EFFECT OF CASING TUBING WEAR ON BURST STRENGTH

by

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14171

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CERTEFICATION OF APPROVAL

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A project dissertation submitted to the

Petroleum Engineering Department

Universiti Teknologi PETRONAS

in partial fulfillment of the requirement for the

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(PETROLEUM)

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CERTEFICATION 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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BEZAWIT TEMESGEN BELETE

ABSTRACT

Casing wear has recently become one of the areas of research interest in the oil and gas industry. Casing wear is mainly caused by the rotation of the drill string, bending actions during directional drilling and due to the chemical composition of drilling fluid. The decrease in the thickness of the casing wall results in the weakness of the mechanical strength of the casing. The burst strength of a worn out casing is one of the affected mechanical properties and yet an area less researched.

Studies had been conducted to come up with the most reliable theoretical methods to estimate the resulting burst strength of a worn out casing. The most commonly used equation is Barlow's equation. However, this equation is considered to be more conservative as it incorporates high safety factor which in the long term results in more economic expenditure. In addition to Barlow's equation, the initial yield burst, the full yield burst and the rupture burst equation are other equations that are used to estimate casing burst strength.

The objective of this project is to estimate casing burst strength after wear through Finite Element Analysis (FEA) method and compare the results with theoretical values. The project work includes building various models with different defect shapes and depths to represent wear on a casing and simulating the models using linear and nonlinear analysis methods. The von Misses stress is used in the estimation of the burst pressure. The result obtained confirms that casing burst strength decreases as the wear depth percentage of the casing increases. Moreover, the burst strength value of the casing obtained from the FEA yields a higher value compared to the theoretical burst strength values. Casing with crescent shaped wear gives the highest burst strength value when simulated under nonlinear analysis.

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NOMENCLATURE

FEA	Finite Element Analysis
P_i	Casing internal pressure
P_o	Casing External pressure
P_{axial}	Axial Load
r_o	Casing outer radius
r_i	Casing inner radius
r	Casing Radial Coordinate
t	Casing wall thickness
d	Casing wear depth
D	Casing out diameter
L	Length of casing
σ_θ	Casing hoop stress
σ_a	Casing axial stress
σ_r	Casing radial stress
σ_{VME}	Casing Von Mises stress
l	Wear length
l_1	Minor wear length
l_2	Major wear length

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND OF STUDY

In order to balance between the increasing demand between energy from oil and gas and the depleting resources, several wells in the category of extended reach are being drilled. These wells often follow highly-deviated, horizontal, and multilateral well path trajectories. As the well paths get complicated and as the well depths are deeper, the revolution per minute (RPM) required to reach the target depth increases. As the search for oil and gas has progressed to deeper water, the use of top drive system and the capability of back reaming while rotating remains the common practice. Such practices lead to high contact force between casing and tools which through time leads to the decrease in the wall thickness of a casing.

Wear is defined as the removal of material from a surface as a result of dynamic conditions (Jones, 1971). Wear can be caused due to the rotational effect of the drill string or due to the contact force in a dogleg section when a directional drilling is conducted. In the years prior to 1980s, casing wear was not considered as a big problem in oil and gas industry (White and Dawson, 1987). However, recently more emphasis has been given on the investigation and monitoring of casing wear following the increase in the drilling of deviated wells. Understanding of the effect wear has on the strength of the casing becomes essential in such practices.

A number of oil and gas companies have focused their research on various experimental and numerical designs that can help to estimate and analyze the effect of wear on the overall strength of the casing. This is achieved by taking in to consideration the various loads, specifically the burst and collapse loads, the casing needs to resist during its life time. The burst strength of a casing is the ability of a casing to resist the internal pressure exerted on it. If a thorough analysis of the burst strength of a casing is not performed, well control problem might occur. Thus, a burst strength analysis helps to avoid unexpected well control problem such as blow out and aid in a realistic economic planning. Figure 1.1 shows a casing wear by a drill string rotation.

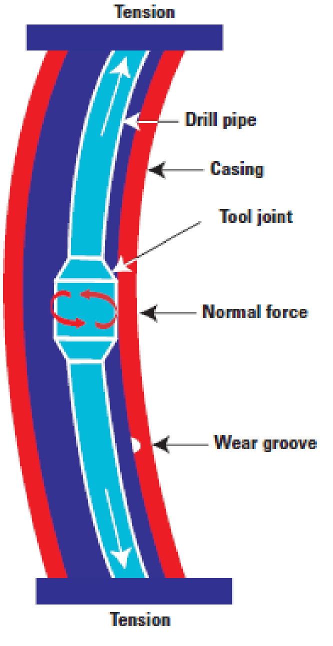

Figure 1.1 Casing wear by drill string rotation (Wu and Zhang, 2005)

1.2. PROBLEM STATEMENT

One of the critical areas to focus on while performing a casing design is to identify the different load cases that can be applied to the casing string throughout the wells life. Casing wear can be caused due to the rotational effect of the drill string or due to the contact force at the dogleg section when a directional drilling is conducted. The carrying capacity of the casing reduces after the casing is worn out which as a result affects the subsequent well drilling, well completion, oil extraction and well repair. If the condition of the casing after it faces wear is not studied thoroughly a casing burst situation might occur. Lack of optimal estimation of the effect of casing wear in casing burst strength results poor economic planning for the specific drilling job. Thus selection of casing string needs to be made based on prediction of the expected casing wear to allow a reasonable wear factor.

1.3. OBJECTIVES

The objectives of this project are:

- To estimate the casing burst strength after wear using Finite Element Analysis (FEA).
- To compare simulation results obtained from FEA with theoretical values calculated

1.4. SCOPE OF STUDY

The scope of this research mainly focuses on analyzing the existing mathematical equations developed to estimate the casing internal pressure after casing wear. It also focuses on generating various models using FEA to estimate the burst strength after wear. Finally, the theoretical and simulation results are compared with each other.

1.5. RELEVANCY AND FEASIBILITY OF THE PROJECT

The relationship between casing wear and burst strength is an area that requires more research work. The feasibility of any project depends on the economics of implementing it and the time frame given to successfully finish the project. With available resources (i.e. ANYSY software) and expertise, the project has been completed within the given time frame. The overall project plan is given in appendix- 1.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1.THEORY ON CASING

In order to successfully drill and complete a well, it is necessary to line the drilled open hole with a steel pipe also called casing. Some of the significances of installing a casing are to provide support to the open hole, to prevent the flow of formation fluid in to the hole, to protect the underlying aquifer from being polluted by drilling and completion fluid and to provide support to wellhead equipment (Azar and Samuel, 2007). The number of casings used to complete a well depends on the depth and other geologic characteristics of the formation to be drilled. The four major types of casing strings widely used in the oil and gas industry are conductor casing, surface casing, intermediate casing, production casing and production liner.

Casings are characterized by various properties. The most common are outside diameter, wall thickness, weight per unit length, steel grade, the type of connection and the length a casing joint. A casing grade refers to the chemical composition of the steel used and the heat treatment it receives during manufacturing. The casing property that is the focus of this project is the wall thickness.

2.1.1. Strength of Casing

One of the main responsibilities of a well engineer is to design a casing that has the strength to withstand the various forces it may face in its life time. The three important mechanical properties that are used to describe the strength of a casing are collapse, burst and tensile strength. Burst Strength of a casing is the casing's ability to resist the internal pressure exerted on it before failure. Collapse strength of a casing refers to the casing ability of resistance if the external pressure exerted on it is higher than the internal pressure. On the other hand tensile strength characterizes the casing's capacity to withstand stress before failure (Azar and Samuel, n.d.).

The customary practice to estimate the burst strength of a casing is by using the API equation which is also known as Barlow's equation. Barlow's equation relates the internal pressure exerted on a casing with the tensile strength of the pipe and its dimensions in order to estimate burst strength. In addition to Barlow's equation, there are three other casing burst strength estimation equations which Wu and Zhang (2005) had briefly discussed in their paper titled casing burst strength after wear. The initial yield burst equation calculates the burst pressure as the casing yields only at the inner diameter and before reaching the entire wall thickness. The full yield burst equation, is related to the pressure as casing yield throughout its entire wall thickness and the casing rupture burst equation refers to the pressure where ductile failure of the casing takes place (Wu and Zhang, 2005). Equation 2.1, 2.2, 2.3 and 2.4 represent the four equations used to estimate the burst strength as discussed above.

