STRESS ANALYSIS OF SUBSEA WELLHEAD HOUSING

by

Muhammad Faris Bin Mohd Pakri (10823)

A Project Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

SEPTEMBER 2011

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

CERTIFICATION OF APPROVAL

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Approved by,

____

(AP. Dr. Othman bin Mamat)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2011

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.

MUHAMMAD FARIS BIN MOHD PAKRI

ABSTRACT

Wellhead system is one of the main systems in a subsea production. As the subsea industry has been growing at an impressive rate. The growth of the industry has been driven by the price of oil, which has allowed companies to invest in developing reserves in increasingly difficult-to-access areas. It the wellhead fails, there is little hope of keeping the flow of toxic crude oil from potentially annihilating an entire ecosystem. The affects of such a catastrophe would be felt throughout the entire globe, not just on the environment, but on people as well. Economically, environmentally and psychologically, the damage from this oil spill will be incalculable in more ways than we can imagine right now. Therefore, it is necessary for us to ensure that the wellhead components are good enough to use for a certain working condition. This project consists of the stress analysis of one of the components in the wellhead system. The analysis of the wellhead component is done by using computer-based simulation software, which is SolidWorks Premium. The result from the analysis reveals that the current component and design is suitable for its specific working condition.

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.

First and foremost, I would like to extend my sincere gratitude to my supervisor AP. Dr. Othman bin Mamat for being a wonderful mentor in guiding, supporting and assisting me, also for his knowledge shared with me through the year, which are simply precious.

Not forgetting to other lecturers of UTP especially from the Mechanical Engineering department, thanks for useful thoughts and assistance that help me a lot in completing this project.

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CHAPTER 1

PROJECT BACKGROUND

1.1 Background of Study

The subsea industry has been growing at an impressive rate. The growth of the industry has been driven by the price of oil, which has allowed companies to invest in developing reserves in increasingly difficult-to-access areas. At the same time the industry has matured to the point where subsea technology is no longer a specialist area. It has become a routine choice, and often the only choice, for many long-distance or deepwater developments.

In order to distinguish between the different facilities and approaches which are needed, the subsea oil field developments are usually split into:

i) *Shallow water:* Continental shelf, or the area at the edges of a continent from the shoreline to a depth of 600 feet [200 m], where the continental slope begins.
ii) *Deepwater*: Exploration activity located in offshore areas where water depths exceed approximately 600 feet [200 m], the approximate water depth at the edge of the continental shelf.

First application of subsea technology in Malaysia is for shallow operation in 1999 (F23SW Shell operated Gas fields). With the increase of deepwater activities in Malaysia in recent years, subsea technology application has become more prominent [1]. Table 1.1 below shows all systems that involve in subsea production system [2]:

Table 1.1: Subsea Production System

System	Description
Template and Manifold Systems	Systems that provide an interface between the production flowlines and/or the wells. This system also act to distribute injected chemicals and control fluid, and to distribute the electrical and hydraulic systems.
Tie-in Systems	Provide connection between Xmas Tree/Manifold with the jumper/spool
Workover Systems	This system will is to ensure the workover can be done when there is a need to replace one or more non-retrievable completion string components
Subsea Production Control System	Control the wells by opening and closing the valves installed on the Xmas tree and other subsea equipments. The hydraulic pressure generated at either the platform or the onshore terminal is sent through umbilical hoses to activate submarine valves.
Wellhead and Xmas Tree Systems	In this system, the Xmas tree provides a pressure containing method to safely cap the well via its interface with the subsea wellhead

In this paper, the focus is on the Wellhead and Xmas Tree System but will only cover the wellhead component instead of both of the Wellhead and Xmas Tree.

1.2 Problem Statement

The oil and gas industry is headed toward design of high pressure, high temperature (HPHT) wells with increasing service pressures and temperatures in H2S environments. As the well conditions become more challenging, it becomes necessary to better understand the limits of reliable material performance, so that casing materials can be utilized to their full potential without crossing over to levels of unwanted or excess risk. [3]

It the wellhead fails, there is little hope of keeping the flow of toxic crude oil from potentially annihilating an entire ecosystem. The affects of such a catastrophe would be felt throughout the entire globe, not just on the environment, but on people as well. Economically, environmentally and psychologically, the damage from this oil spill will be incalculable in more ways than we can imagine right now. The future is indeed something to both dread and fear, for millions of inhabitants on this planet.

As the effect of the fail wellhead will produce worse situation, not only for the company itself, but also for the environment, it is necessary for us to ensure that the wellhead components are good enough to use for a certain working condition.

1.3 Objective

Knowing that one of the ways to ensure the wellhead can sustain its working condition is by doing analysis using software, this project is all about the stress analysis of the wellhead. Besides, doing analysis is the cheapest way, safe and need not much of time to accomplish it.

