained. However, strengthening mechanisms are accompanied by the caveat that some mechanical properties of the material may degenerate in an attempt to make the material stronger.

In general, the yield strength of a material is an adequate indicator of the material's mechanical strength. Considered in tandem with the fact that the yield strength is the parameter that predicts plastic deformation in the material, one can make informed decisions on how to increase the strength of a material depending on its microstructure properties and the desired end effect. Strength is considered in terms of compressive strength, tensile strength, and shear strength, namely the limit states of compressive stress, tensile stress and shear stress, respectively. The effects of dynamic loading are probably the most important practical part of the strength of materials, especially the problem of fatigue. Repeated loading often initiates brittle cracks, which grow slowly until failure occurs.

2.4 Corroded Pipeline

Corroded pipeline are referred to the pipeline that undergo the chemical reaction between a metal or alloy and its environment. A pipeline may experience significant internal and external corrosion defects that will reduce its strength and resistance to fatigue, local buckling, leakage and bursting. Corrosion mechanisms include electrochemical corrosion, chemical corrosion, and stress-promoted corrosion [4].

The strength of old pipelines declines because of a number of reasons, with corrosion being the major one. This is especially true when the pipeline is not well corrosion–protected. The study of increasing corrosion resistance is essential to reduce the maintenance cost. The factors that most influence the behavior of the corrosion of the stainless steel are listed as follow [4]:

1. Presence of oxidizing species which aids formation of the oxide film
2. Chloride ion concentration because chloride hinders oxide film repair
3. Conductivity of the electrolyte, which affects the cathode/anode ration
4. Crevices that can initiate corrosion

5. Sediments that prevent formation of the oxide film
6. Scales and deposits that prevent formation of the oxide film
7. Chlorinating practice that alters the chlorine content of the environment
8. Surface condition of the stainless steel
9. pH(if below 5) that increase the cathodic reactions
10. Temperature that alters the relative rates of oxide film breakdown, corrosion processes and oxide film formation rate.

2.5 Types of Corrosion

Corrosion is the breakdown of the parent material primarily due to electrochemical methods where there is an exchange of electrons between two materials. Corrosion has the potential to reduce a product's design life by premature degradation. The rates of attack and severity of corrosion will vary depending on the influencing factors mentioned above. The type of corrosion (refer to Appendix 1 for pipeline corrosion sample) that is experienced may vary as well. Typical corrosion types found on pipelines include [4]:

- **Pitting** – occurs at the surface due to localized corrosion. (chosen for the modelling throughout the project)
- Crevice corrosion - occurs in or immediately around a break in the material.
- Inter-granular corrosion - corrosion at or near the grain boundaries of the metal.
- Erosion Corrosion - involves conjoint erosion and corrosion that typically occurs in fast flowing liquids that have a high level of turbulence.
- Environment-induced cracking - results from the joint action of mechanical stresses and corrosion. Stress Corrosion Cracking (SCC) falls within this group
- Uniform or general corrosion **-** proceeds at approximately the same rate over the whole surface being corroded and the extent can be measured as mass loss per unit area.

2.5.1 Pitting corrosion

Pitting corrosion is a localized form of corrosion by which cavities or "holes" are produced in the material. Pitting is considered to be more dangerous than uniform corrosion damage because it is more difficult to detect, predict and design against. Corrosion products often cover the pits. A small, narrow pit with minimal overall metal loss can lead to the failure of an entire engineering system. Pitting corrosion, which, for example, is almost a common denominator of all types of localized corrosion attack, may assume different shapes.

Pitting is a corrosion of a metal surface, confined to a point or small area (Figure 2.1) that takes the form of cavities. Pitting factor is a ratio of the depth of the deepest pit resulting from corrosion divided by the average penetration as calculated from weight loss [4].

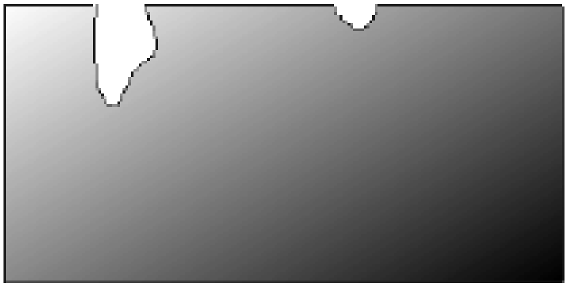
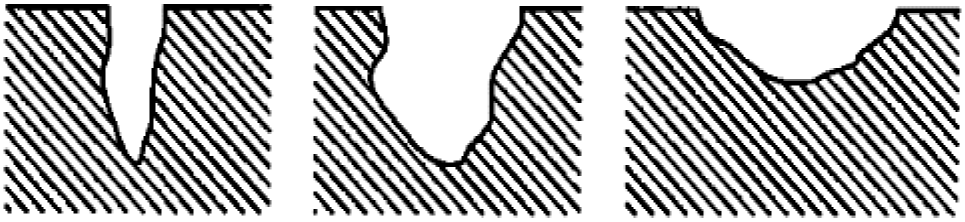


Figure 2.1: Pitting Cross Section

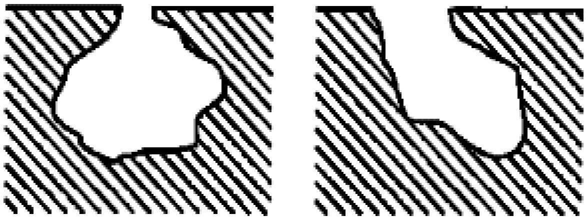
For a defect-free "perfect" material, pitting corrosion is caused by the reaction with environment (chemistry) that may contain aggressive chemical species such as chloride. Chloride is particularly damaging to the passive film (oxide) so pitting can initiate at oxide breaks. The environment may also set up a differential aeration cell (a water droplet on the surface of steel, for example) and pitting can initiate at the anodic site (centre of the water droplet) [4].

For a homogeneous environment, pitting is caused by the material that may contain inclusions (MnS is the major culprit for the initiation of pitting in steels) or defects. In most cases, both the environment and the material contribute to pit initiation.

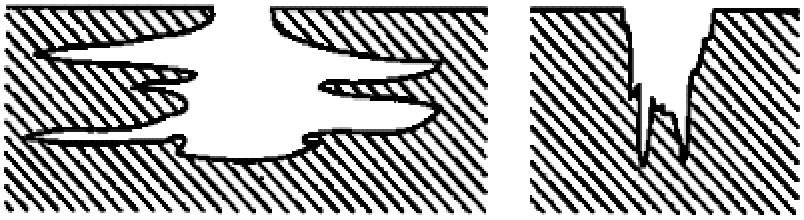
The environment (chemistry) and the material (metallurgy) factors determine whether an existing pit can be passivated or not. Sufficient aeration (supply of oxygen to the reaction site) may enhance the formation of oxide at the pitting site and thus passivate or heal the damaged passive film (oxide) - the pit is passivated and no pitting occurs. An existing pit can also be passivated if the material contains sufficient amount of alloying elements such as Cr, Mo, Ti, W, N, etc... These elements, particularly Mo, can significantly enhance the enrichment of Cr in the oxide and thus heals or passivates the pit. Figure 2.2 below shows the types of pitting corrosion [4].



Narrow, Deep Eliptical Wide, Shallow



Subsurface Undercutting



Horizontal Vertical

Figure 2.2: Types of pitting corrosion defect

Pitting corrosion can be prevented through a few methods. The most common method is the cathodic protection and/or anodic protection. The proper selection of material with known resistance to the service environment also will help the pitting from occur. By controlling environment pH, chloride and temperature would also help preventing the pitting corrosion [4].

There are several factors that can prevent and contribute to the initiation of pits on pipelines. They are:

Pipe Coating

Buried pipe is coated to offer protection from the surrounding environment. A breakdown in the coating will result in pipeline metal being exposed. The material used for coating pipes varied over the years as technology evolved.

Cathodic Protection

The introduction of an electrical current on a buried pipe such that the electrode potential of the buried pipe is lowered creates an environment where metal loss is reduced.

Soil Condition

Soil structure and conditions will not only impact the effectiveness of the cathodic protection but also may contribute to the creation of a corrosive environment. Factors such as soil type, drainage, temperature, CO_2 concentration, and electrical conductivity all contribute to the environment surrounding the pipe.

Temperature

The temperature of the soil as well as the temperature of the pipe may create favorable conditions for attack on pipeline materials. Liquid and gas lines have slightly different operating temperature characteristics but both are still susceptible

Stress (residual and others)

Stresses in the pipe may lead to premature degradation of the pipeline strength [1]. Stresses acting on the pipe include:

a. Residual stress from the manufacturing process.
b. External stress such as those incurred due to bending, welding, mechanical gouges, and corrosion.
c. Secondary stresses due to soil settlement or movement.

Pipe Pressure

Corrosion, in particular cracking, is related to the pressures exerted on the pipe. As the pressure within the pipe is increased, the growth rates for cracks also increase. The circumferential stress (hoop stress) generated by the pipeline operating pressure is usually the highest stress component that exists.

Cyclic Loading Effect

Conditions where the pipe is under cyclic loads may result in increased crack growth rates. Operating pressures for large diameter pipe can measure up to 8700kPa (1250psi). The pipeline pressure continually fluctuates due to loading and unloading of product and is influenced by pump activity. This applies to both gas and liquid lines but has greater influence in liquid systems

2.6 Finite Element Analysis

The finite element analysis (FEA), sometimes referred to as finite element method (FEM), is a computational method used to obtain approximate solutions of boundary value problems in engineering. Boundary value problem is mathematical problems in which one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain. The most common software used in finite element analysis are ANSYS and ABAQUS as they offer wide range of engineering analysis.

This project was carried out by using ANSYS. The main reasons for using ANSYS for failure prediction discussed as follows:

1. ANSYS provide wide range of engineering solution.
2. ANSYS is well known finite element software as it offers powerful tools to construct and to model engineering product.
3. Capable in operating various types of analysis such as thermal stress and pressure/load analysis.

2.6.1 Application of the Finite Element Method

The FEM can be used in various application and analysis for both structural and non-structural problem [3]. The application of FEM that are widely used nowadays on structural and non-structural cases :

Structural:

- a) Buckling
- b) Vibration analysis

Non-structural:

- a) Heat transfer
- b) Fluid flow
- c) Distribution of electric or magnetic potential

2.6.2 Advantages of Finite Element Method

The FEM of structural and non-structural enables the designers to analyze the linear and non-linear problem according to their case of study during the design stage and to evaluate any changes done to the model before the construction of the prototype. Furthermore, FEM bring a lot of advantages such as it can model irregularly shaped bodies easily, handle multiple load condition, handle various types of boundary conditions and alter the finite element model easily and relatively low cost [3].

2.7 Empirical Method

Empirical method is referred as conventional method. It is a method where formal specifications of the system, tasks and context of use serve as an input. The results of empirical evaluation can be seen as the output of a mathematical function which only depends on the formal input specifications. In general analytical methods are objective and access no empirical data. They can be applied very early in the design cycle. The reliability of measures calculated on the basis of these methods is not in question. Empirical methods are often based on simulation: the interaction of a (future) user with the system is simulated.