Barlow's equation: $$P_{API} = \frac{1.75\sigma_y t}{D} \quad (2.1)$$

Initial yield burst equation: $$P_{Initial} = \frac{1.75\sigma_y}{\sqrt{3}} \frac{2t}{D} \left(1 - \frac{t}{D}\right) \quad (2.2)$$

Full yield burst equation: $$P_{Full} = \frac{1.75\sigma_y}{\sqrt{3}} \frac{2t}{D} \left(1 + \frac{t}{D}\right) \quad (2.3)$$

Rupture burst equation: $$P_{Rupture} = \frac{1.75\sigma_{ult} t}{D - t} \quad (2.4)$$

2.2.CASING WEAR ANALYSIS

2.2.1. Overview of casing wear

Casing wear has a significant impact in the performance of a casing in the life of a well especially for operational plans such as artificial lift. The oil and gas industry allocates additional investment per year on additional well thickness to allow for wear (White and Dawson, 1987). A better understanding of the basic wear process helps allocate this money in the most efficient manner. Casing wear refers to the decrease in the thickness of the inner diameter of a casing due to various factors. Some of these factors are the rotational action of the drill string, during directional drilling when a casing is bent or due to large axial compressive force resulting in a casing buckling (Wu and Zhang, 2005). Some researchers studied the wear depth caused by the contact pressure applied to the inner wall of casing. They utilized different sizes of drill string to find the wear depth as a function of time (Shen, Beck, & Ling, 2014)

Field studies have revealed the different parameters that affect the intensity of wear. The most common parameters are side loads, dogleg severity, chemical composition of drilling mud, ability of drill pipe to cause wear, resistance of casing to wear, rotation time and revolution per minute (Haberer, 2000). In directional wells, the rotating tool joint is forced by the drillstring against the inner wall of the casing for a longer period of time. As a result, it grinds against the casing wall, creating material erosion i.e. wear in both the rotating tool and casing surfaces. The decrease in the thickness of a casing wall affects the geometry and load distribution on the casing. The most common aspects that are affected as a consequence of casing wear are integrity of the well, the life of the well and the cost of drilling (Haberer, 2000).

2.2.2. Effect of casing wear on burst strength

One of the effects of casing wear is the decrease of the casing burst strength i.e. the casing’s ability to resist the internal pressure exerted on the it decreases which as a result may cause burst. Song et al. (1992) conducted a study focusing on the burst strength of a casing after wear. A theoretical solution for the hoop stress of worn casing was developed by dividing the entire worn casing into three shapes that are mirror to one another. This superimposition principle was used to obtain the induced hoop stress of the worn casing. Other studies were conducted to show assumptions of slotted ring in a casing wall can be used to create a more simplified casing wear models (Wu and Zhang, 2005). The casing burst strength as a result of casing wear is investigated by using the concept of hoop stress. Hoop stress is the highest internal pressure that is exerted around the circumference of the casing. Equation 2.5 represents the hoop stress exerted on a casing.

$$\sigma_\theta = \frac{p_i r_i^2 - p_o r_o^2}{r_o^2 - r_{oi}^2} + \frac{(p_i - p_o) r_i^2 r_o^2}{r_o^2 - r_i^2}\frac{1}{r^2} \qquad (2.5)$$

where: r= $\{r_i, r_o\}$

Equation 2.5 shows the internal pressure is directly proportional to the hoop stress. The research conducted by Wu and Zhang (2005) reflects the relationship between casing wear, hoop stress and burst strength. When a casing is worn, its thickness decreases; this leaves the remaining unworn section of the casing with a reduced thickness to handle the internal pressure exerted on the casing. The hoop stress for the worn casing is higher as the internal pressure acting on the casing needs to be balanced. In their research, Wu and Zhang (2005) performed FEA modeling to study the effect of internal pressure on the hoop stress. They observed the casing is deformed in to an oval shape when exposed to an internal pressure loading and zero external pressure. Figure 2.1 shows the result of the FEA for a 30% wear case under 1000 psi internal pressure loading.

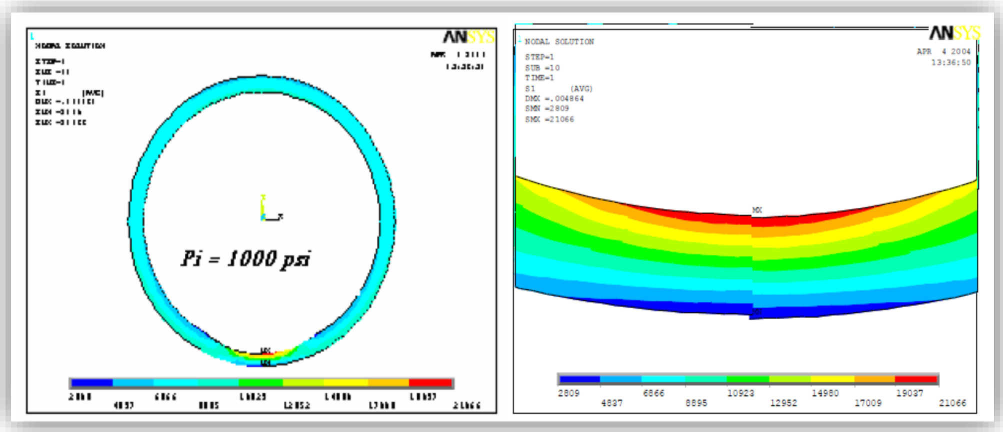

Figure 2.1 Stress on a worn casing from FEA modeling (Wu and Zhang, 2005)

Higher hoop stress can occur at either the inside or the outside surface of the casing which brings the need for the von Mises yield criterion (VME) to be evaluated. The VME stress is the equivalent stress at which yielding occurs. As it can be seen from equation 2.6, the axial, the radial and the induced hoop stress are used to calculate the equivalent VME. The axial and radial stresses are assumed to stay the same before and after wear (Song *et al.*, 1992). The calculated VME is used to calculate the burst pressure of the casing.

$$\sigma_y = \sqrt{\sigma_{\theta,w}^2 + \sigma_r^2 + \sigma_a^2 - \sigma_{\theta,w}^2\sigma_r^2 - \sigma_{\theta,w}^2\sigma_a^2 - \sigma_r^2\sigma_a^2} \qquad (2.6)$$

Wu and Zhang (2005) simplified equation 2.6 further by only considering the hoop stress and ignoring the effect of radial and axial stresses to calculate the yield strength. The four different burst strength equations discussed in section 2.1.1. i.e. the Barlow equation, the initial yield burst equation, the full yield burst equation and rupture burst equation can be derived from the reduced equation.

Moreover, Bradley, (1976) performed a theoretical analysis to determine the effects of wear on the burst strength of casing and showed that the API method for determining burst resistance may result in burst values that have very low probabilities of failure.

2.3.FINITE ELEMENT ANALYSIS (FEA)

Finite element analysis (FEA) refers to the numerical method used to solve various types of engineering problems with complicated geometries, loadings, and material properties where it is not easy to obtain theoretical solution. As the name implies it solves a given engineering problem by dividing it in to finite elements. Finite element analysis consists of three major procedures namely: preprocessing, analysis and post processing.

Preprocessing involves defining the material properties, construction of geometric models, meshing of the models, applying boundary conditions and loads. Analysis on the other hand computes the unknown values and supply solution based on the input data provided in the processing procedure. The last step of the FEA is post processing which mainly involves sorting and plotting selected results from a finite element solution.

Hanning, Doherty and House (2012) performed FEA modeling of an eccentrically worn casing to determine the burst capacity of a worn out casing. Hanning *et al* (2012) analyzed the various casing burst strength equations i.e. API burst capacity equation, rupture burst strength equation and Klever Stewart’s burst capacity. Their research concluded as Barlow equation is more stringent compared to the rest of the existing burst strength equations.

CHAPTER 3

METHODOLOGY

3.1. EXPERIMENTAL MATERIAL

The casing material used in this project is L-80-9 5/8”, 47ppf which is a production casing string. The reasons for choosing L-80 casing are:

i. It is suitable for sour drilling environment.
ii. It is widely available.
iii. It is suitable for effective steam injection in shallow wells.

Table 3.1 shows the mechanical and physical properties of the casing material chosen for this project.

Table 3.1 Experimental material

Material Grade	L-80 Steel
Length, L (mm)	2000
Nominal Outer Diameter, OD(mm)	244.475
Nominal Wall Thickness, t (mm)	11.9888
API Minimum yield strength (MPa)	552
API Minimum Tensile strength (MPa)	655
Poisson ratio	0.3
Modulus of elasticity (MPa)	200,000

3.2. PROCEDURE

The major steps involved in this project are summarized in the flow chart below.