The objective of this project is:

1) To perform stress analysis of one of wellhead component which is Wellhead Housing.
2) To interpret the result and decide whether the Wellhead Housing is safe to operate or not, based on its design specification and material, AISI 4130.

1.4 Scope of Study

The scope of study revolves around:

1) One of the wellhead components which is Wellhead Housing.
2) Focus on only 10M-Wellhead Housing, which is the working pressure of the wellhead housing will only strict on 10,000 Psi
3) Apply only one type of common material for the Wellhead Housing which is AISI 4130

1.5 The Relevancy of the Project

The analysis of the wellhead system is the common method for engineer to ensure that the components are in a good condition before it use in the real system. This project will simulate the stress analysis of the wellhead housing that made by common material. This is an approach to understand and prove that the material that has been use to make the component definitely can sustain its working condition.

1.6 Feasibility Study

All final year students need to complete their Final Year Project (FYP) within 2 semesters. As this project will only focus on one of the Wellhead components, it has a potential to be done within the timeframe. The objective can be achieved if the procedures are closely followed and succeed.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Introduction

Wellheads can involve dry or subsea completion. Dry completion means that the well is onshore or on the topside structure on an offshore installation. Subsea wellhead is located under water on a special sea bed template. The wellhead has equipment mounted at the opening of the well to regulate and monitor the extraction of hydrocarbons from the underground formation. This also prevents oil or natural gas leaking out of the well, and prevents blow-outs of the well due to high pressure formations. Formations that are under high typically require wellheads that can withstand a great deal of upward pressure from the escaping gases and liquids [8]. Typical wellhead system can be seen in Figure 2.1 [11].

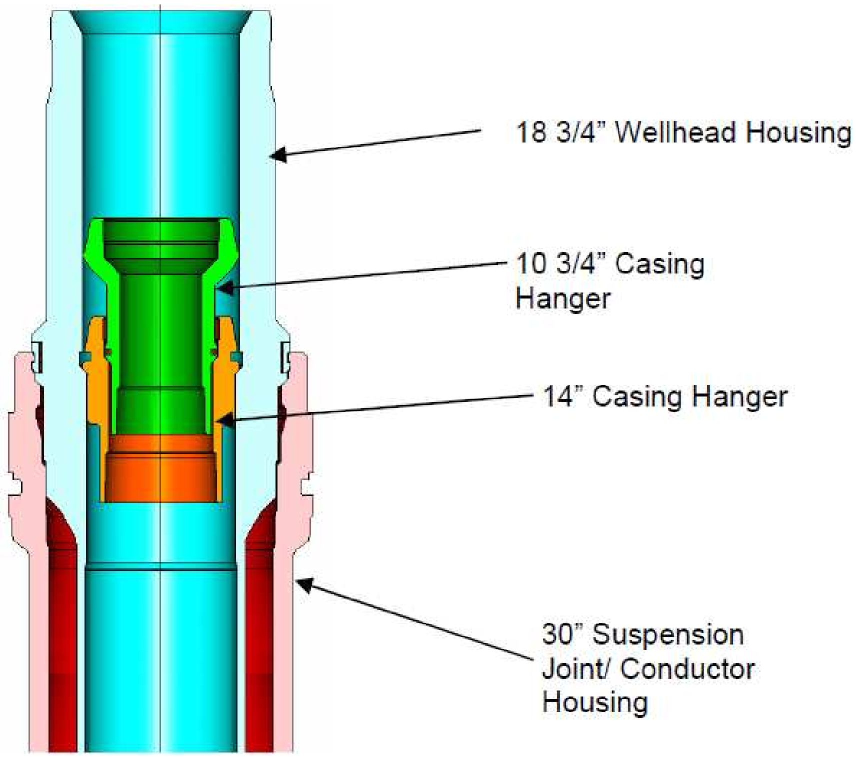


Figure 2.1: Typical Wellhead System

Subsea wellheads and Christmas Trees are one of the most vital pieces of equipment in a subsea production system. The subsea wellhead system performs the same general functions as a conventional surface wellhead. It supports and seals casing strings and also supports the Blow Out Preventer (BOP) stack during drilling and the subsea tree after completion. The subsea wellhead system mainly consists of wellhead housing, conductor housing, casing hangers, annulus seals and guide base (Temporary Guide Base and Permanent Guide Base). The high-pressure wellhead housing is the primary pressure-containing body for a subsea well, which supports and seals the casing hangers, and also transfers external loads to the conductor housing and pipe, which are eventually transferred to the ground [6]. Main codes for wellhead are shown in Table 2.1 [7]:

Table 2.1: Codes for Subsea Wellhead

American Petroleum Institute (API)	International Organization for Standardization (ISO)
API 6A Specification for Wellhead and Christmas Tree Equipment	ISO 10423 Wellhead and Christmas Tree Equipment
API 17D Specification for Subsea Wellhead and Christmas Tree Equipment	ISO 13628-4 Subsea Wellhead and Tree Equipment