In this project, empirical method is crucial as it referred as the benchmark and guidance of the results of finite element method (FEM). Available codes and standard have been a great reference for the comparison of analytical method. Therefore 2 codes and standards were used throughout the project:

1. **ASME B31G-1991**, “Manual for determining the remaining strength of corroded pipeline” [5]. This codes discuss the step by step procedure on determining the remaining strength of corroded pipeline. It also defines the terminology and methodology used for determining the integrity of corroded pipeline

2. **DNV RP F101**, October 2004 “Recommended Practice of Corroded Pipelines” [2]. This recommended practice discusses few types of defects (single, interacting and complex shaped defects). It also explains the procedures used for assessment of various types of defects with calibration of safety factor and specification.

Throughout the project few assumptions has been made. The assumptions have to be followed to yield accurate results and not beyond the limitations [6]. The assumptions are:

1. Material of the pipe is carbon steel
2. Grade of the pipeline is below X80
3. The measured defect depth exceeding 85% of wall thickness is not accepted.
4. The case of defects of welds is not taken into account. Limited to corrosion on weldable pipeline steels categorized as carbon steels or high strength low alloy steel
5. Applies only to defects in the body of pipeline which gave relatively smoothes contours and cause low stress concentration
6. This procedure should not be used to evaluate the remaining strength of corroded girth or longitudinal welds or related heat affected zones, defects caused by mechanical damage, such as gouges and grooves, and defects introduced during pipe or plate manufacture, such as seams, laps, rolled ends, scabs, or slivers.
7. The criteria for corroded pipeline to remain in service presented in this manual are based only upon the ability of the pipe to maintain structural integrity under internal pressure. It should not be the sole criterion when the pipe is subjected to significant secondary stresses (e.g. bending), particularly if the corrosion has a significant transverse component
8. This analysis does not predict leaks or rupture failure

2.8 Development of Limit Load Solutions for Corroded Gas Pipelines

J. B Choi (2003), introduces procedures for development of the limit load solution. A specific limit load solution for the assessment of corrosion defects in API X65 gas pipelines is developed by comparing experimental data with FEA results. An extensive series of 3D elastic-plastic FEA was performed, and as a result, a limit load solution, which provides the maximum allowable pressure as a function of corrosion defect geometry, is proposed [7].

They introduce the factors that affect the defects for low toughness and mid-high toughness pipeline. It is observed that the plastic collapse for low toughness pipeline is based on the mechanism controlled by material flow stress while the mid-high toughness pipeline collapse due to the material ultimate stress (specific material tensile properties). They also documented the analysis of pipeline burst test versus finite element simulation.

2.9 Types of Pipeline Stress

2.9.1 Hoop stress

The wall thickness required for internal pressure design is calculated using the thin wall hoop stress equation [1] given below:

$$\sigma_H = \frac{P_i D}{2t}$$

where:

σ_H = Hoop Stress (MPa)

P_i = Internal Pressure (MPa)

t = Pipe wall thickness (mm)

D = Outside Diameter (mm)

2.9.2 Longitudinal Stress

The equivalent stress check shall be carried out for installation, hydrotest and operational cases. When tangential shear stress is ignored, the Von Mises equivalent stress shall be calculated by:

$$\sigma_E = ({\sigma_H}^2 + {\sigma_L}^2 + \sigma_H\sigma_L)^{\frac{1}{2}}$$

where:

σ_H = Hoop Stress (MPa) as in Figure 2.3

σ_L = Longitudinal Stress (MPa) as in Figure 2.3

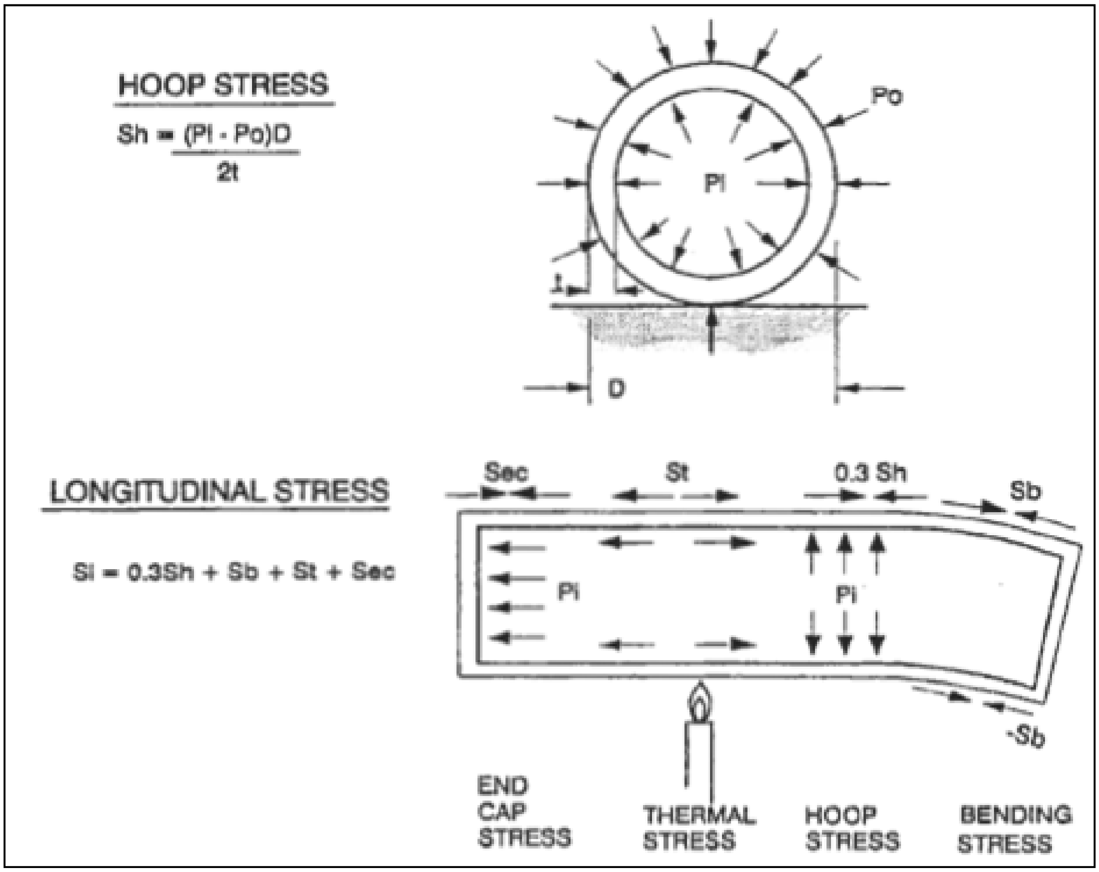


Figure 2.3: Stress and Pressure Implication (Source: Yong Bai, R. Bhattacharyya & M.E. McCormick, Pipelines And Risers, Volume 3, Norway, Stavanger University College)

2.9. 3 Longitudinal corrosion defect, internal pressure loading only (from DNV RP F101)

The allowable corroded pipe pressure of a single metal loss defect subject to internal pressure loading is given by the following acceptance equation [2].

$$Pcorr = \gamma_m \frac{2tfu(1 - \gamma_d(\frac{d}{t})}{(D - t)(1 - \frac{\gamma_d(\frac{d}{t})}{Q}}$$

where:

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

Pcorr = allowable corroded pipe pressure of a single longitudinal corrosion defect under internal pressure loading

γ_m = partial safety factor for longitudinal model prediction

γ_d = partial safety factor for corrosion depth

d = pitting depth

f_u = ultimate tensile strength of pipe material

t = pipeline wall thickness

l = pitting longitudinal length

Q = length Correction Factor

Pmao = maximum allowable operating pressure

Pcorr is not allowed to exceed Pmao. The static head and pressure reference height should be accounted for. Measured defects depth exceeding 85% of the wall thickness is not accepted.

CHAPTER 3

METHODOLOGY

3.1 Pipeline Stresses and Loads identification

At the early stage, stresses and loads need to be identified as they influence the failure prediction of a corroded pipeline. Internal pressure, axial and/or bending loads may need to be considered. The classifications of the pressure loading are important in this project. In this project, the case of internal pressure loading only is considered.

3.2 Empirical Failure Prediction

Empirical approach in failure prediction of corroded pipelines is crucial as it will be used to compare with the finite element method results. Examples of case studies were obtained from the codes and standards and these will be used as the guidelines of the empirical analysis.

3.3 Corroded Pipeline Modelling using FEM

Corroded pipelines modelled using FEM allow wide range of analysis. The finite element modelling often involves various shapes of model and various material behavior. The ANSYS software allows the user to simulate the critical area (the are where it is expected to fail) and to simulate deforming surfaces. The multiphysic capabilities of ANSYS enable the user to improve user product development processes, reduce analysis time, and improve product innovations and performances. Schematic flow of FEA for this project was discussed in Figure 3.1, Figure 3.15 and Figure 3.16.

Modelling of corroded pipeline involves few stages before the analysis can be done. The stage consists of defining element type, assigning material properties, modelling, meshing, defining loads and read results from solution. All of the stages mentioned are as follow:

1. Element type

   The 3-D 20-Node Structural Solid – Solid95 type of element has been selected to be the element of the pipeline model (Figure 3.2). SOLID95 can tolerate irregular shapes without as much loss of accuracy. SOLID95 elements have compatible displacement shapes and are well suited to model curved boundaries. The 20-node structural solid have mid-side nodes to facilitate modeling curved surfaces.

   The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element may have any spatial orientation. SOLID95 has plasticity, creep, stress stiffening, large deflection, and large strain capabilities. Various printout options are also available. The geometry, node locations, and the coordinate system for this element are shown in Figure 3.2

2. Material properties

   Elastic of modulus – this properties define the stiffness of the material used for the pipeline model. This property was defined in the ANSYS by defining in the column EX in ANSYS (Figure 3.4). Poisson’s ratio was defined in the ANSYS in the column PRXY.

3. Modelling

   Hollow cylinder modelling - pipeline were defined as hollow cylinder with known wall thickness, outer and inner radius and the length of the pipeline. All the dimensions were then defined in the ANSYS (Figure 3.5)

Pitting defect modelling – pitting defect were defined as rectangular shape. It is defined as the volume taken out from the pipeline model (Figure 3.6 and Figure 3.7). The modelling of the pitting were controlled by 3 dimensions which were the depth, longitudinal length and circumferential length.

4. Meshing

General meshing – Meshing is one of the methods used in Finite Element Method (FEM). Meshing is a method of representing field variables such as displacement by polynomial function that produce a displacement field compatible with applied boundary condition. Polynomial function will become very complex if we do not do meshing. In this project, element size of 0.05 is selected (Figure 3.8 and Figure 3.9).

Refinement – the refinement has been done to produce more refined mesh (Figure 3.10 and Figure 3.11). This refined meshing produces convergence stress results and will be discussed later. The refinement area was selected only around the pitting defect as that area is the area of interest for maximum Von Mises stress to occur.