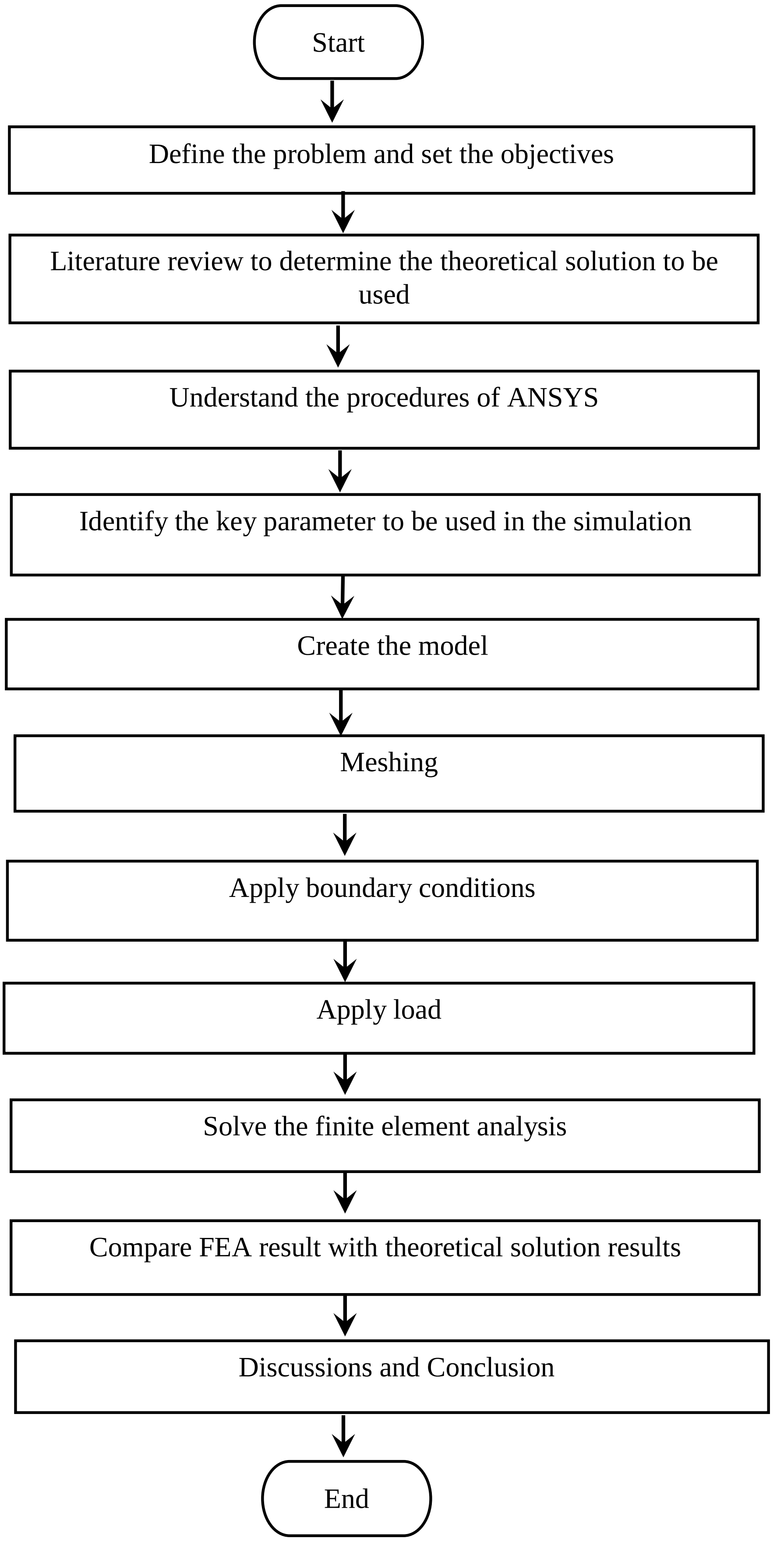

Figure 3.1 Flow chart for the Project Work

3.3. THEORETICAL SOLUTION

In order to compute the theoretical solution four different equations are utilized. The equations used in this project to obtain theoretical solutions are Barlow equation, initial yield burst equation, full yield burst equation and rupture burst equations which are explained in chapter 2 of this paper (equation 2.1 to equation 2.4). To recall the equations:

Barlow's equation: $$P_{API} = \frac{1.75\sigma_y t}{D} \quad (3.1)$$

Initial yield burst equation: $$P_{Initial} = \frac{1.75\sigma_y}{\sqrt{3}}\frac{2t}{D}\left(1 - \frac{t}{D}\right) \quad (3.2)$$

Full yield burst equation: $$P_{Full} = \frac{1.75\sigma_y}{\sqrt{3}}\frac{2t}{D}\left(1 + \frac{t}{D}\right) \quad (3.3)$$

Rupture burst equation: $$P_{Rupture} = \frac{1.75\sigma_{ult} t}{D-t} \quad (3.4)$$

3.4. SIMULATION WORK

ANSYS workbench 15 is the software used to perform the finite element analysis. The following sections give detailed descriptions of the steps performed in ANSYS to solve the finite element model. The first step to FEA is to define the parameters needed for the simulation which are summarized in table 3.1 using the engineering data tool in ANSYS.

3.4.1. Geometry Modeling

The geometry modeling involves of modeling a casing pipe of the required dimension and placing the defect or wear accurately. Three different cases of defects are considered for the modeling purpose. These are rectangular defect, crescent shaped defect and multiple defects. Different wear depths are considered for each case. The wear is placed at the center of the casing to ease the process of applying symmetric boundary conditions.

The wear depth percentage refers to the ratio of the casing wear depth to the original thickness of the casing.

$$\text{Wear depth (\%)} = \frac{d}{t} * 100\% \qquad (3.5)$$

The three different cases of defect are presented using idealized geometric models in figure 3.2, figure 3.4 and figure 3.6 and their respective geometric dimensions are shown in table 3.2, table 3.3 and table 3.4.

Case 1: Rectangular shaped defect

The models for the first case are built assuming the shape of the wear created has a rectangular shape. The length of the defect is 1/10th of the total length of the casing. Figure 3.2 illustrates the geometric model for a rectangular shaped wear placed at the center of the casing

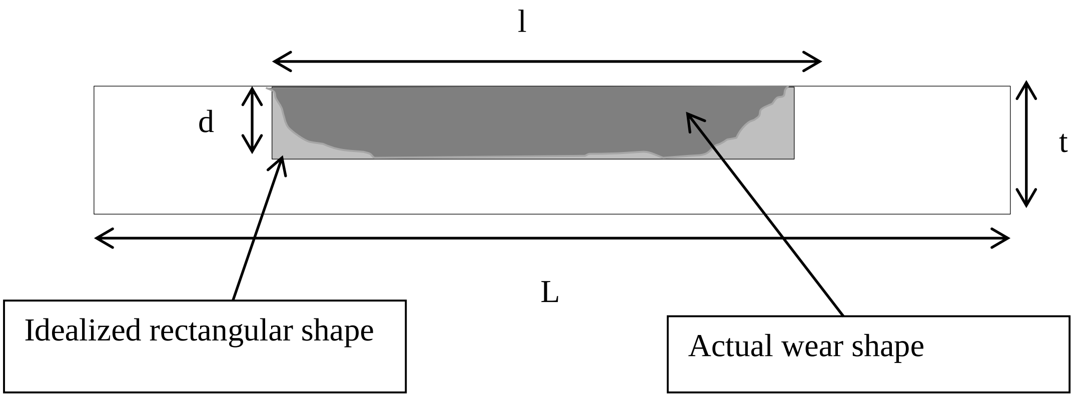

Figure 3.2 Geometry of case 1

Table 3.2 shows the various wear depths used to build the models for case 1 and the corresponding wear length.

Table 3.2 Dimensions for the models of case 1

Wear depth (%)	Wear depth, d (mm)	Wear length , l (mm)
20	2.39776	200
40	4.79552	200
60	7.19328	200
80	9.59104	200

The figure below, figure 3.3, is a pipe modelled using ANSYS with a rectangular shaped wear located at the center of the pipe.

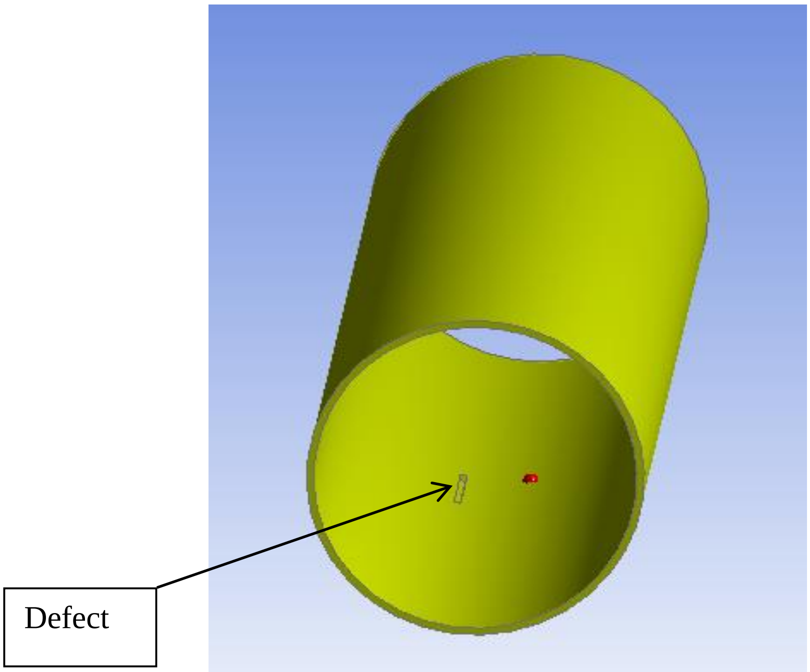

Figure 3.3 ANSYS Model for case 1

Case 2: Crescent shaped defect

Figure 3.4 demonstrates the idealized geometric model for a crescent shaped wear located at the center of the casing. The length of the defect is 1/10th of the total length of the casing

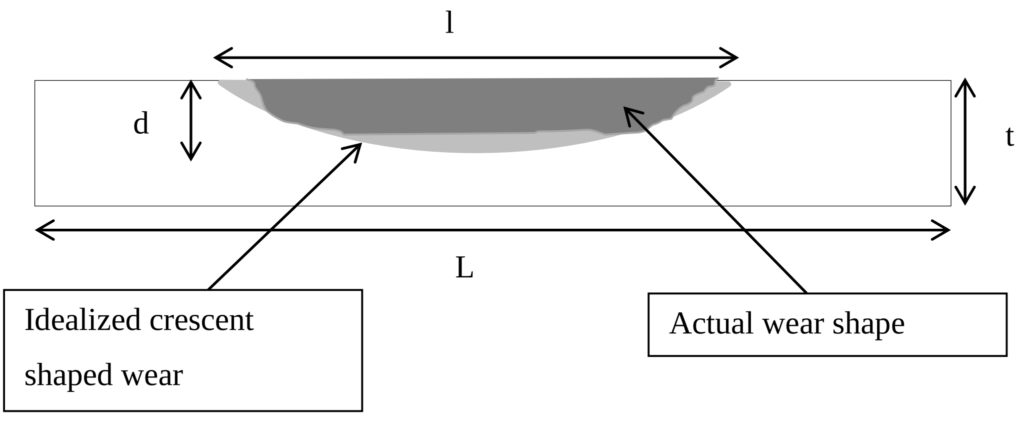

Figure 3.4 Geometry of case 2

Table 3.3 shows the various wear depths used to build the models for case 2and the corresponding wear length.