2.2 Working Pressure and Load

The wellhead system suspends the casing and serves as a barrier for well fluids against the environment. The standard maximum rated working pressure for subsea wellheads shall be 2,000, 5,000, 10,000, or 15,000 (13.8; 34.5; 69.0; and 103.5 MPa). Tools and internal components such as casing hangers may have other pressure ratings depending on size [4]. The main component of the system which is Wellhead Housing also has its own rated working pressure according to the API 17D. The maximum rated working pressure for the wellhead housing pressure boundary shall be 2,000, 5,000, 10,000 or 15,000 psi (13.8; 34.5; 69.0 or 103.5 MPa). Selection of the rated working pressure should consider the maximum expected SCSSV operating pressure. This component needs to go through the hydrostatic body test pressure in order to ensure that the component can withstand the required working pressure. The hydrostatic body test pressure shall not be less than the following values [4]:

Table 2.2: Working and Test Pressure

Rated Working Pressure Rating (PSI) (Mpa)	Body Hydrostatic Test Pressure (PSI) (MPa)
2,000 (13.8)	4,000 (27.6)
5,000 (34.5)	10,000 (69.0)
10,000 (69.0)	15,000 (155.2)
15,000 (103.5)	22,500 (155.2)

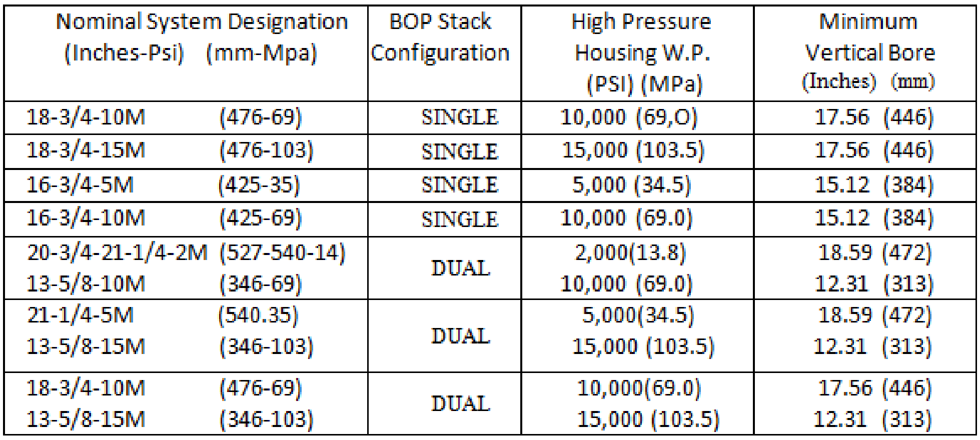
In designing the high pressure equipment, there are a lot of criteria's that need to be follow and one them is the housing should hold the test pressure against the housing seat without exceeding allowable stress levels [5].

2.3 Design

In the design, as a minimum, some loads shall be considered and documented by the manufacturer when designing the wellhead housing. The loads that need to be considered are Riser Forces, BOP Loads, Subsea Tree Loads, Pressure, Radial Loads, Thermal Loads, Environmental Loads, Flowline Loads, Suspended Casing Loads, Conductor Housing Reactions, Tubing Hanger Reactions, and also Hydraulic Connector Loads [9].

The dimensions also vary based on the working condition of the wellhead housing. The minimum vertical bore of the wellhead housing shall be design according to the table below [9]:

Table 2.3: Wellhead Systems Standard Sizes and Types



Nominal System Designation (Inches-Psi) (mm-Mpa)		BOP Stack Configuration	High Pressure Housing W.P. (PSI) (MPa)	Minimum Vertical Bore (Inches) (mm)
18-3/4-10M	(476-69)	SINGLE	10,000 (69,O)	17.56 (446)
18-3/4-15M	(476-103)	SINGLE	15,000 (103.5)	17.56 (446)
16-3/4-5M	(425-35)	SINGLE	5,000 (34.5)	15.12 (384)
16-3/4-10M	(425-69)	SINGLE	10,000 (69.0)	15.12 (384)
20-3/4-21-1/4-2M 13-5/8-10M	(527-540-14) (346-69)	DUAL	2,000(13.8) 10,000 (69.0)	18.59 (472) 12.31 (313)
21-1/4-5M 13-5/8-15M	(540.35) (346-103)	DUAL	5,000(34.5) 15,000 (103.5)	18.59 (472) 12.31 (313)
18-3/4-10M 13-5/8-15M	(476-69) (346-103)	DUAL	10,000(69.0) 15,000 (103.5)	17.56 (446) 12.31 (313)

Standard wellhead housing based on the API 17D is shown in Figure 2.2[9].