5. Define loads

The load was applied on the internal surface of the pipeline to represent the internal pressure subjected to pipeline. The magnitudes of load were manipulated in the ANSYS by setting the value of load in the ANSYS (Figure 3.12 and Figure 3.13). These value of load are based on the pipeline operating data available(Appendix 2).

6. FEM results

Comparing the Von Mises Stress with the material yield stress is an accepted way of evaluating yielding for **ductile metals** in a combined stress state, so we enter the postprocessor and plot the **element solution** of von Mises stress (Figure 3.14). Further mesh refinement gives a slightly different stress value. The refinement will converge the result of failure pressure of the pipeline.

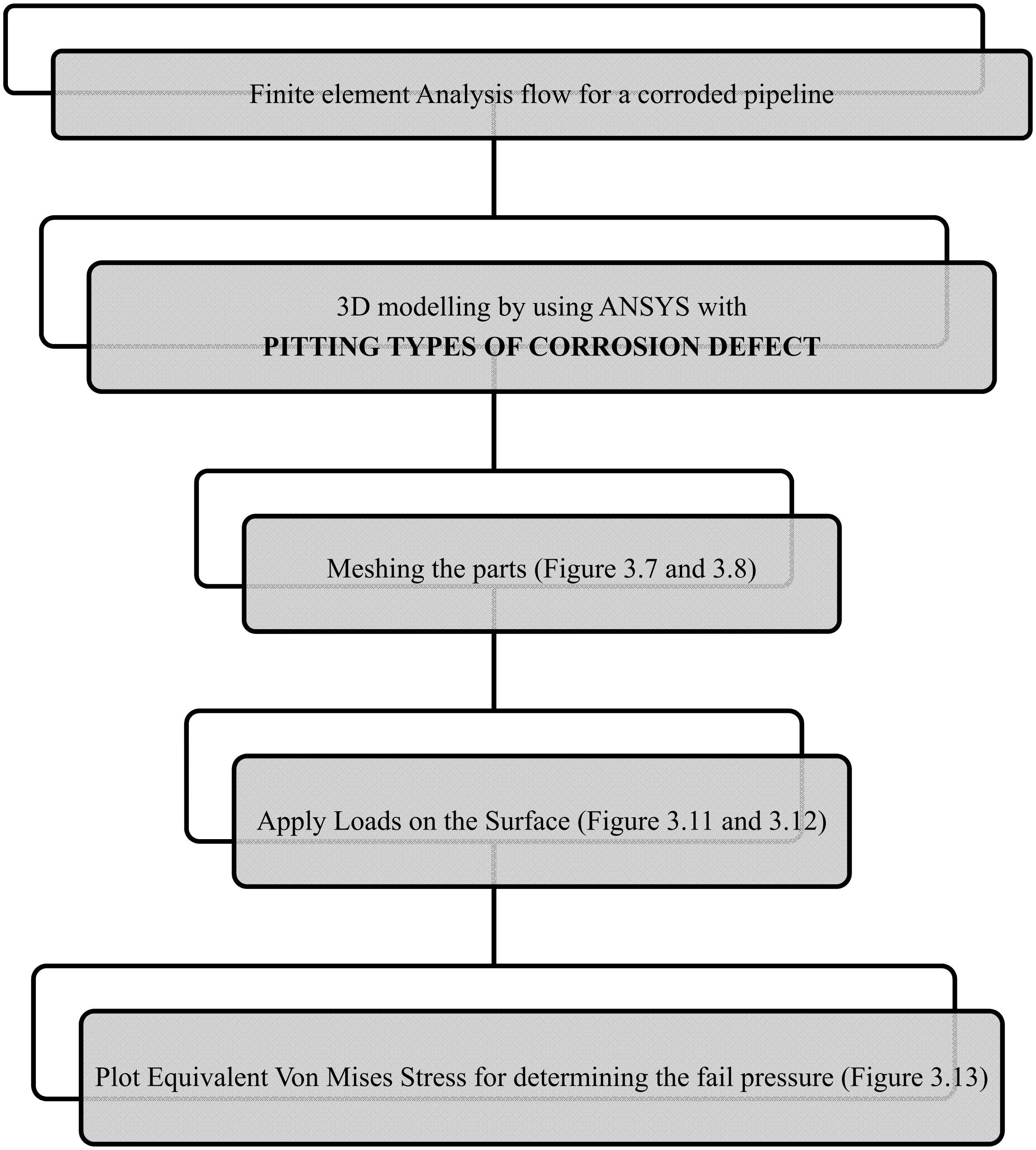


Figure 3.1 : Schematic Flow of Finite Element Analysis of Corroded Pipeline

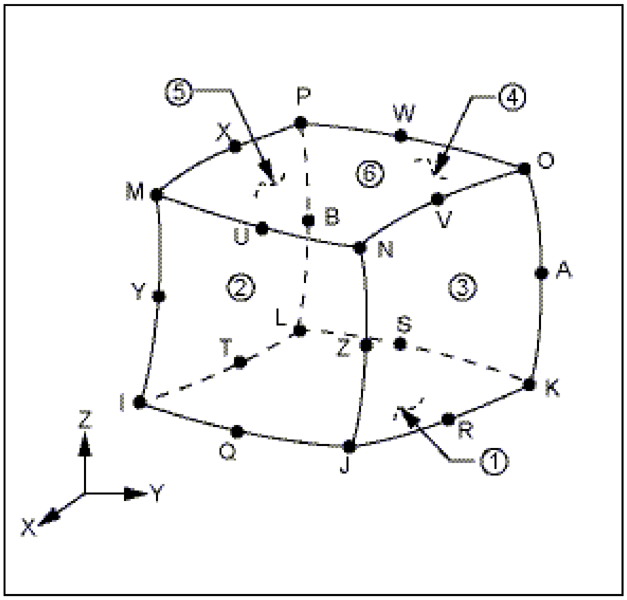
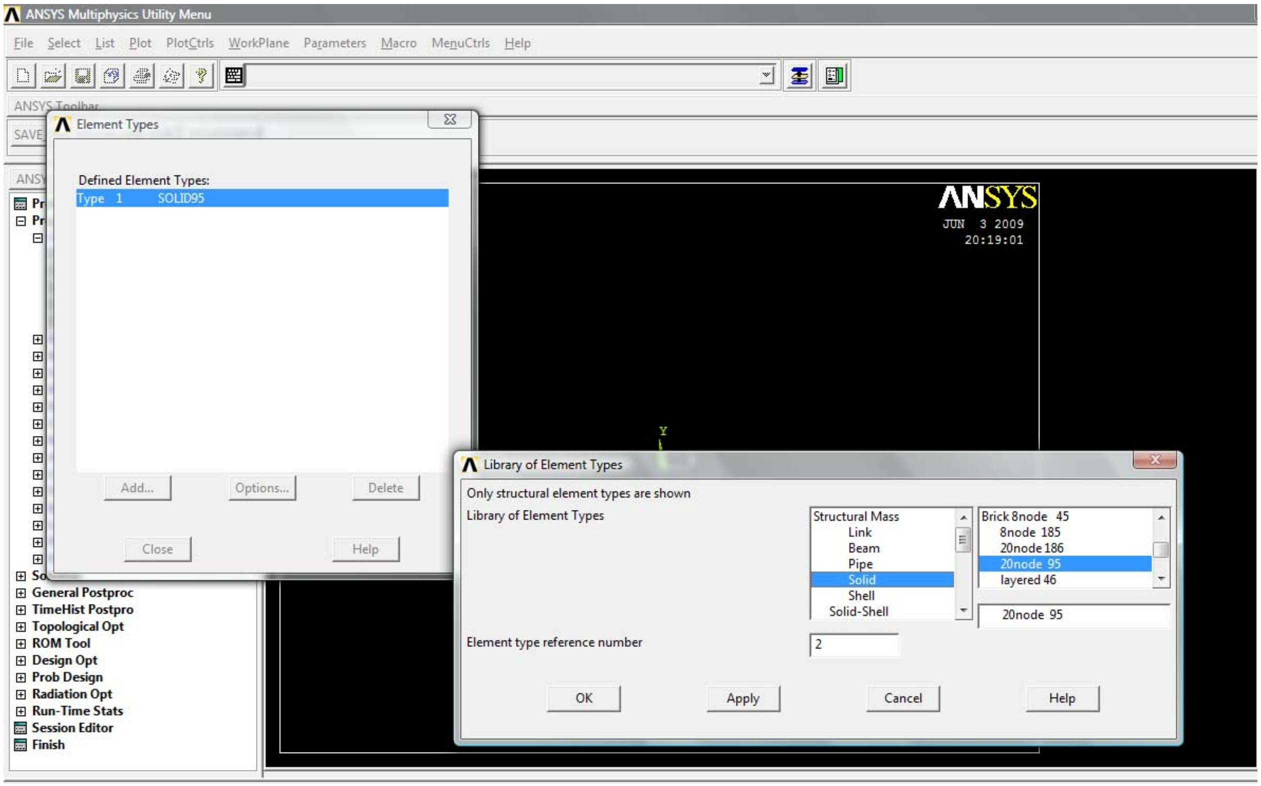