Table 3.3 Dimensions for the models of case 2

Wear depth (%)	Wear depth, d (mm)	Wear length , l (mm)
20	2.39776	200
40	4.79552	200
60	7.19328	200
80	9.59104	200

The model in figure 3.5. is built using ANSYS with an crecent shaped wear located at the center of the pipe.

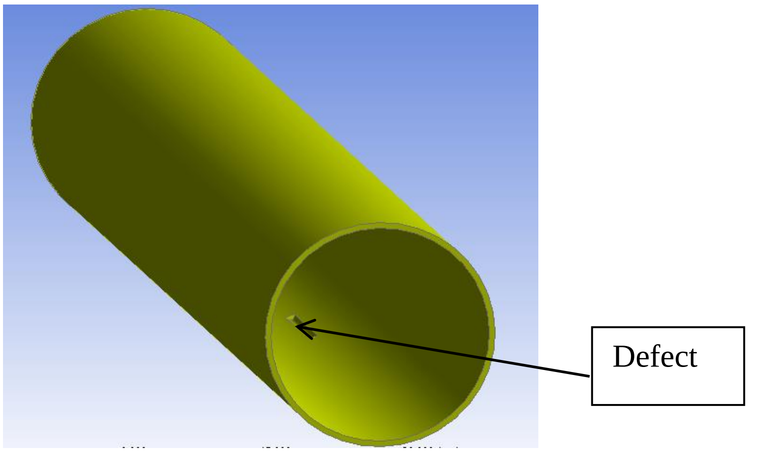

Figure 3.5 ANSYS Model for case 2

Case 3: Multiple Defects

The idealized geometric model for a casing with multiple wear is illustrated in figure 3.6.

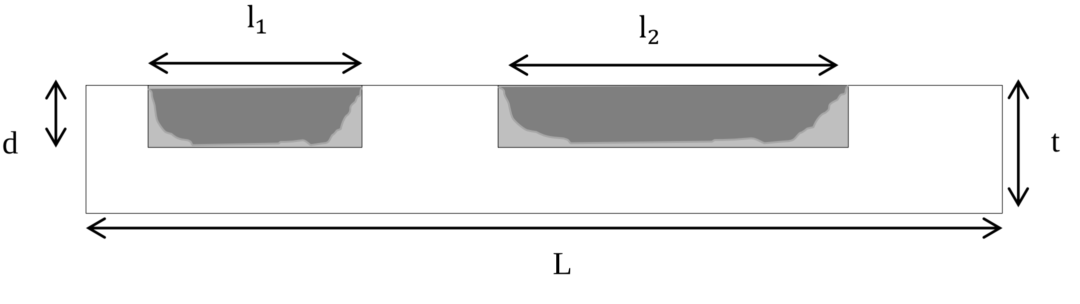

Figure 3.6 Geometry of case 3

Table 3.4 shows the various wear depths used to build the models and the corresponding wear length.

Table 3.4 Dimensions for the models of case 3

Wear depth (%)	Wear depth, d (mm)	Minor Wear length l_1(mm)	Major Wear length l_2(mm)
20	2.39776	100	200
40	4.79552	100	300
60	7.19328	100	400
80	9.59104	100	500

The model in figure 3.7 shows a model built using ANSYS with a multiple wear.

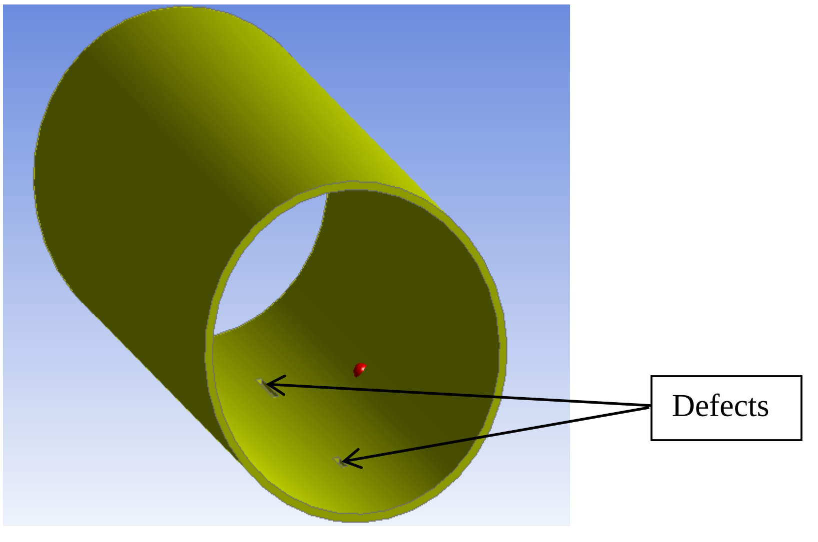

Figure 3.7 ANSYS Model for case 3

3.4.2. Meshing

Meshing demonstrates the basic concept behind finite element modeling. Meshing is a process of dividing a given model in to finite number of sections called elements. These elements are connected at points called nodes. The combination of nodes and elements form a mesh. The finer the mesh the more accurate the result is.

In this project a Hexahedron meshing method is used. Mapped meshing of the different faces of the model is performed. Figure 3.8 shows how a sample meshing of the models looks like.

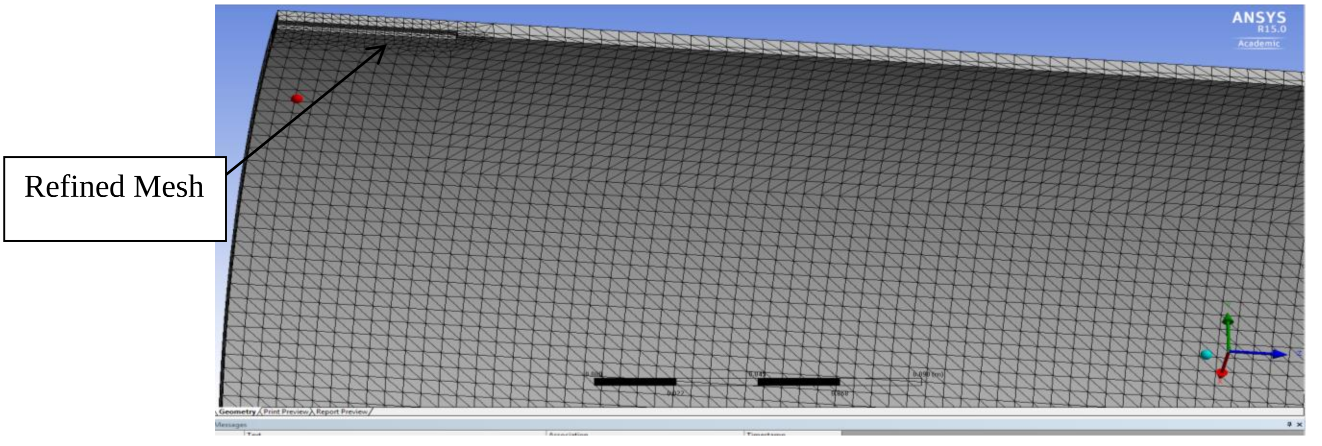

Figure 3.8 Meshing

Table 3.5 shows the mesh properties i.e. node and element number for the meshes generated for the various models.

Table 3.5 Meshing properties

Model	Wear depth (%)	Number of Nodes	Number of Elements
Case 1	20	23566	11843
	40	26194	13751
	60	26497	13619
	80	26828	13790
Case 2	20	27022	14053
	40	26491	13674
	60	26295	13481
	80	27386	14128
Case 3	20	16684	8410
	40	18566	9636
	60	21428	11706
	80	16686	8799

3.4.3. Boundary Conditions

Boundary conditions refer to the settings used to model the boundaries of the model. Here, a symmetric boundary condition is applied. A symmetric boundary condition enables simulating quarter or half of the model giving the advantage of saving time of running simulation.