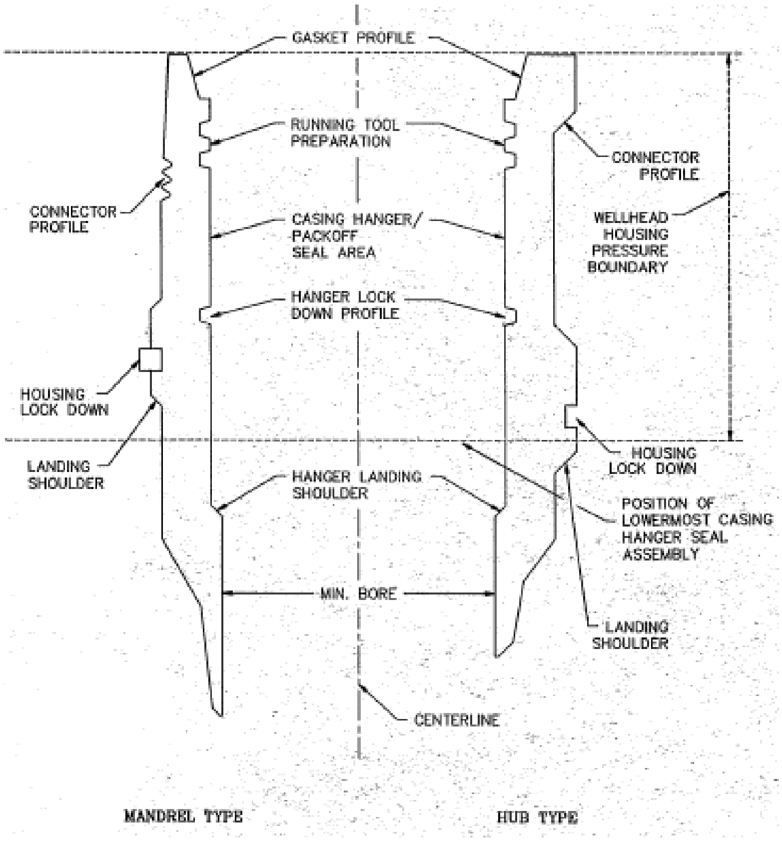


Figure 2.2: Wellhead Housing

The wall thickness criteria for Wellhead Housing also need to follow the industrial standard. The sizing of the basic wall thickness of a Wellhead Housing is based on the standardization in API 6A. For a cylindrical pressure vessel at a point remote from the ends, the membrane hoop stress is [13]:

$$S_h = p.R / t \qquad \textit{(Equation 1)}$$

where: p = the internal pressure
R = the inside radius
t = the wall thickness

The longitudinal stress is approximately half that value assuming the vessel has capped ends. The radial stress is compressive at the inner surface and has a value of –p. At the outer surface, the radial stress is zero. Therefore the membrane, or average, radial stress is approximately:

$$S_p = -p / 2 \qquad \textit{(Equation 2)}$$

These are principal stresses. Therefore, the stress intensity is the algebraic difference between the membrane hoop stress and the membrane radial stress.

$$P_m = p.R / t + p / 2 \qquad \textit{(Equation 3)}$$

Therefore, solving for t, where S is the allowable stress intensity,

$$t = pR / (S – 0.5 p) \qquad \textit{(Equation 4)}$$

For API 6A, the general primary membrane stress intensity at test pressure is limited to 0.83 S_y, and at working pressure, 2/3 of S_y. Therefore for this situation, test pressure is the controlling case [13].

The following chart shows the relationship of wall thickness to inside radius for four cases:

6A : The ASME Method in API 6A
16A : The ASME Method in API 6A
DE1 : The distortion energy method assuming full tension
DE2 : The distortion energy method with zero tension

Table 2.4 below shows nine different combinations of test pressure and working pressure, since for 2000 and 3000 psi equipment, different test pressure are used for different size ranges [13]

Table 2.4: Thickness to Radius Ratios for Various API Pressure Ratings

WP psi	TP psi	S_{yp} psi	------------ t/R Ratio -------------			
			6A	16A	DE1	DE2
2000	3000	60,000	0.062	0.057	0.047	0.053
2000	4000	60,000	0.084	0.077	0.064	0.072
3000	4500	60,000	0.095	0.087	0.073	0.082
3000	6000	60,000	0.128	0.118	0.100	0.122
5000	7500	60,000	0.163	-	0.130	0.144
5000	10,000	60,000	-	0.204	0.186	0.205
10,000	15,000	60,000	0.355	0.323	0.329	0.354
15,000	22,500	75,000	0.441	0.400	0.445	0.471
20,000	30,000	75,000	0.635	0.571	0.810	0.835

It can be seen from the table that no one method is always most conservative. However, the ASME/API 6A method is most conservative for all ratings through 10,000 psi. For 15,000 and 20,000-psi ratings, the Distortion Energy method is most conservative.

Figure 2.3 below shows Wellhead stackup during 13-inches hole drilling [20]. At this moment, the end part of the Wellhead Housing will be covered by cement, which is used to ensure the Wellhead is stable enough during the installation.