Figure 3.2 : Solid95 element geometry



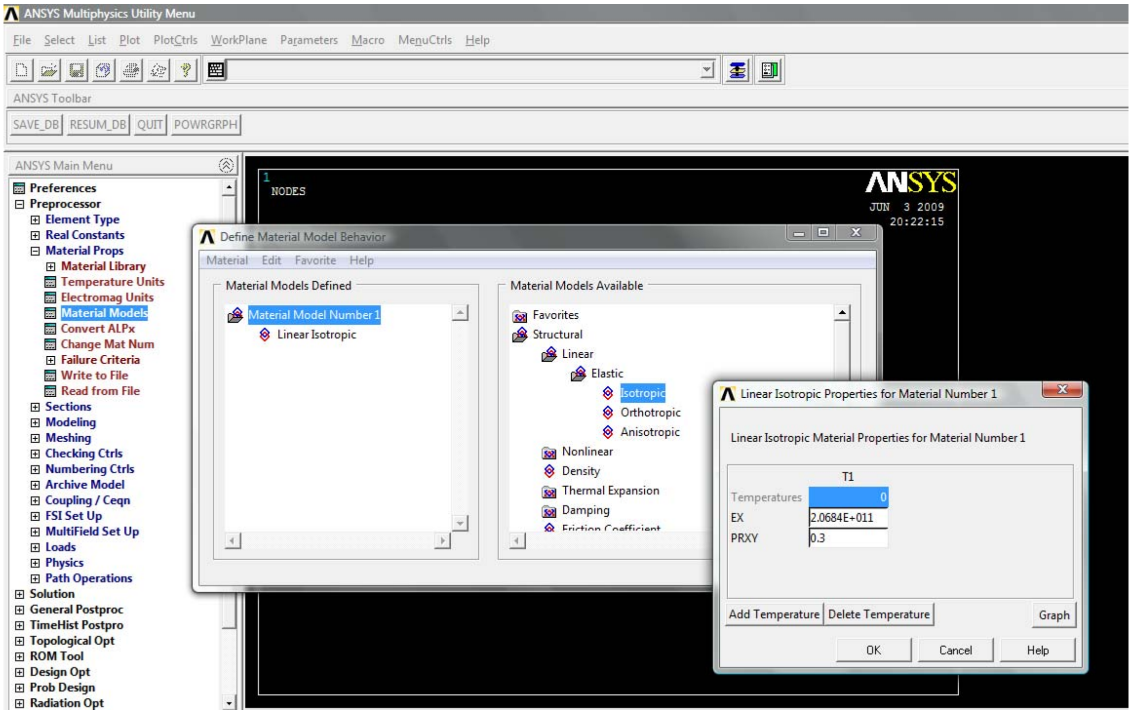
Defined Element Types:
Type 1 SOLID95

Only structural element types are shown

Library of Element Types: Solid — 20node 95

Element type reference number: 2

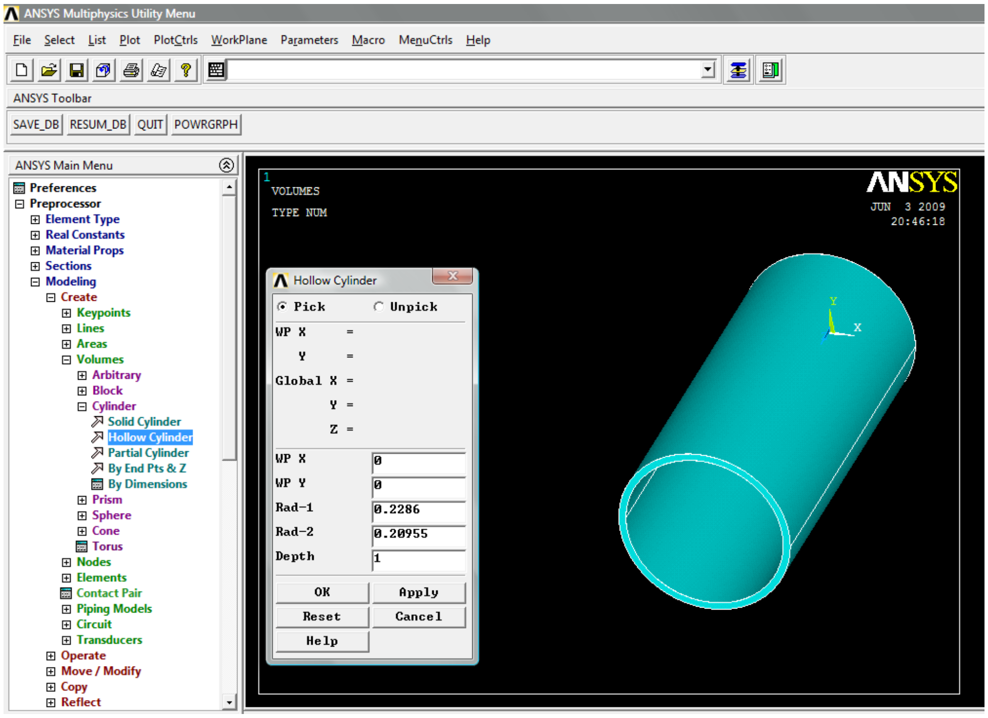
Figure 3.3 : Defining FEM element



Linear Isotropic Material Properties for Material Number 1

	T1
Temperatures	0
EX	2.0684E+011
PRXY	0.3

Figure 3.4 : Defining FEM material properties



● Pick ○ Unpick

WP X =

Y =

Global X =

Y =

Z =

WP X	0
WP Y	0
Rad-1	0.2286
Rad-2	0.20955
Depth	1

Figure 3.5 : Pipeline model

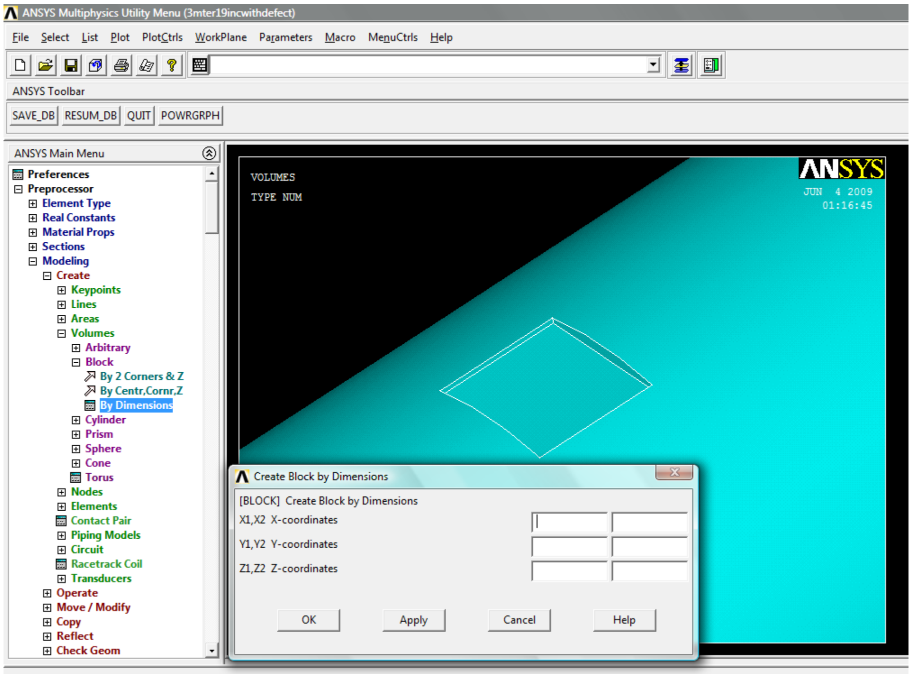


Figure 3.6 : Pitting modelling

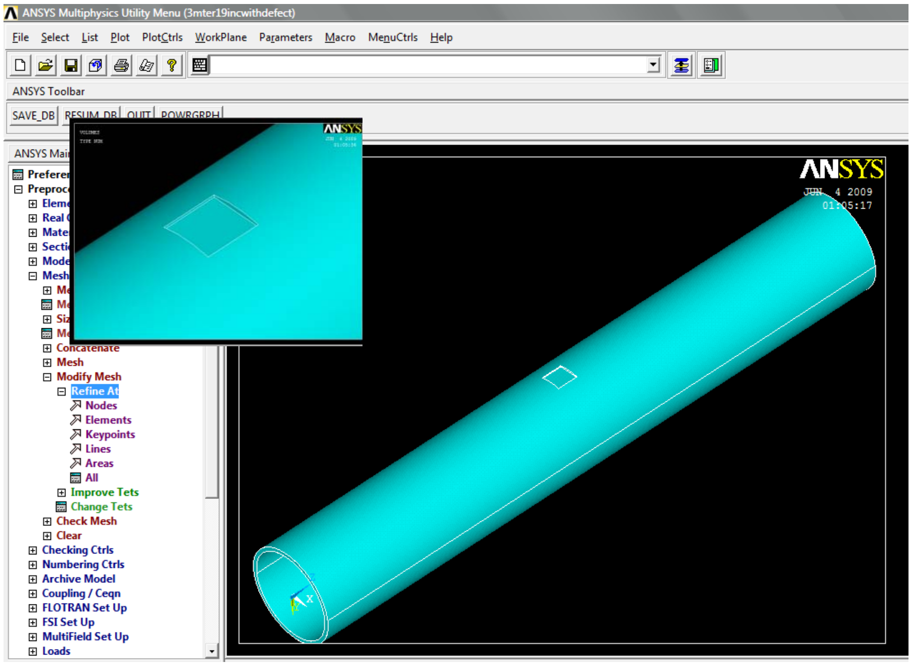
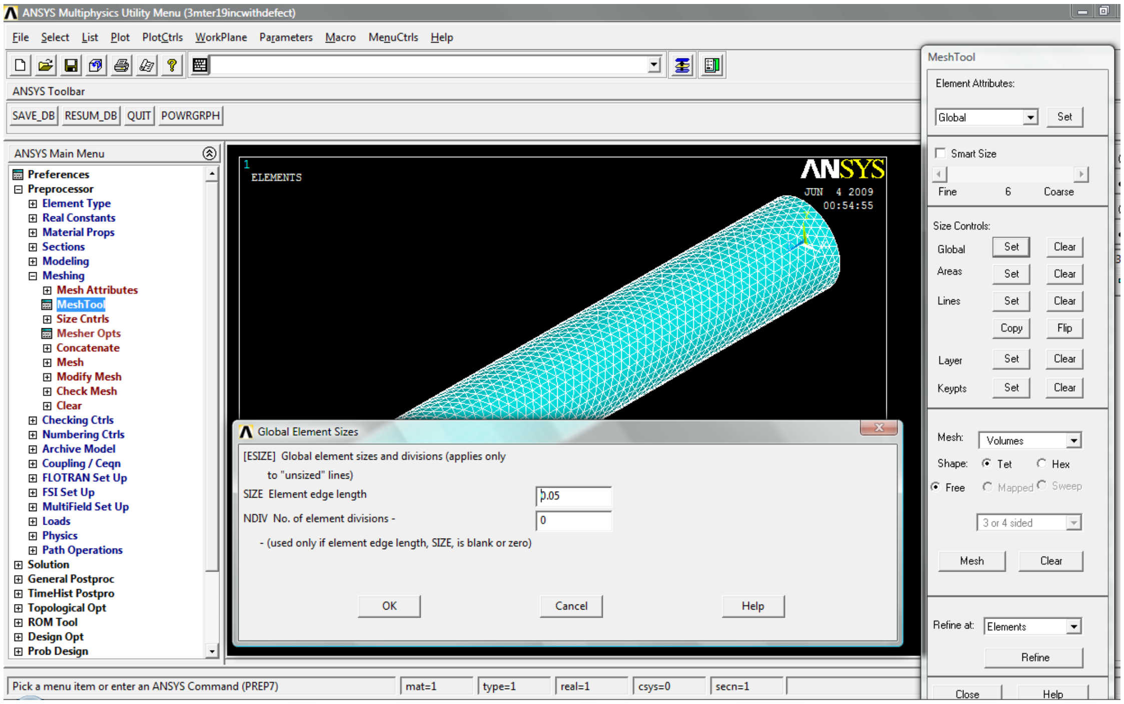


Figure 3.7 : Pipeline model with pitting



Global Element Sizes

[ESIZE] Global element sizes and divisions (applies only to "unsized" lines)

SIZE Element edge length 0.05

NDIV No. of element divisions - 0

- (used only if element edge length, SIZE, is blank or zero)