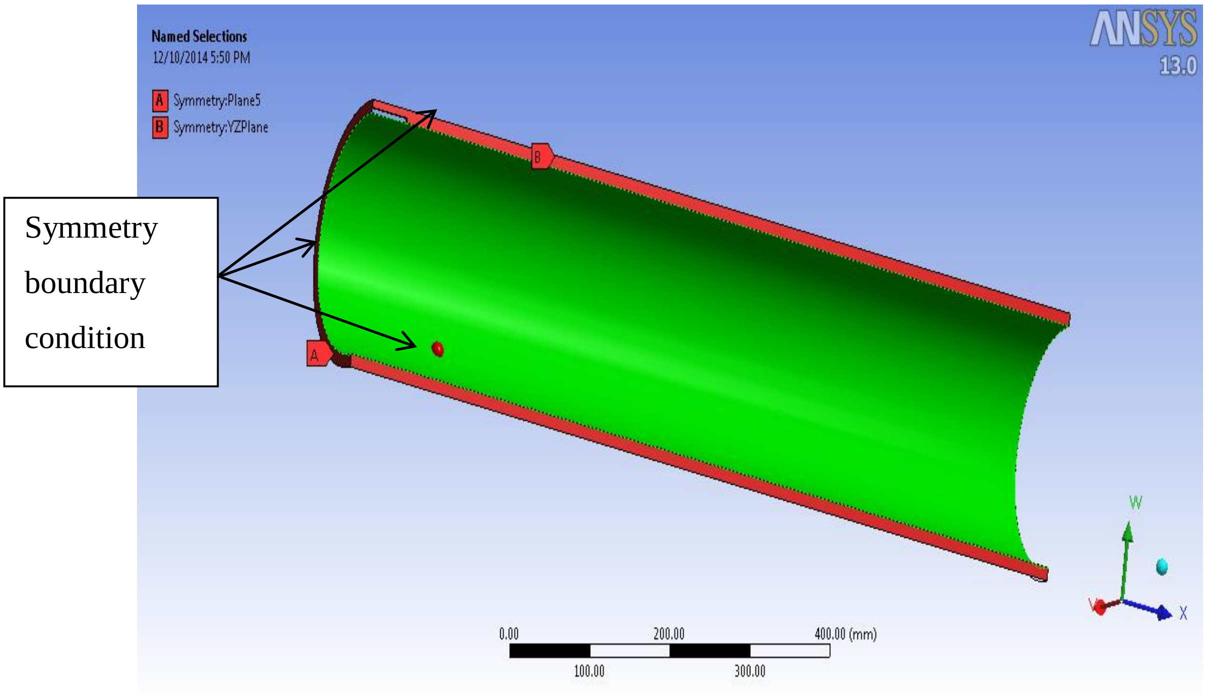

Figure 3.9 Boundary Conditions

3.4.4. Load Application and Constraints

A pressure is applied to the internal face of the model to represent the internal pressure load on the casing that mainly leads to burst. The magnitude of the internal pressure is varied until the equivalent von Mises stress reaches the pipe's minimum yield strength. Furthermore, an axial load is applied at the ends of the pipe to represent the closed end of the pipe during a burst test. The axial load is a function of the internal pressure applied. It's estimated using equation 3.6.

$$P_{axial} = \frac{P * r_o}{2t} \qquad (3.6)$$

Moreover, a support load on the end of the pipe is expressed in terms of displacement equals to zero in order to constrain the body from moving during the burst test. These two conditions are shown in figure 3.10.

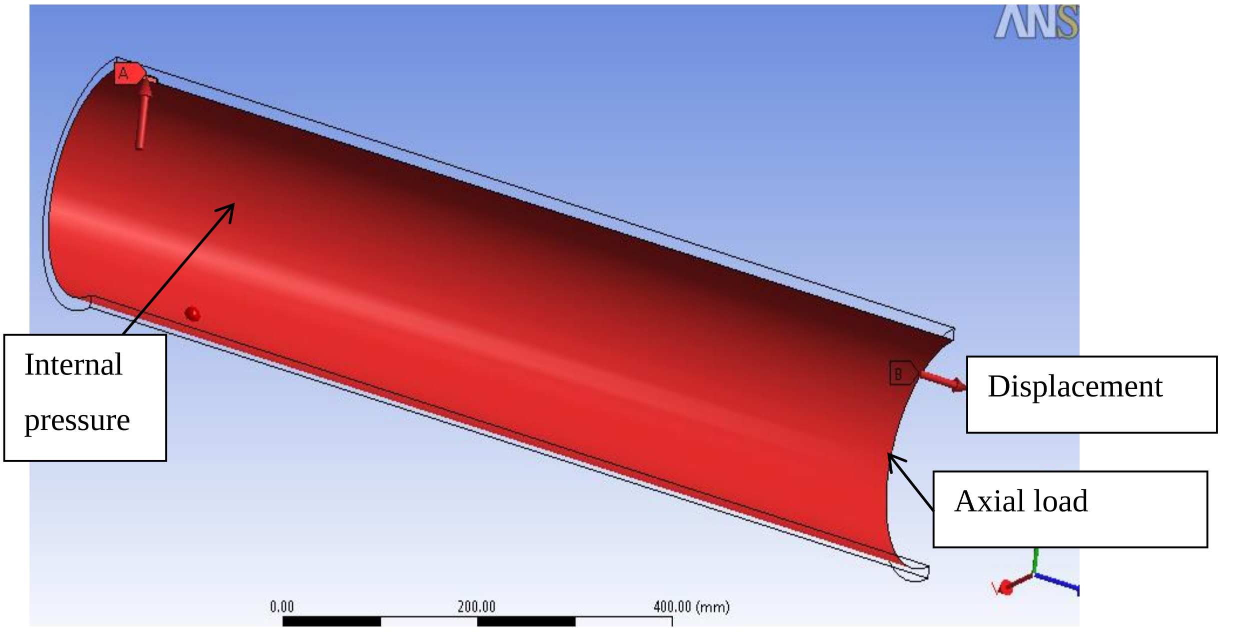

Figure 3.10 Internal pressure load and constraint

3.4.5. Linear and Non- linear Analysis

ANSYS has two analysis options to solve. Both linear and nonlinear analyses are considered in this project. A linear analysis demonstrates a direct relationship between stress and strain. A material responds following the straight line Hook's law when a load is applied on it.

On the other hand a nonlinear analysis allows for a nonlinear relationship between stress and strain beyond the yielding point and it takes in to account the effect of temperature on material properties. Non-linear analysis is known to provide a more representative solution to structures that undergo deformation. The stress strain data used for the nonlinear analysis is shown in Appendix 3.

CHAPTER 4

RESULTS AND DISCUSSION

RESULTS

After geometric modeling, meshing and applying loads to the finite element models, the burst pressure values for each of them are determined. The models are simulated with increasing internal pressure loading, P until the Von Mises Stress, $\sigma_{VonMises}$ of the entire nodes ligament values is equal to the yield strength of the casing, i.e. 552 MPa. To simulate the closed end of the casing during the burst test P_{axial} is applied at the end of circumferential area of the models; the value is calculated using the axial load equation, equation 3.6. The defect depth percentage represents the ratio of defect depth to original thickness of the pipe.

Figure 4.1 shows a sample output result of how the casing string with a 40% wear percentage under nonlinear analysis looks like when exposed to an internal loading and it reaches the its burst strength value.

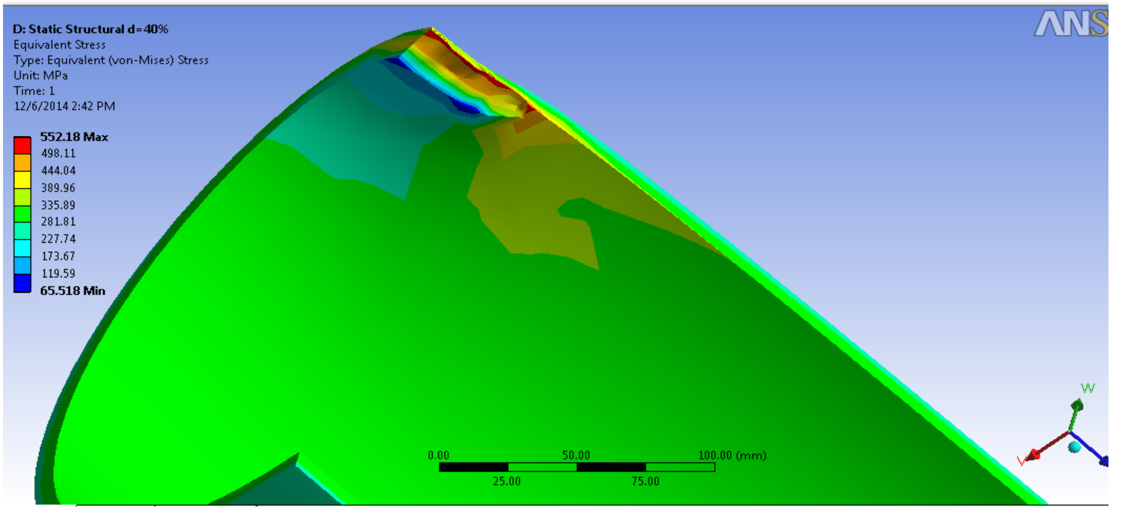

Figure 4.1 Sample von Mises distribution for nonlinear crescent shaped defect

Table 4.1 shows the burst pressure values for L-80 casing without any wear. Results from theoretical solutions using equations 2.1 to 2.4 as well as results from finite element analysis using both linear and nonlinear analysis methods are presented.