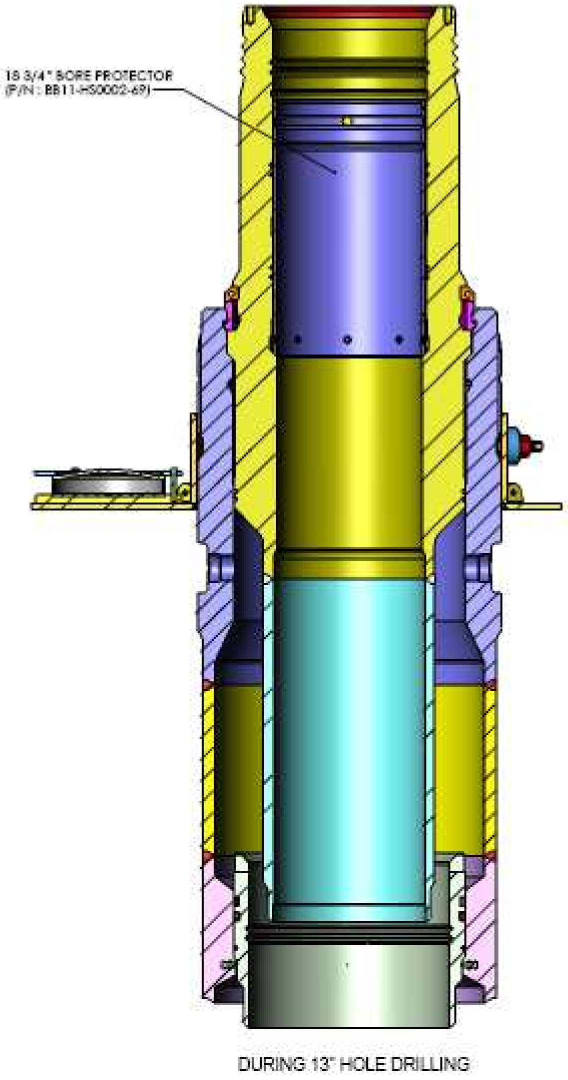


Figure 2.3: Wellhead Stackup

2.4 Material Selection

The materials that are documented will combine corrosion resistance with strength, toughness and weld-ability. In addition, machine-ability, availability, and cost will also feature highly during the final material selection suitability review [10]. The lists of materials recommendation for subsea equipment are shown in Table 2.5 [12]:

Table 2.5: General Metallic Materials Recommendation – Subsea Equipment

Component	Large Steel Forgings (Wellheads, Tubing Spools, Master Valve Blocks)
Recommend Base Case Material	Materials Class "EE": Low alloy steel with Alloy 625 trim. Class "FF": ASTM A182 F6NM with Alloy 625 trim. Class "HH": Low alloy steel, all surfaces exposed to produced fluids clad with Alloy 625.
Alternative Material	"FF": AISI 410, in special cases CA6NM. "HH": Full body CRA in accordance with ISO 15156/MR0175.
Remarks	"Trim" applies to pressure controlling parts (seal faces), stems and mandrel hangers. Low alloy steels: AISI 4130 or AISI 8630 low alloy steel, or ASTM A182 F22 (2-1/4Cr 1Mo) low alloy steel. CA6NM is used for very large valve bodies that cannot be forged. Qualification procedures shall be agreed by the Principal.

2.5 Theory

2.5.1 Nodal and Element Stresses

When running a COSMOS analysis, the solver internally evaluates the stresses for each element in the model at specific locations inside the element (also called as Gaussian or Quadrature points). These points form the basis of numerical integration schemes used in Finite Element codes. The number of points selected is determined by the type and quality of the element. The subsequent stresses obtained at the Gaussian points inside each element are extrapolated to the nodes of the element.

Nodal Values are the averaged values of stresses at each node. The value shown at the node is the average of the stresses from the Gaussian points of each element that it belongs to. In the adjoining Figure 2.4, the central node would carry a stress that is an average of the 6 stresses coming from the 6 elements that it belongs to. [14]

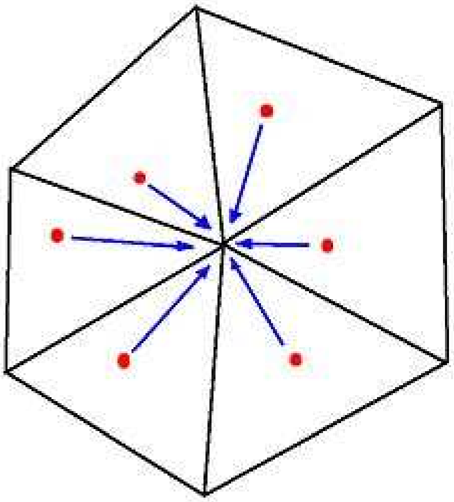


Figure 2.4: Nodal Values

The alternative method of displaying stresses is called Elemental Values. In this method, each element individually looks at the stresses at its nodes from the Gaussian points. The stress at the element is the average of the stresses seen at its corresponding nodes. Figure 2.5 and Figure 2.6 show the difference of approach to average stresses between the nodal and element stress [14].