Figure 3.8 : Defining meshing size

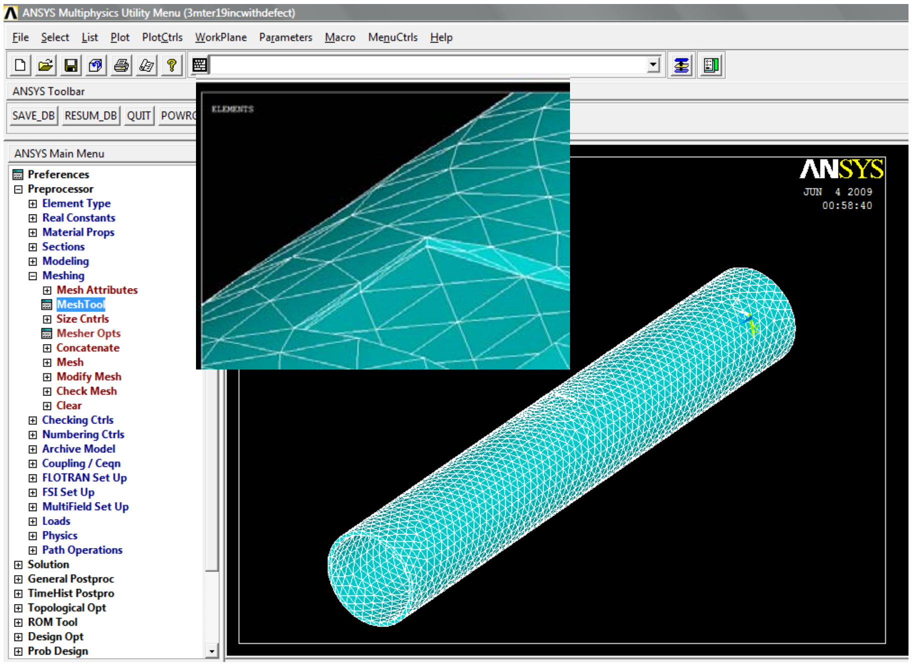


Figure 3.9 : Meshed pipeline model

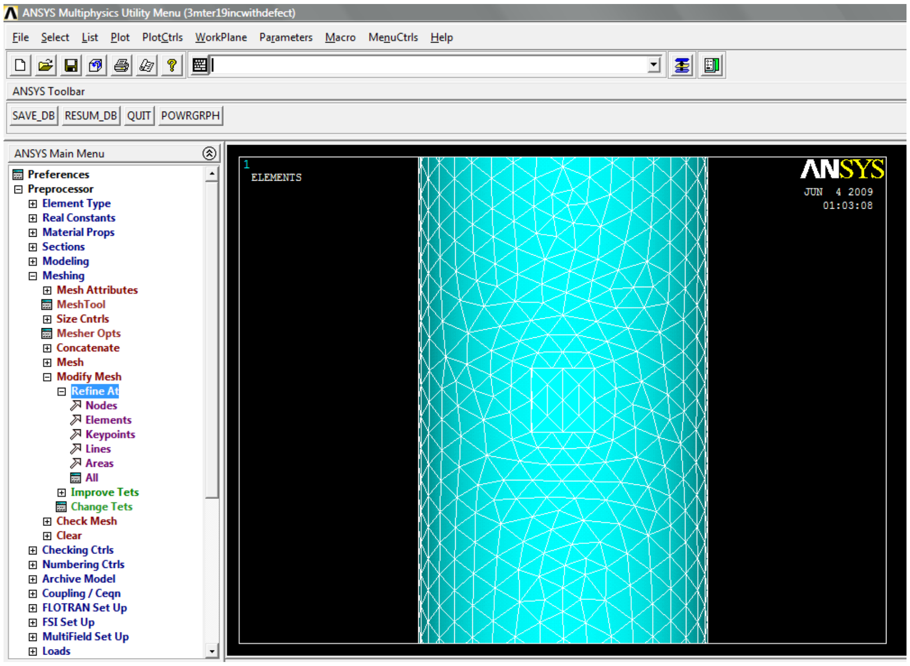
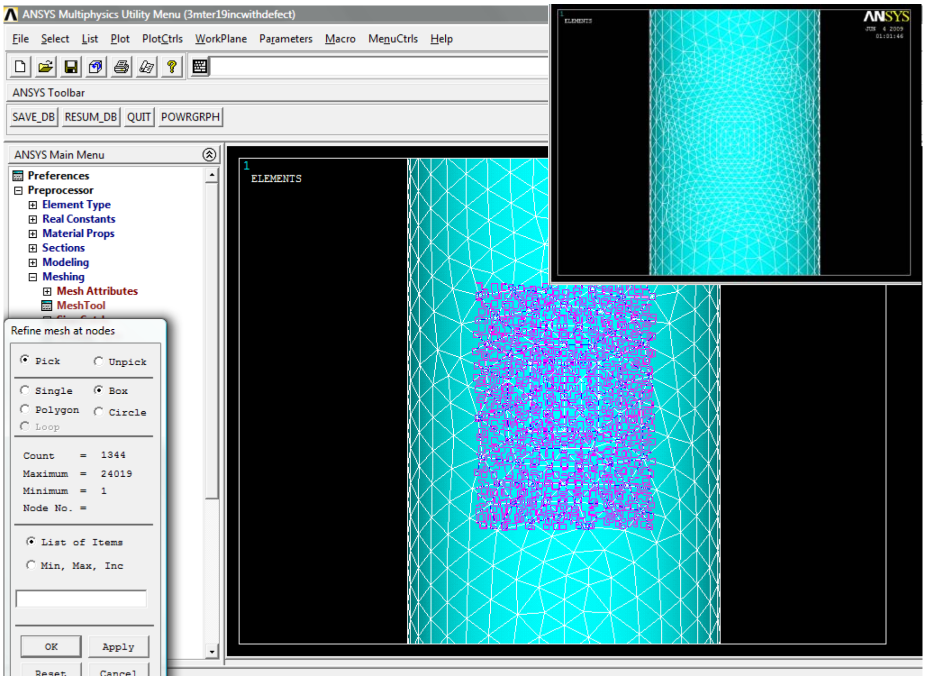


Figure 3.10 : Pitted pipeline model before refinement



● Pick ○ Unpick

○ Single ● Box

○ Polygon ○ Circle

○ Loop

Count = 1344

Maximum = 24019

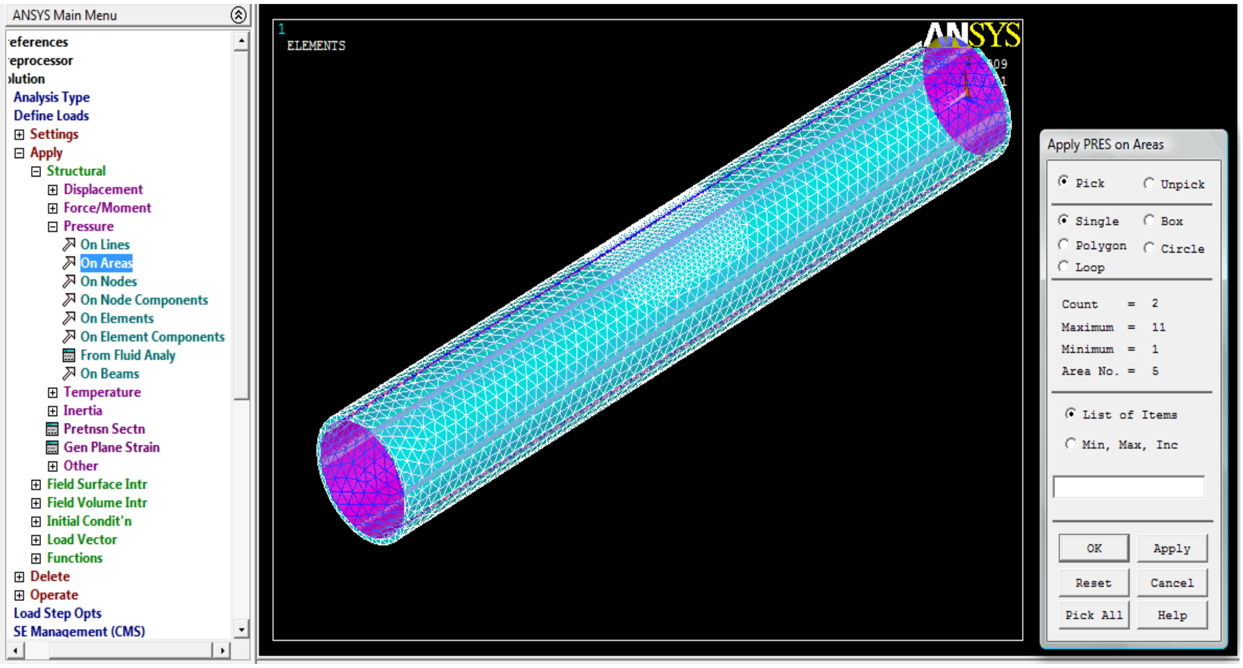
Minimum = 1

Node No. =

● List of Items

○ Min, Max, Inc

Figure 3.11 : Pitted pipeline model after refinement



● Pick ○ Unpick

● Single ○ Box

○ Polygon ○ Circle

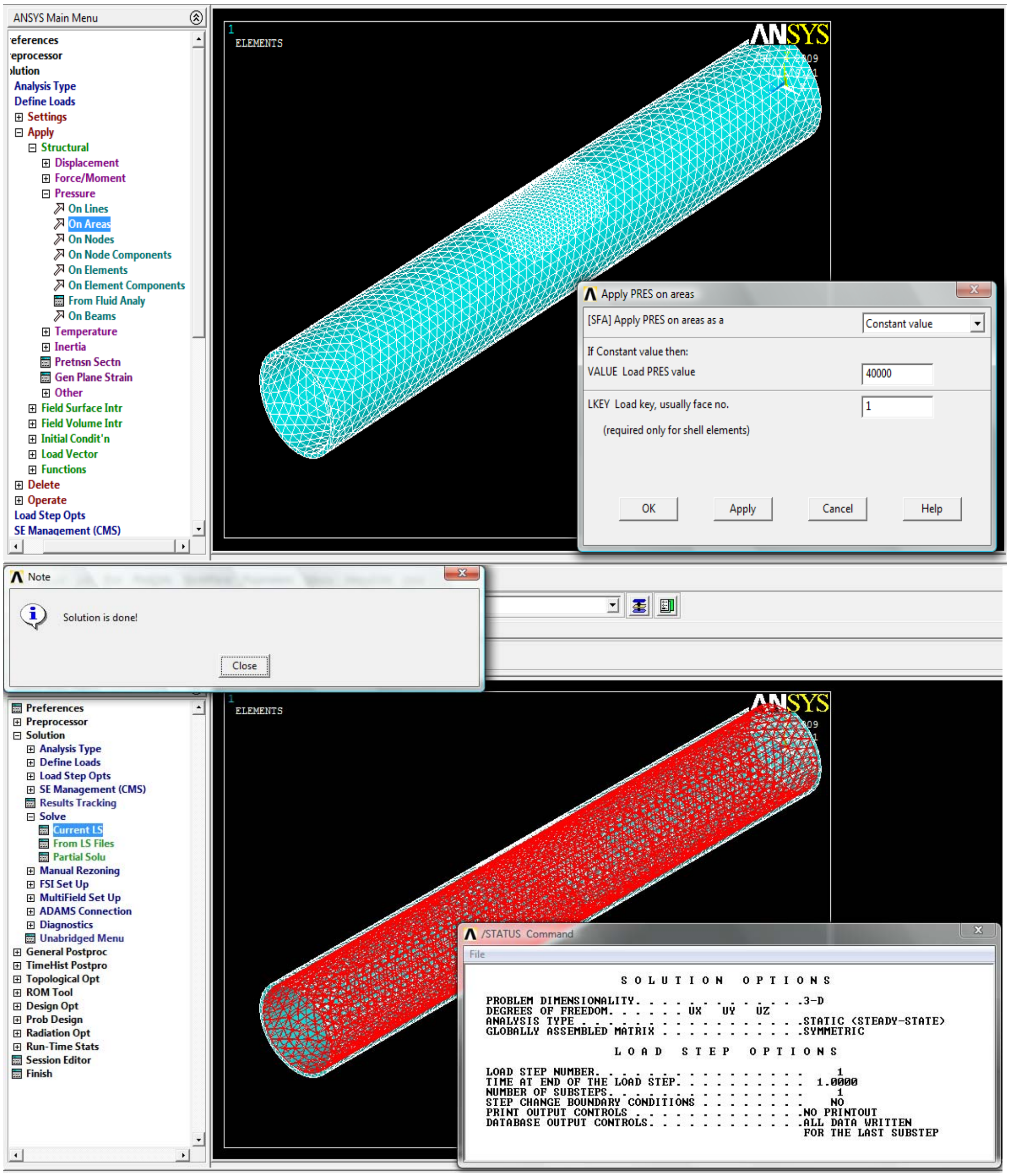
○ Loop

```
Count    =  2
Maximum  =  11
Minimum  =  1
Area No. =  5
```