Table 4.1: Theoretical result for intact L-80 9 5/8”, 48 ppf casing

Analysis type	Burst Strength (MPa)				
	Barlow’s	Initial yield	Full yield	Rupture	FEA
Linear	47.37	52.017	57.38	59.11	57.11
Non Linear	47.37	52.017	57.38	59.11	65

The results displayed in table 4.2 are obtained by using the theoretical equations for casing strings with different wear depth percentages.

Table 4.2: Theoretical burst strength values for L-80 9 5/8", 48 ppf casing with defect

Wear Depth (%)	Burst Strength (MPa)			
	Barlow	Initial yield	Full yield	Rupture
20	37.897	42.043	45.477	46.805
40	28.423	31.854	33.786	34.749
60	18.949	21.451	22.309	22.934
80	9.474	10.833	11.047	11.354

The theoretical values presented in table 4.2 are compared among each other as shown in figure 4.2. The theoretical result obtained using the four equations provided by Wu and Zhang (2005) shows as Barlow’s equation gives the lowest value of burst strength whereas the rupture burst equation gives the highest value of burst strength. The burst strength decreases as the wear depth percentage increases.

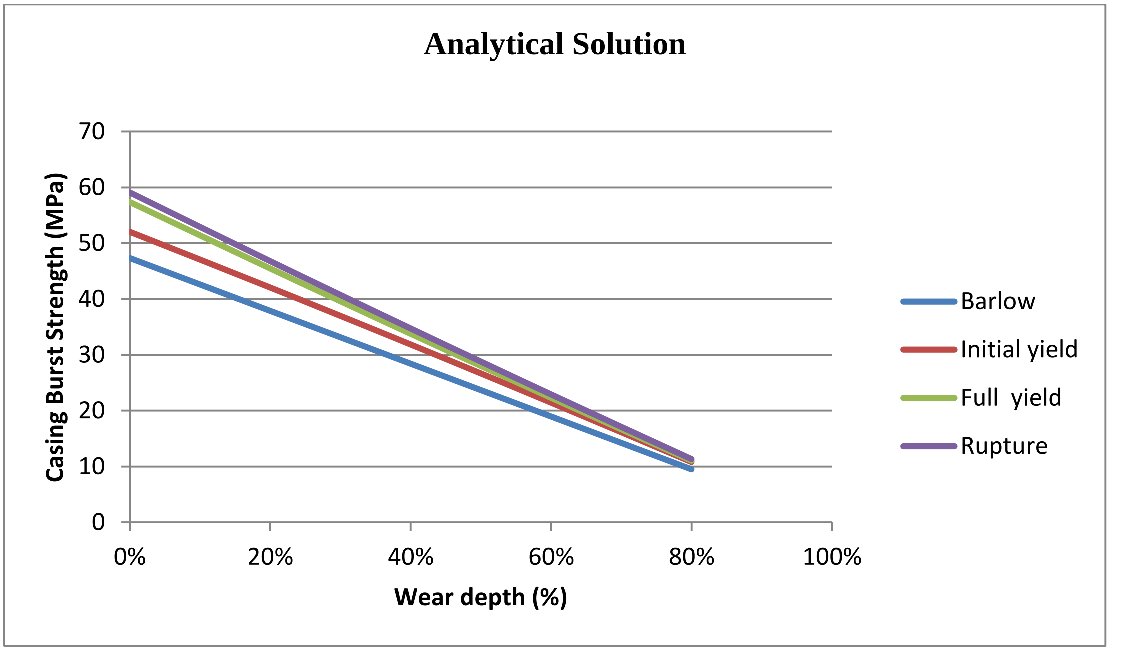

Figure 4.2 Theoretical casing burst strength values

Linear Analysis

Burst strength values obtained for a linear FEA analysis of L-80 casing with different defect size and shapes yields the burst pressure values presented in table 4.3

Table 4.3 FEA linear analysis result for L-80 9 5/8", 48 ppf casing with defect

Wear Depth (%)	Burst Strength (MPa)		
	Rectangular wear	Crescent wear	Multiple wear
20%	46.38	46.85	38.2
40%	32	34	29.1
60%	20	21.21	20.44
80%	14	14.028	11.06

Figure 4.3 is a graphical representation of the linear FE analysis of a worn out casing with varying wear depth and shape.

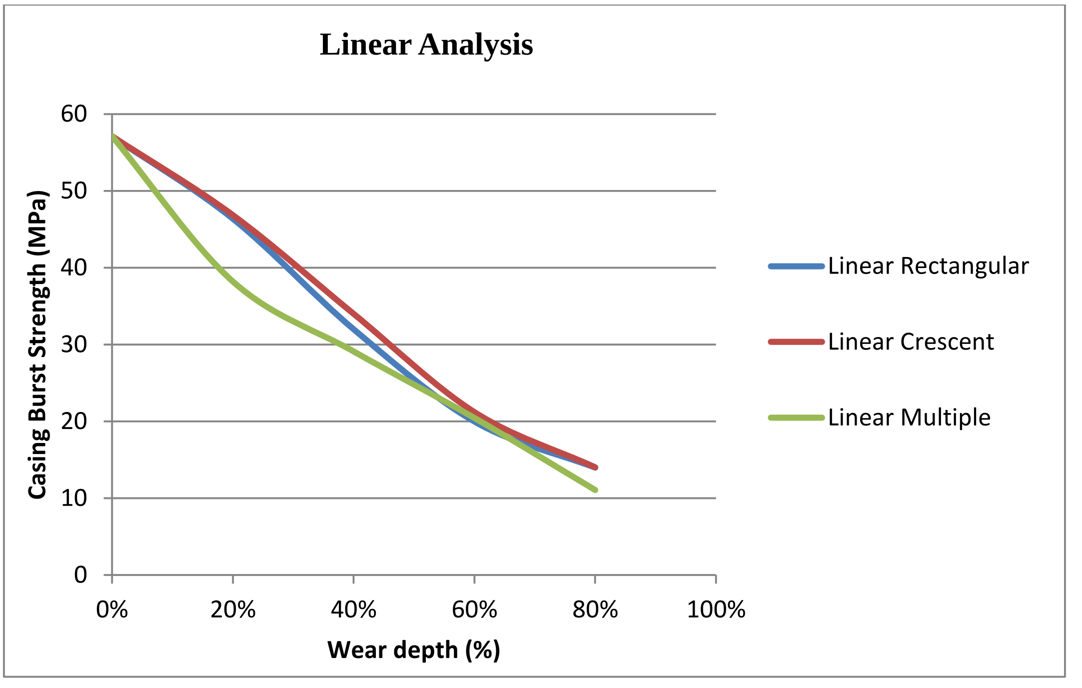

Figure 4.3 Linear analysis results for casing burst strength with wear

Non-linear Analysis

Table 4.4 shows the burst strength obtained when a nonlinear finite element analysis used to simulated the casing with wear.

Table 4.4 FEA non-linear analysis result for L-80 9 5/8", 48 ppf casing with defect

Wear Depth (%)	Burst Pressure (MPa)		
	Nonlinear Rectangular	Nonlinear Crescent	Nonlinear Multiple
0%	65	65	65
20%	53.8	56.1	47.7
40%	45.8	52.5	42.75
60%	43.7	49.9	35
80%	30	32.95	22.6

Figure 4.4 illustrates how the burst strength for different wear shape and depth changes when a nonlinear analysis is performed.