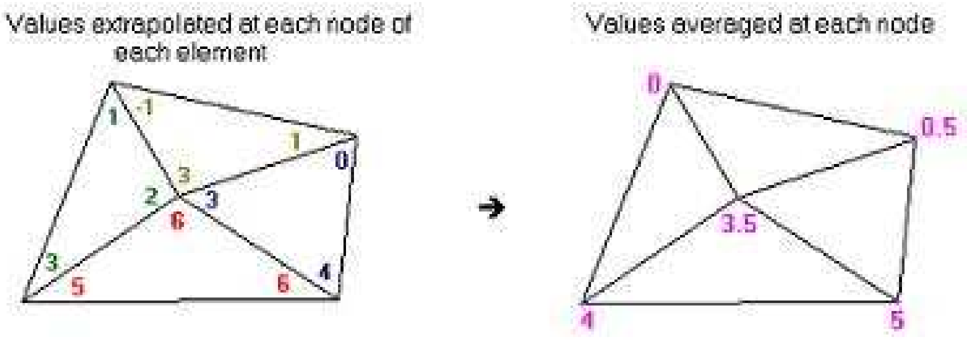


Figure 2.5: Nodal Average Stress

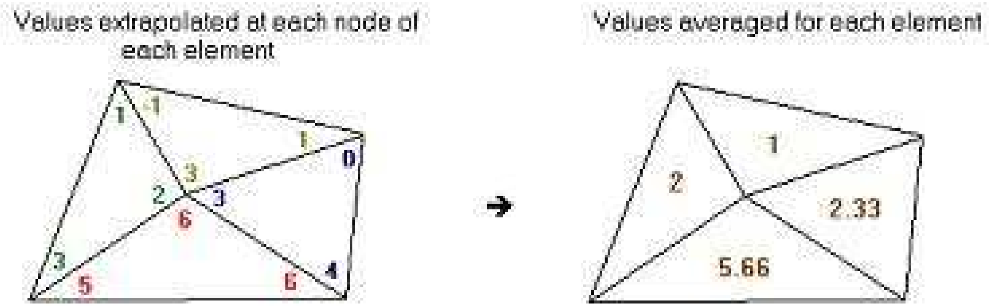


Figure 2.6: Element Average Stress

The degree of difference in the values is a reflection of the coarseness of the mesh, and hence the convergence of stress results. If the values are very different, it is a reflection of the mesh being too coarse at the high stress location. Hence, the mesh needs to be refined at those locations using Local Mesh Control [14].

2.5.2 Hoop or Circumferential Stress

A hoop stress which, in a pipe or pressure vessel would tend to make the pipe diameter or circumference increase. As fluid which has filled the pipe is pressurized the hoop stress causes the diameter or circumference to increase.

This is the stress which is set up in resisting the bursting effect of the applied pressure and can be most conveniently treated by considering the equilibrium of half of the cylinder as shown in Figure 2.7 [15].

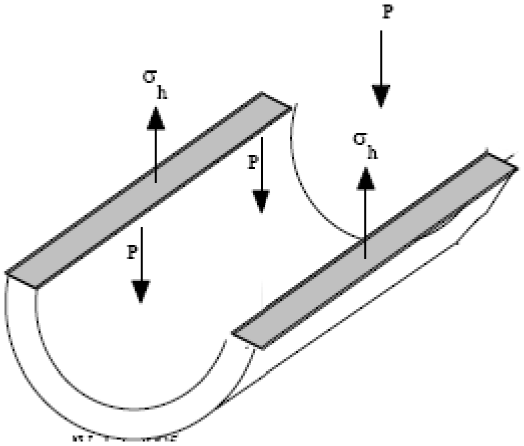


Figure 2.7: Half of thin cylinder subject to cylinder pressure showing the hoop stress

The equation for total force on half-cylinder owing to internal pressure is shown in below equation [16],

Total Force (internal Pressure) = p x projected area

= p x dL (Equation 5)

where, p = internal pressure

d = diameter

L = length

While total force owing to hoop stress, σ_h set up in the cylinder walls is given by [16]:

Total Force (hoop stress) = 2 σ_h x Lt *(Equation 6)*

where, t = thickness of cylinder wall

By balancing both total forces, the new equation for hoop stress is:

Total Force (internal Pressure) = Total Force (hoop stress)

$$p \times dL = 2\,\sigma_h \times Lt$$

$$\sigma_h = pd/2t \qquad \textit{(Equation 7)}$$

2.5.3 Von Mises and Tresca

Von Mises Criterion (1913), also known as the maximum distortion energy criterion, octahedral shear stress theory, or Maxwell-Huber-Hencky-von Mises theory, is often used to estimate the yield of ductile materials.