● List of Items

○ Min, Max, Inc

Figure 3.12 : Defining direction of internal pressure loading



[SFA] Apply PRES on areas as a Constant value

If Constant value then:

VALUE Load PRES value 40000

LKEY Load key, usually face no. 1

(required only for shell elements)

Solution is done!

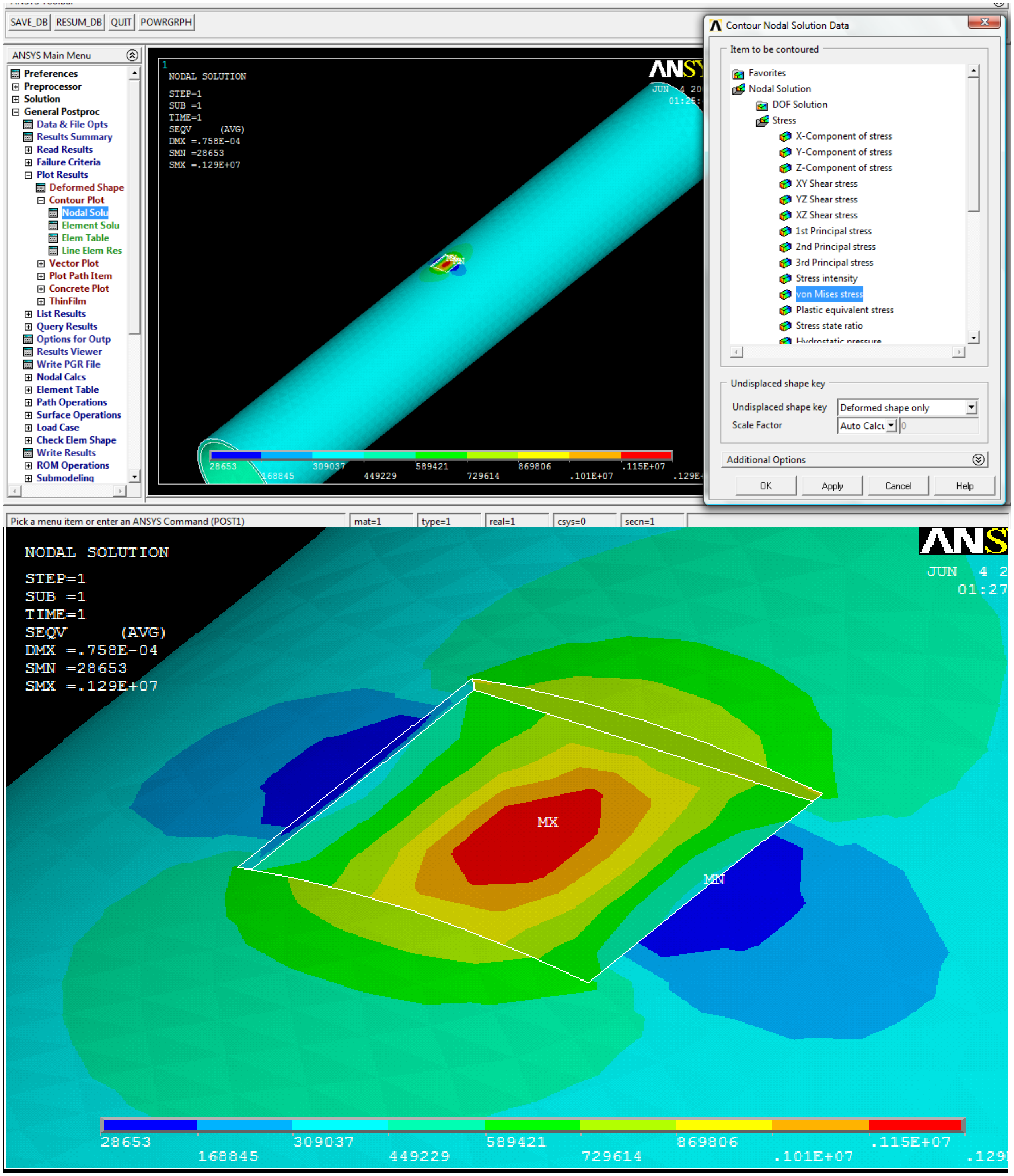
```
                    S O L U T I O N   O P T I O N S

   PROBLEM DIMENSIONALITY. . . . . . . . . . . . .3-D
   DEGREES OF FREEDOM. . . . . . UX   UY   UZ
   ANALYSIS TYPE . . . . . . . . . . . . . . . . .STATIC (STEADY-STATE)
   GLOBALLY ASSEMBLED MATRIX . . . . . . . . . . .SYMMETRIC

                   L O A D   S T E P   O P T I O N S

   LOAD STEP NUMBER. . . . . . . . . . . . . . . .    1
   TIME AT END OF THE LOAD STEP. . . . . . . . . .  1.0000
   NUMBER OF SUBSTEPS. . . . . . . . . . . . . . .    1
   STEP CHANGE BOUNDARY CONDITIONS . . . . . . . .   NO
   PRINT OUTPUT CONTROLS . . . . . . . . . . . . .NO PRINTOUT
   DATABASE OUTPUT CONTROLS. . . . . . . . . . . .ALL DATA WRITTEN
                                                  FOR THE LAST SUBSTEP
```

Figure 3.13 : Defining magnitude of internal pressure loading



Undisplaced shape key: Deformed shape only

Scale Factor: Auto Calc 0

Pick a menu item or enter an ANSYS Command (POST1)

mat=1 type=1 real=1 csys=0 secn=1

```
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
SEQV       (AVG)
DMX =.758E-04
SMN =28653
SMX =.129E+07
```

Figure 3.14 : Plotting Von Misses Stress result

3.4 Compliance with Design Codes

All results are expected to comply with the standards and recommended practice used. This project requires analysis which follows the design codes. This research project will use DNV RP F101 with conjunction of ASME B31G as the design codes.