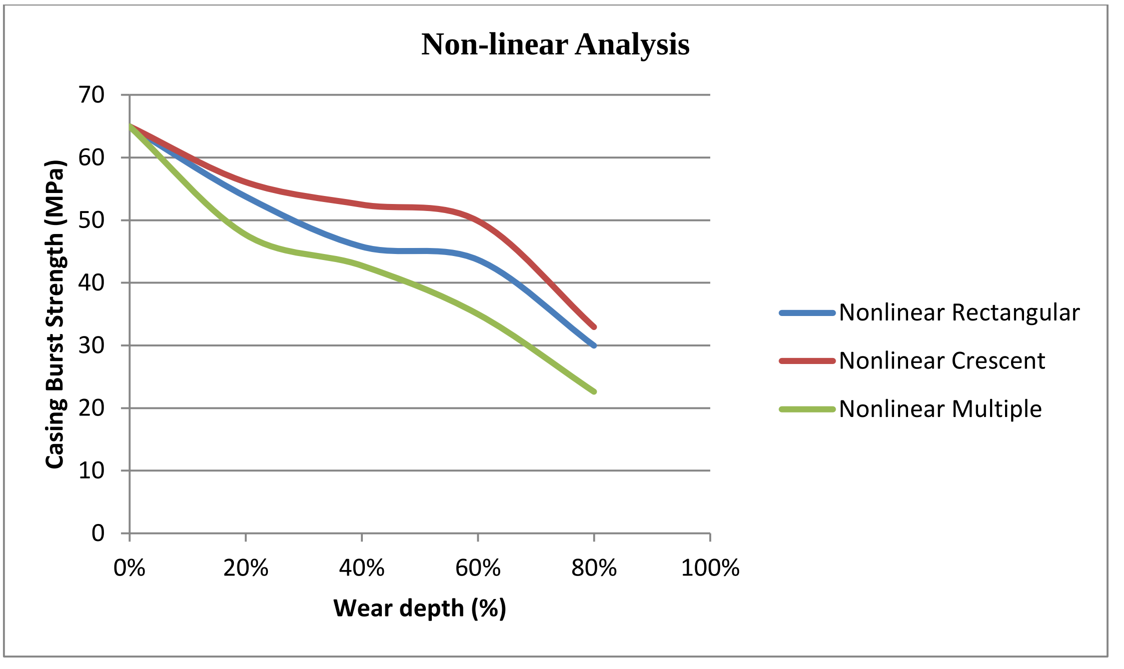

Figure 4.4 Nonlinear analysis results for casing burst strength with defect

DISCUSSION

All the results obtained from simulation and manual or theoretical calculation are presented above. These results prove that the casing burst strength decreases as the wear depth percentage increases. The values presented in table 4.1 show for a casing pipe with no defect, the Barlow's equation yields the lowest burst strength value and the rupture burst strength gives the highest theoretical value. This is reasonable considering fact that the rupture strength assumes burst after the casing string has completely failed or ruptured. The results obtained from nonlinear finite element analysis for the intact casing string yield higher values than the rupture yield strength. This is justified by the nonlinear material property of steel where the casing responds nonlinearly having the capability of higher resistance to defect as more load is applied on it.

Results presented in figure 4.2 show that the theoretical burst strength values change linearly as the wear depth percentage increases. The plot for linear analysis FEA solution shows similar trend as the theoretical solution i.e. the burst strength values decrease in a similar linear trend with increase wear depth percentage (figure 4.3). However, the result for the nonlinear analysis shows that the values for burst strength do not decrease linearly rather they show a slightly constant trend between 40% wear depth and 60% wear depth percentage, figure 4.4. Similar to the observation for the intact casing string during a nonlinear analysis, the casing string has a nonlinear material property i.e. the material responds nonlinearly when a load is exerted on it which gives it the ability to deform at higher load than the casing under linear analysis.

Figure 4.5 shows the comparison between linear and nonlinear analysis for a casing with crescent shape wear. Result for nonlinear analysis gives higher burst strength value than linear analysis and exhibits a nonlinear change in burst strength values. The highest difference in burst strength between linear and nonlinear analysis is observed when the wear depth percentage is greater than 40%.

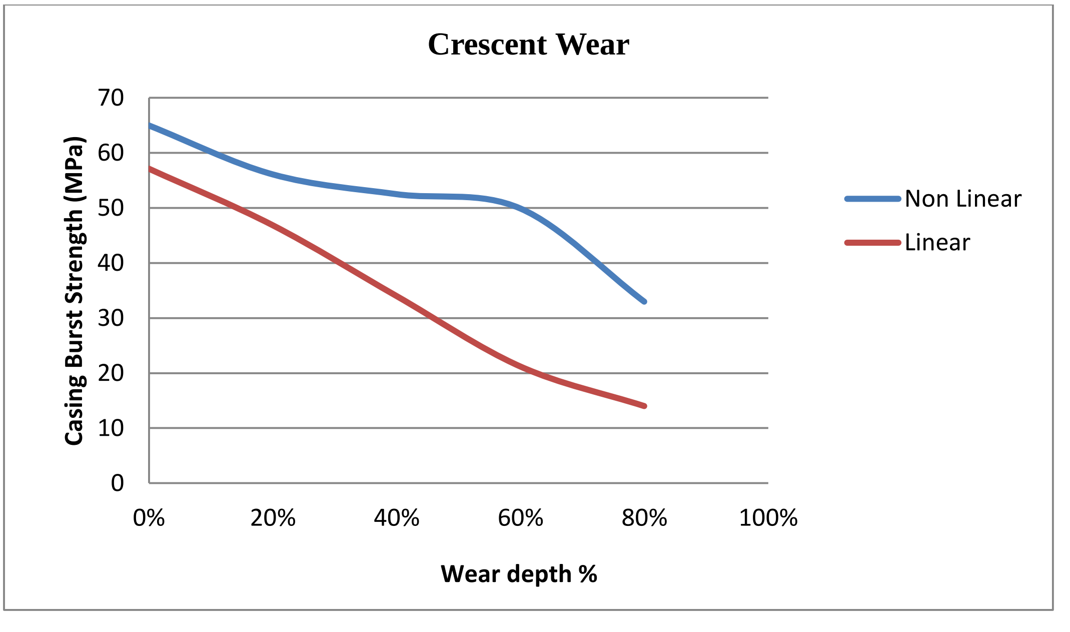

Figure 4.5 Comparison between linear and nonlinear analysis for a crescent shaped wear

In addition to the type of analysis and variation in wear depth value, the burst strength value changes with the shape of wear as well. Figure 4.3 and 4.4 show crescent shaped wear yields higher burst strength value compared to rectangular shaped wear. In reality the wear groove formed by the tools do not have any definite shape (as shown in section 3.4.1.), however it is more reasonable for the resulting wear to resemble crescent shape than rectangular as can be deduced from the orientation of the casing and the tool joint and; the shape of the tool joint (figure 1.1). Therefore, the author concludes the result obtained using crescent shaped wear is more representative of the actual wear of the casing than the rectangular shaped wear. The result for a multiple wear analysis yields the smallest value; as the number of defects in a single casing string increases the amount of steel material removed from the wall increases which leads to a decrease in the strength of the casing material.

The result from nonlinear analysis for a crescent shaped wear is selected to be the most representative of the actual burst strength condition as it takes in to consideration the nonlinear material property of steel and the shape of the tool joint causing the wear. The values of burst strength obtained using this case are the highest among the cases analyzed. Barlow's equation gives a smaller burst pressure value compared to the result from FEA as shown in figure 4.6.

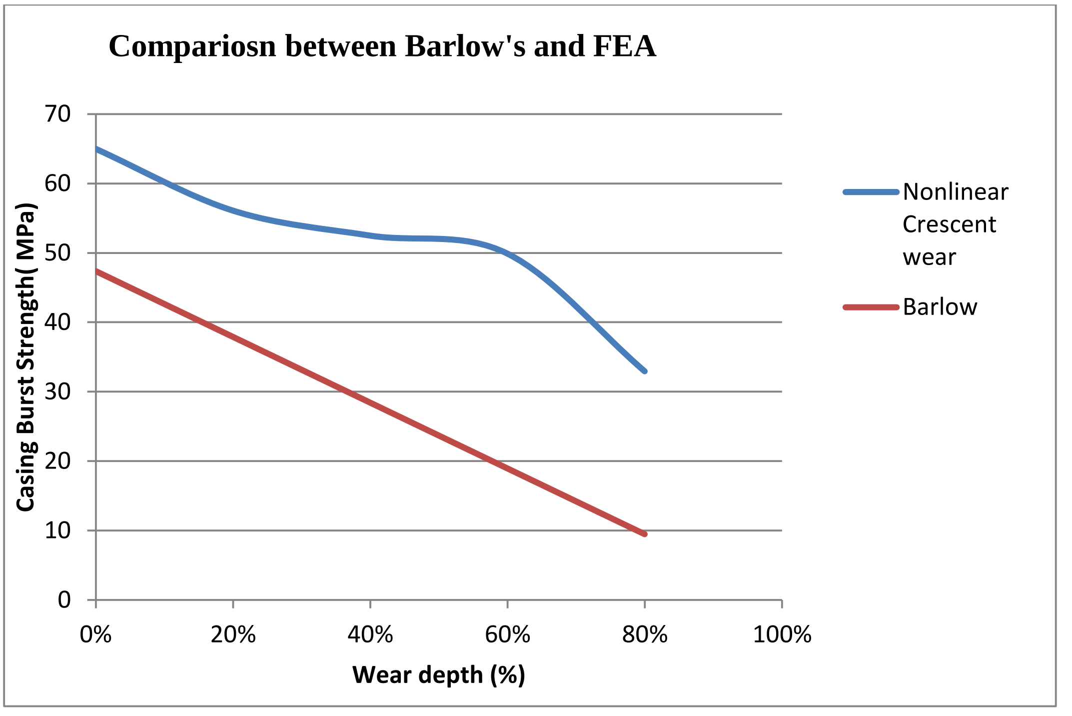

Figure 4.6 Comparison between Barlow’s burst strength and nonlinear FEA for a crescent shaped wear

In order to simplify future tasks and not spend more time designing defects with specific length, an effort has been made to express the relationship between burst strength for a casing with a wear throughout the length of the casing and the selected model i.e. a casing with a crescent shaped defect under nonlinear analysis. This model has a defect length equals to one tenth of the casing string length which had already been specified in section 3.4.1.

Figure 4.6 is a comparison between the burst strength for the selected model and the casing with a wear throughout the length of the pipe.