This theory postulates that failure will occur when the distortion energy per unit volume due to the applied stresses in a part equals the distortion energy per unit volume at the yield point in uniaxial testing[17]. Mathematically, the failure of material will occur when its value is above critical value as state in *Equation 8* [18]:

$$\{(\sigma_1 - \sigma_{2)}^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\} > 2\,\sigma_y^2 \qquad (\textit{Equation 8})$$

The von Mises stress also can be referred as the effective stress. The alternate forms of effective stress are [19]:

$$\sigma_{\text{eff}} = (\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1\sigma_2 - \sigma_2\,\sigma_3 - \sigma_3\,\sigma_1)^{1/2} \qquad (\textit{Equation 9})$$

$$\sigma_{\text{eff}} = \{[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]/2\}^{1/2} \qquad (\textit{Equation 10})$$

The maximum shear stress criterion is also known as Tresca's or Guest's criterion. Yield in ductile materials is usually caused by the *slippage* of crystal planes along the maximum shear stress surface. Therefore, a given point in the body is considered safe as long as the maximum shear stress at that point is under the yield shear stress σ_y obtained from a uniaxial tensile test. From that, design equation can be obtained, as shown in Equation 10.

$$(\tau_{\max})_{\text{component}} < \sigma_y / 2 \qquad (\textit{Equation 9})$$

$$\tau_{\max} = \sigma_y / 2\,n \qquad (\textit{Equation 10})$$

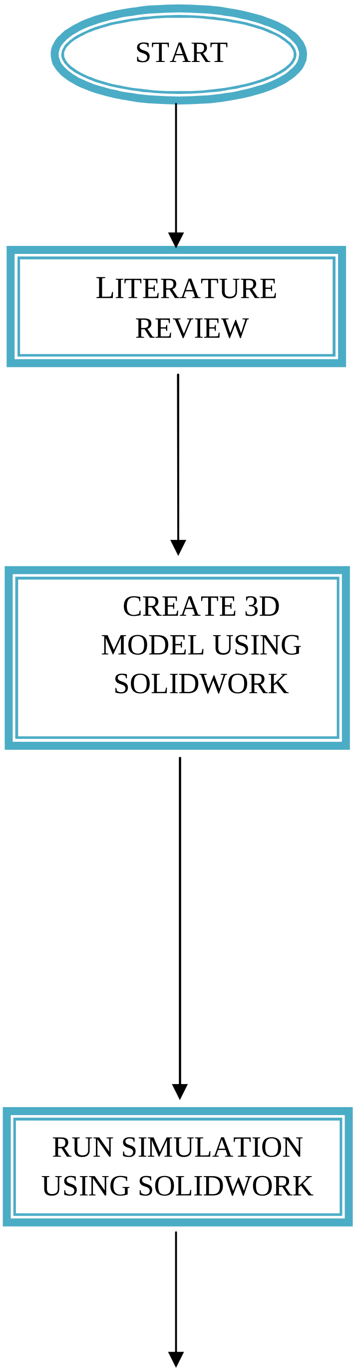
where n = safety factor

CHAPTER 3

METHODOLOGY

3.1 Research Methodology and Project Activities

The research methodology and project activities to accomplish the analysis are shown in Figure 3.1 below:

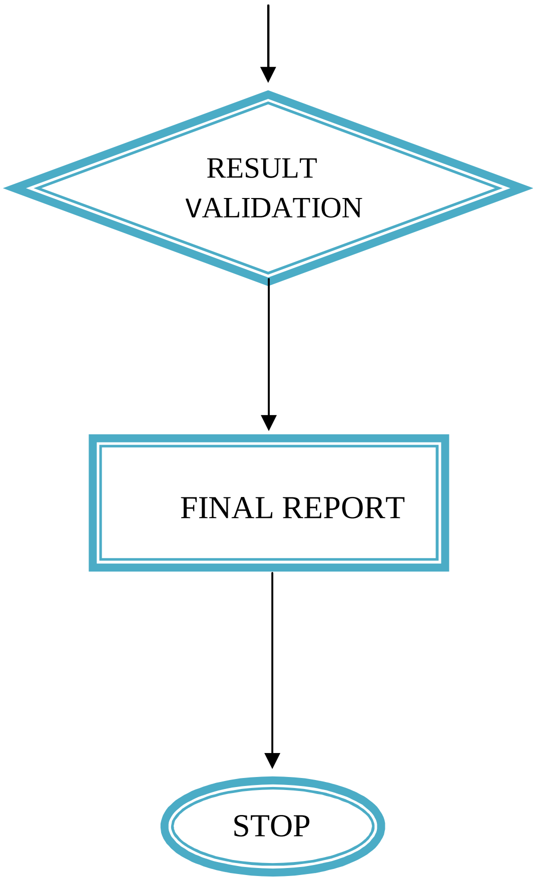


PROJECT ACTIVITIES TO ACCOMPLISH EACH PROCESS IN THE FLOW

- Preview / Analyze problem
- Analyze requirement for Wellhead Housing according to standardize code (API)
- Fundamental studies from references and journals