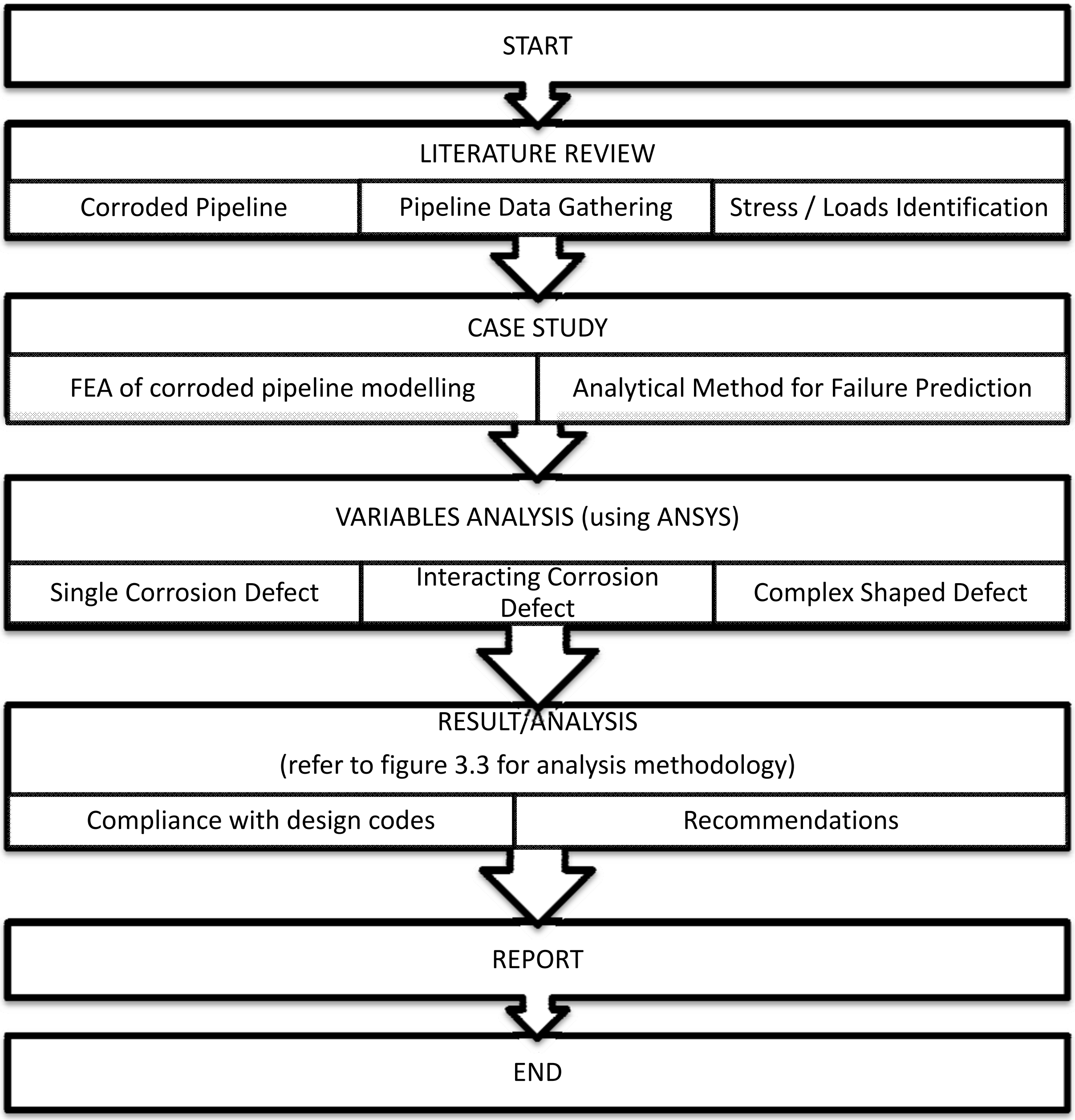


Figure 3.15 : Project Methodology

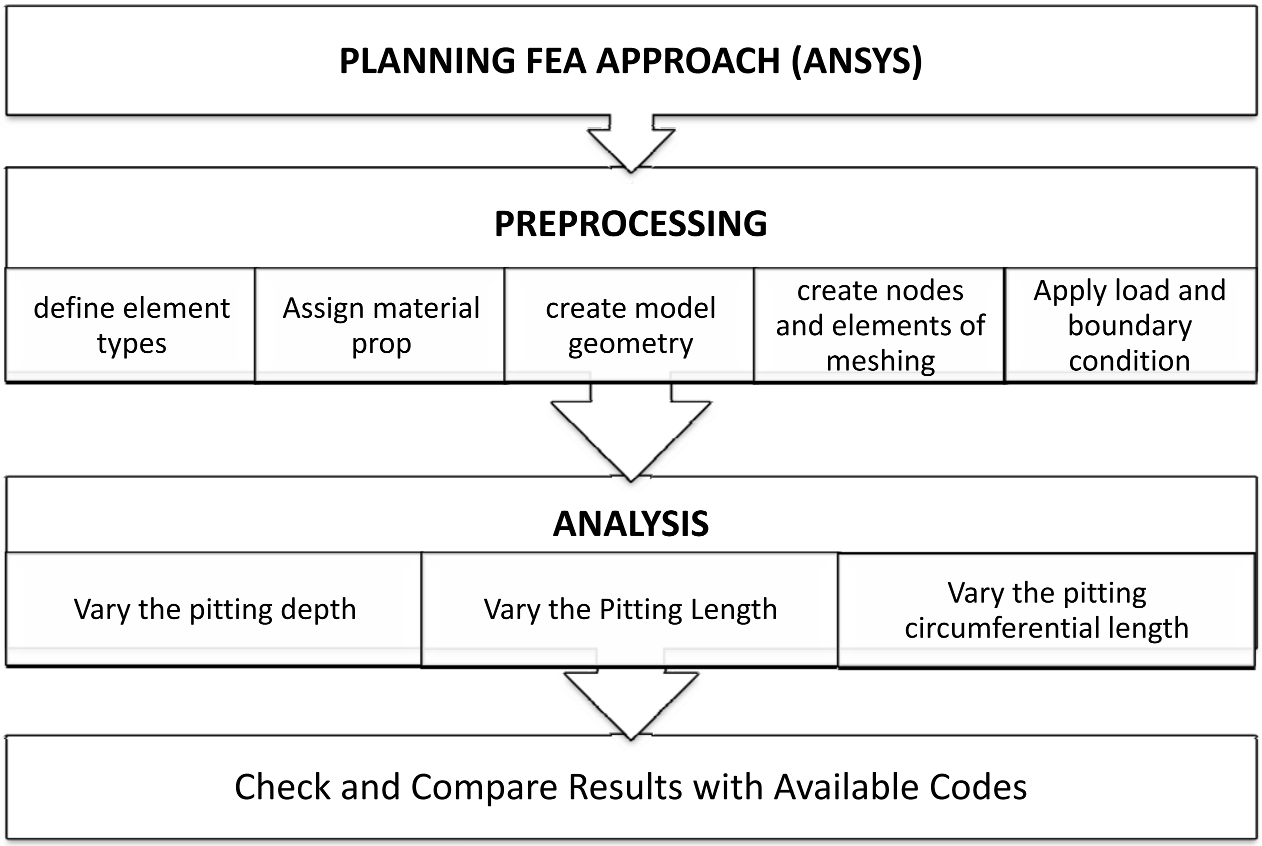


Figure 3.16 : Analysis Methodology

CHAPTER 4

RESULTS AND DISCUSSION

Results

4.1 Assessment of longitudinal corrosion defect with internal pressure only

Assessments of longitudinal corrosion defect with internal pressure only have been analyzed. To determine the failure pressure associated with internal pressure only, a graph (Figure 4.1) of maximum Von Mises stress versus internal pressure were plotted. The analysis was conducted on a pipeline with **10mm, 30.98mm and 30.98mm** of depth, longitudinal length and circumferential length of pitting defect respectively. The results from the calculation (empirical method) and from FEA were obtained and a graph of the results were constructed (Figure 4.1).

From Figure 4.1, we can see the linear trend line. This shows that the principle stress is directly proportional with the internal pressure exerted on the pipe. The red line in Figure 4.1 corresponds to the ultimate yield strength of the material which is **460MPa**. The red line projected to the internal pressure axis represents the failure pressure which in this case is **53.1MPa**. Therefore it is concluded that the pipe will fail at **37.76MPa**. Furthermore, the result of failure pressure is compared with the theory (DNV RP F101) which is **46.2MPa**.

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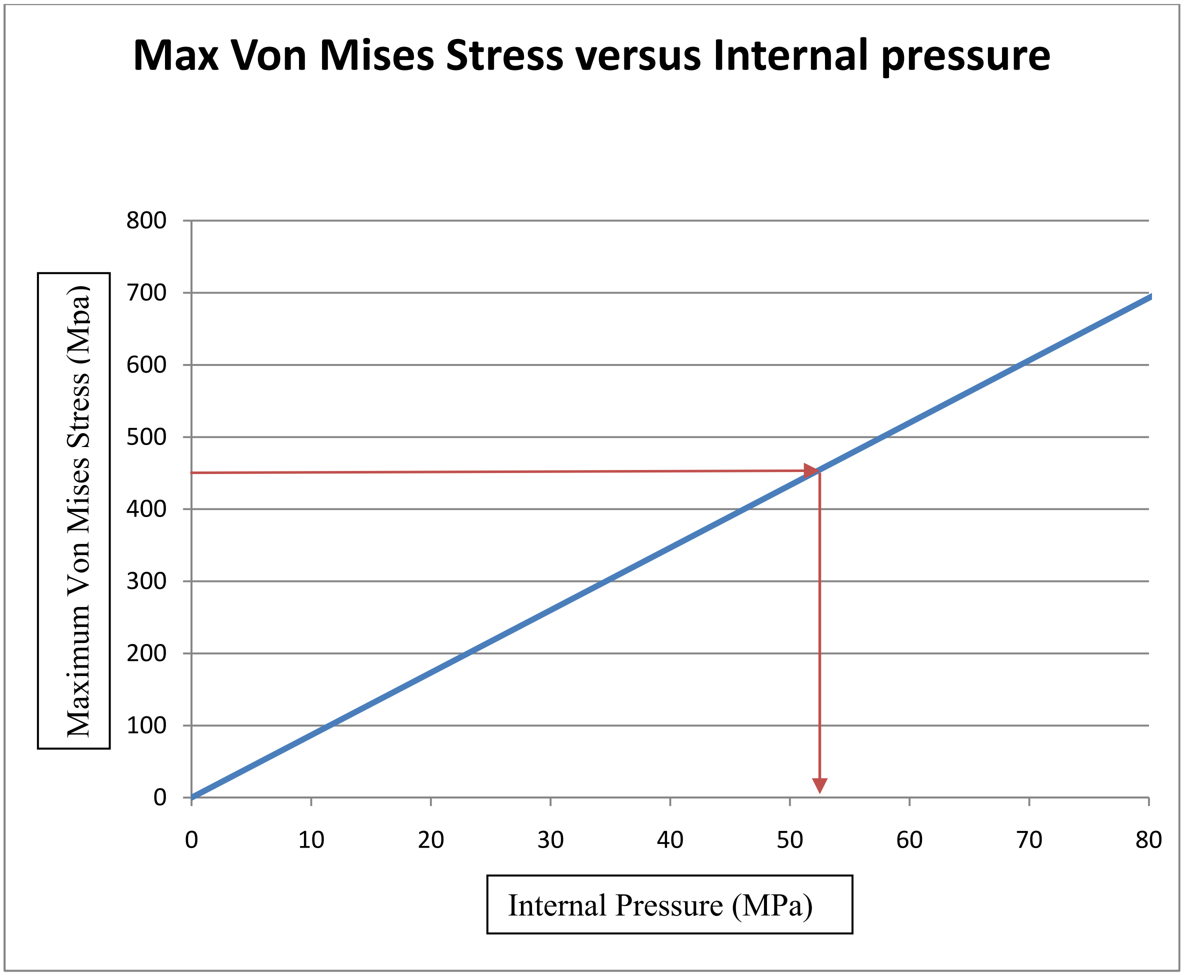

Figure 4.1: Maximum Von Mises stress versus internal pressure (FEA)

4.2 Variation of pitting depth

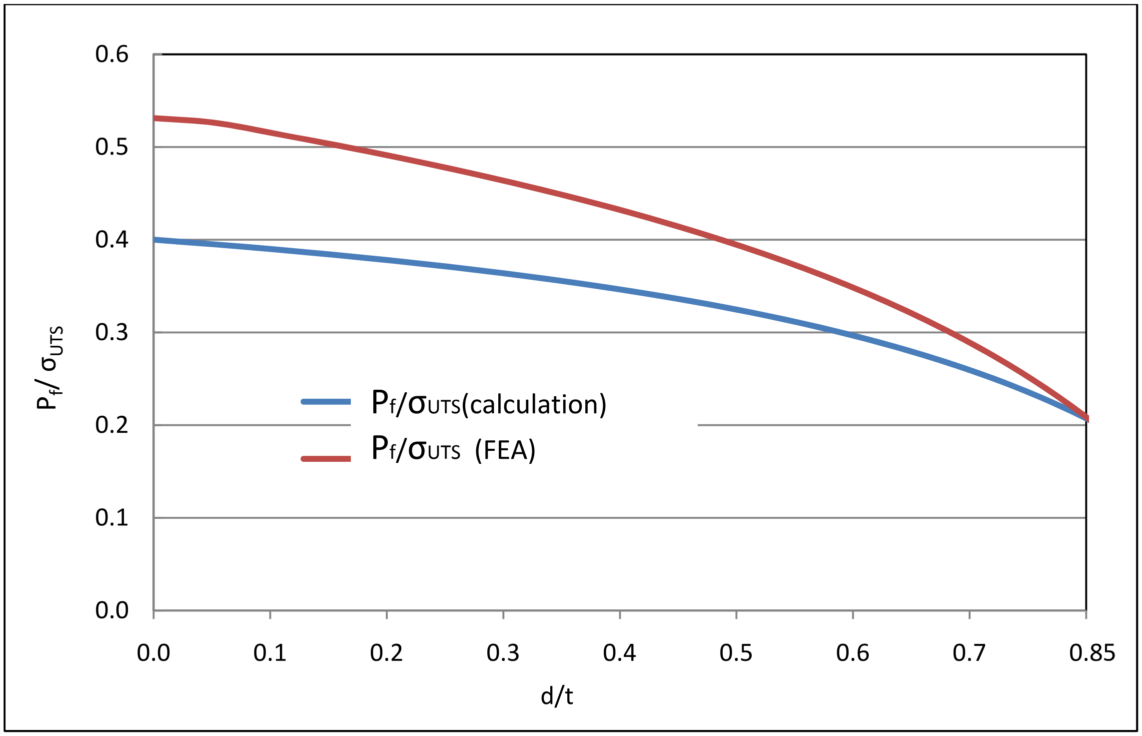

Figure 4.2: Graph of P_f/σ_{UTS} versus d/t

Figure 4.2 represents the generalized data of the effect of varying of pitting depth towards the determination of failure pressure

From the graph plotted, we can see the trend line of calculation (empirical analysis) and FEA are the same. As the depth of pitting corrosion increase, the failure pressure will decrease. The maximum 0.85 value of x-axis represents the 85% of depth of pitting over the thickness of pipeline. According to DNV RP F101, assessment of depth which exceeds 85% of thickness is not applicable. Therefore, the comparison will only be valid until 85% of depth of pitting over thickness of pipe.