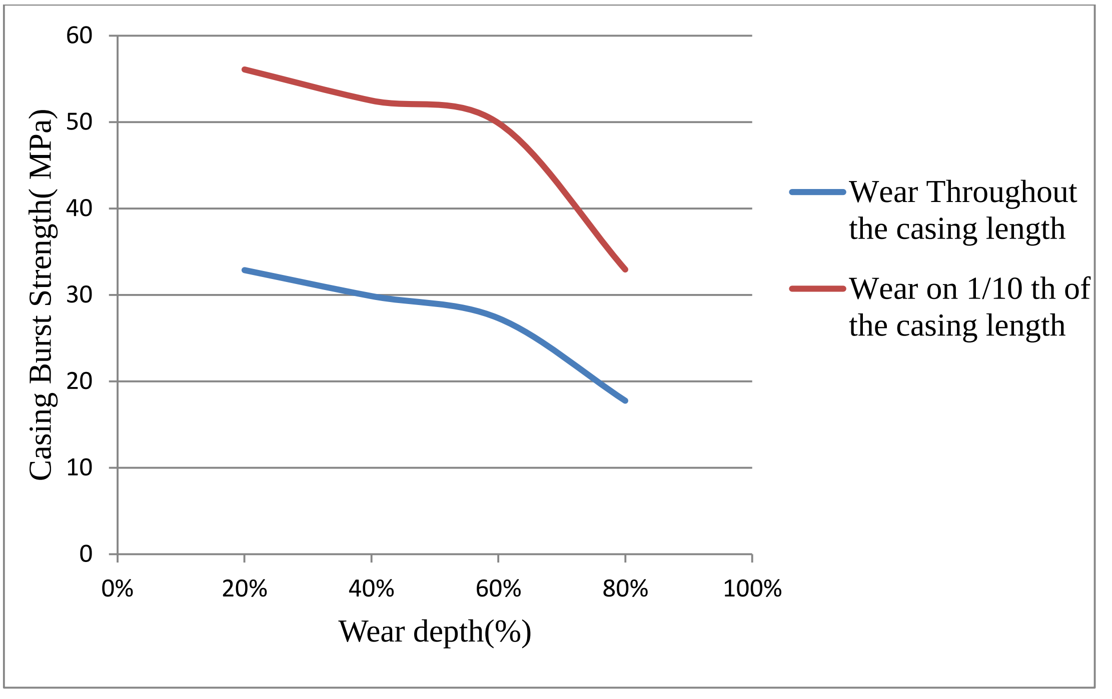

Figure 4.7 Comparison between nonlinear FEA for a crescent shaped wear and casing with a wear throughout the length of the pipe.

The two plots are related mathematically by:

For $\frac{l}{L} = 0.1$,

$$P_{B,model} = 1.78 * P_{B,throughout} \quad (4.1)$$

Where:

l= Wear length

L = Length of casing

$P_{B,model}$ = Burst strength of model

$P_{B,throughout}$ = Burst strength of casing with wear throughout its length

CHAPTER 5

CONCLUSION AND RECOMMENDATION

CONCLUSION

This project studies the effect of casing wear on casing burst strength through finite element analysis. The Different literatures had been reviewed and a methodology for the simulation is drawn. Theoretical values using the four different equations i.e. Barlow's equation, Initial yield burst equation, full yield burst equation and rupture burst equation are computed and compared with the finite element solution obtained.

The outcome of this project shows as a casing wall thickness decreases, its burst strength decreases. The comparison between simulation results and theoretically calculated results demonstrates the API formulas are very conservative. The model with a crescent shape wear with a nonlinear analysis yields the highest value of burst strength. The final burst strength value for L-80-9 5/8", 47ppf with different wear depth is shown in figure 4.6 together with the theoretical value i.e. Barlow's burst strength.

RECOMMENDATION

FEA is a very convenient way to estimate the burst strength of a worn out casing. Nevertheless, the author recommends future works should focus on investigating the burst strength of a worn out casing using experimental works. That will give more validation for the simulation work undertaken in this project

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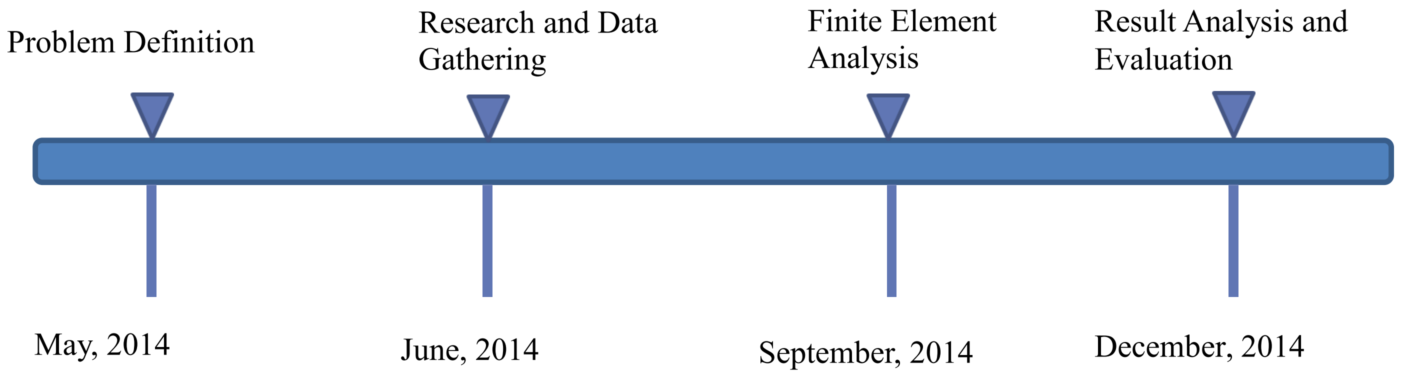
APPENDICES

Appendix 1- FYP Gantt Chart

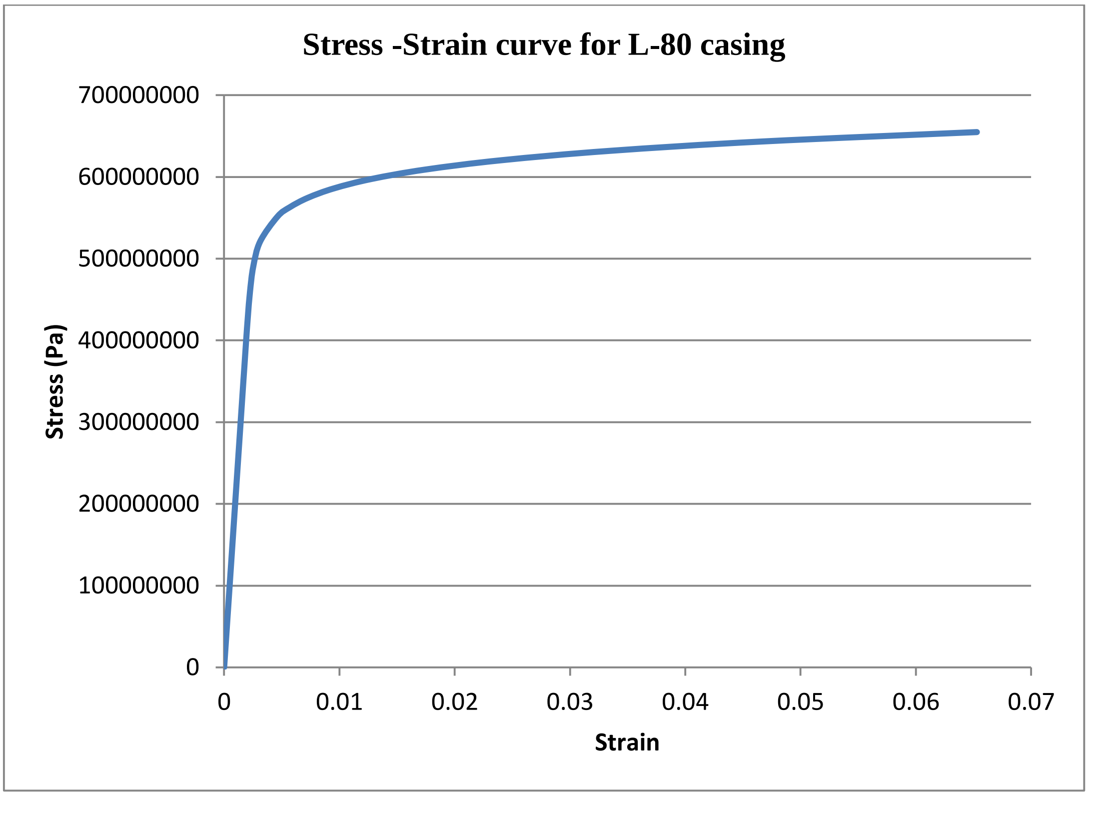
No.	Activity	Time Frame								
		May 14	June 14	July 14	Aug 14	Sept 14	Oct 14	Nov 14	Dec 14	Jan 15
1.	Problem Identification									
2.	Literature Review and Study of theory									
3.	Data gathering									
4.	Familiarization with ANSYS									
5.	Simulation work									
6.	Result Analysis									
7.	Progress with Report									
8	Final report and VIVA									

Appendix 2- Key Milestones

The key milestones of the project are summarized below.



Appendix 3- Stress Strain curve for L-80 casing



Appendix 4- ANSYS interface