4.3 Variation of pitting longitudinal length

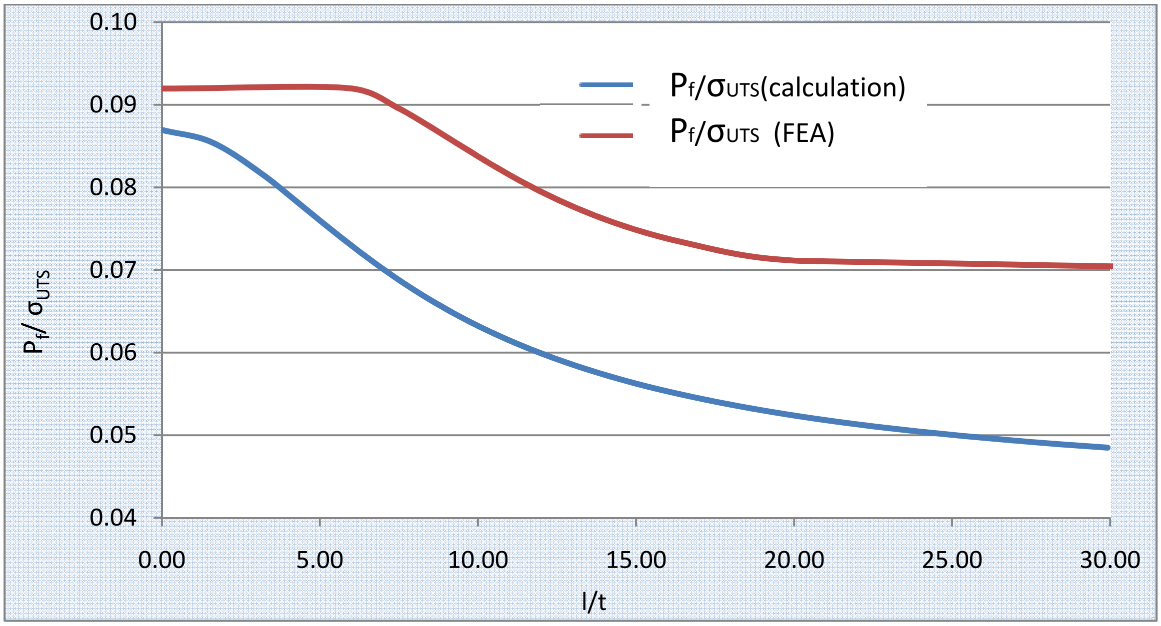

Figure 4.3: Graph of P_f/σ_{UTS} versus l/t

Figure 4.3 represents the generalized data of the effect of varying of pitting longitudinal length towards the determination of failure pressure.

From Figure 4.3, we can see that as the length of pitting increase, the failure pressure of pipe decrease. Pipeline will fail at low internal pressure if the length of defects keeps increase. The comparison between empirical analysis and FEA conducted shows that the trends are equal where failure pressure decrease with increasing pitting length.

4.4 Variation of pitting circumferential length

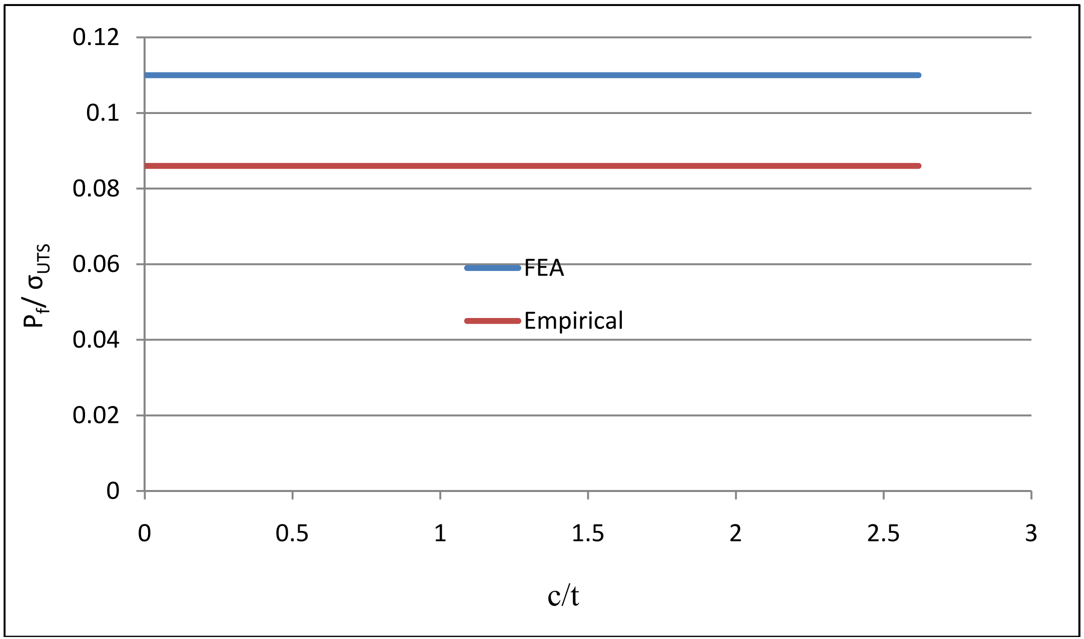

Figure 4.4 : Graph of P_f/σ_{UTS} versus c/t

Figure 4.4 represents the generalized data of the effect of varying of pitting circumferential length, c towards the determination of failure pressure.

From the graph shown, it shows that the FEA and theory (calculation of empirical analysis) results give same trend line. The results also explain that varying the circumferential pitting length will not affect the fail pressure. These results are valid in the case of internal pressure only without any other external loadings/pressure. Therefore it is concluded that the varying circumferential pitting length will not affect the fail pressure.

The discrepancy between the solution of the FEA model and the mathematical model are due to few factors. The mathematical correlation and formulation introduced by the codes were included with design safety factor. This safety factor also contributed to the previous discrepancy.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The major parts of the conclusion are:

1. In the case of internal pressure loading acting on the pipeline, there are 2 variables that contribute to failure pressure. They are :
    a. **Depth of the pitting**; it is observed that depth of pitting are directly proportional to the failure pressure. These results of FEA have been compared to codes (DNV RPF101) and it shows the same trend of results.
    b. **Longitudinal length of the pitting**; from the analysis done, longitudinal length also give directly proportional trend toward increasing of failure pressure.
2. In the case of internal pressure loading acting on the pipeline also, it is observed that the **varying circumferential length of pitting** does not affect the failure pressure of the corroded pipe. It is later been compared to codes and it shows same results which they circumferential length of pitting does not affect the failure pressure of corroded pipeline

The design safety and mathematical correlation factor contributed to the differences between the solution of the FEA model and the mathematical model.

Overall, the objectives of the project have been succeeded where integrity and prediction of remaining strength of corroded pipeline by using FE method can be achieved.

5.2 Recommendations

Referring to the results, we were able to assess the integrity of corroded pipeline subjected to pitting corrosion as the prediction of failure pressure for the corroded pipeline were obvious.

The results obtained were compared with the available codes. The results show few trends which satisfy the theory in the codes (DNV RP F101). The most important recommendation for this project is the enhancement of modelling of corroded pipeline. Several things have been identified to improve the modelling:

1. Refinement of meshing on the ciritical area. The discretization errors will be diminish with mesh refinement.
2. Specification of load and pressure exerted on the pipeline surface has to be specific and certain on its magnitude and types.
3. The types of pitting have to be more specific. (Narrow deep, elliptical, subsurface or horizontal type of pitting defects).

5.3 Suggested future work for enhancement and continuation of the project

For the continuation and enhancement purposes, several suggested future works have been planned. Besides, the enhancement work will benefit both readers and future research. These continuation suggestions will be a good guideline towards achieving project objectives while enhancing the results of the future findings. The planned future work is to enhance the number of analysis. The current analysis is only on the assessment of longitudinal corrosion defect with internal pressure only. For further expansion and research, new assessment can be introduced such as :

i. Longitudinal corrosion defect with internal pressure and superimposed longitudinal compressive stresses.
ii. Circumferential corrosion defects with internal pressure and superimposed longitudinal compressive stresses.
iii. Assessment of interacting corrosion defect.

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APPENDIX 1: Pipeline Corrosion Sample

Deep pitting corrosion with some pits joining to form larger pits and interconnected pitting

Small pit joins together

Examples of corrosion striations

APPENDIX 2: Example of Pipeline Operating Data from Ongoing Project

Parameters	Unit	Dimension
Nominal size	in	24
Pipeline Outside Diameter	Mm	610
Linepipe Grade	-	API 5L X65
Corrosion Allowance	Mm	8.0
Length	Km	4.901
Design Flow rate	MMscfd	200
Design Pressure	Barg	83.0
Design Temperate	C	71.7
Hydro-test Pressure	Barg	124.5
Product Density	Kg/m^3	42.79

Pipeline Properties			
		unit	**Value**
	Nominal Size	in	18
	OD	mm	457
	Grade	-	API 5L X65
	Corrosion Allowance	mm	3
	Length	km	20.814
	Design Pressure	barg	83
	Operating Pressure	barg	41.2
	Hydrotest Pressure	barg	124.5
	Product Density	kg/m^3	42.79
Steel Properties			
	Material Spec for linepipe	#	HF - ERW
	steel density	kg/m^3	7850
	SMYS	MPa	448
	SMTS	MPa	531
	Ultimate Tensile Strength	MPa	460
	Elastic Modulus	N/mm^2	207000
	Poisson Ratio	#	0.3
	Thermal Expansion Coeff.	/ C	11.7 x 10^-6