- Interpret the design specification of the wellhead housing into the model
- Identify the requirement to make a model that will allow analysis to be done on the model
- Ensure the parameters of the model is based on the requirement

- Interpret the material of the wellhead housing based on the fundamental studies that has been done, into the Solidwork
- Define the working pressure and load based on the specification, into the Solidwork
- Define the constraint of the model based on the subsea wellhead system



- Interpret the result and identify whether the result is acceptable or not.
- If not valid, the flow need to go through the previous stage until obtain the valid result, based on industrial specification

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- Report on the result of the stress analysis of the Wellhead Housing
- Recommendation to improve analysis

Figure 3.1: Flow Chart of Methodology

3.2 Gantt Chart and Key Milestones

All activities that involves in the flow to accomplish the analysis have been put in an appropriate schedule or Gantt chart. This is very important in order to make sure that not any single activities will be delayed as it will cause this analysis cannot be done within the time frame. Gantt chart for FYP I is shown in Table 3.1 while Gantt chart for FYP II is shown in Table 3.2

Table 3.1: Gantt chart and Key Milestone FYP I

No	Tasks Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project topic: FEA of Subsea Wellhead - Knowing what kind of analysis involve in FEA - Knowing roughly about Wellhead	■	■						Mid-Semester Break							
2	Research on literatures related to the topic - Background of the project - Knowing the significance of this project in life and industry - Decide the objectives of project		■	■	■	■	■	■								
3	Submission of Extended Proposal						▲									
4	Proposal Defence - Make a presentation to defend this project as an FYP									■	■					
5	Further study on the specification, constraint and working load of Wellhead Housing							■		■	■	■	■	■	■	■
6	Prepare model for simulation software - Creating Wellhead Housing model using computer-based 3D modeling software									■	■	■				
7	Study on simulations by computer-based simulation software - The Wellhead Housing model will be use to run simulation											■	■	■	■	■
8	Submission of Interim Draft Report														▲	
9	Submission of Interim Report															▲

Table 3.2: Gantt chart and Key Milestone FYP II

No	Tasks Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Further research on Wellhead Housing - Working condition and load - Calculation involve to verify the design	▨	▨	▨	▨	▨	▨	▨	Mid-Semester Break	▨	▨	▨	▨	▨		
2	Study on simulation by computer-based software - Getting deep understanding about the software in order to gain better result - Run simulation by using the latest information from latest research	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨		
3	Evaluate the analysis result from Solidwork - Analyze the critical stress of the Wellhead Housing based on the load and pressure - Evaluate the deformation of the model whether acceptable or not					▨	▨	▨		▨	▨	▨	▨	▨		
4	Submission of Progress Report - Done the research and simulation. The result has been compile to be submit as Progress Report									▲						
5	Pre-EDX - An evaluation to compete in EDX												▲			
6	Submission of Draft Report													▲		
7	Submission of Technical Paper														▲	
8	Submission of Technical Paper														▲	
9	Oral presentation															▲

3.3 Tool

The main equipment that will be used for this project is computer-based simulation software, Solidwork Premium. This software is chose instead of other simulation software due to this software has been used by the author during internship starting from 7th June 2010 until 14th January 2011 at Aker Solutions Malaysia Sdn. Bhd. This software can be used to create 3D model of the component, Wellhead Housing. Besides, after creating the 3D model, this software has ability to perform stress analysis, which is the main objective for this Final Year Project.

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 Data Gathering and Analysis

The physical characteristic for the Wellhead Housing is shown in Table 4.1 while the property for material, AISI 4130 Steel, normalized at 870^{o}C, is shown in Table 4.2 and Table 4.3 below.

Table 4.1: Physical Characteristics of Wellhead Housing

Characteristic	**Value**	**Units**
Mass	6,063	Pounds
Surface Area	11, 626	inches^2
Volume	21,402	inches^3

Table 4.2: Physical Property for AISI 4130 Steel, normalized at 870^{o}C

Physical Property	**Value**	**Unit**
Density	0.284	lb/in^3

Table 4.3: Mechanical Property for AISI 4130 Steel, normalized at 870^{o}C

Mechanical Property	**Value**	**Unit**
Ultimate Tensile Strength	97,200	psi
Yield Strength	66, 717	psi
Elastic Modulus	29,732,736	psi
Shear Modulus	11,603,019	psi
Poisson’s Ratio	0.29	-

According to “Wellhead Systems Standard Sizes and Types” from API 17D (refer to Table 4), the minimum vertical bore for Wellhead Housing should be 17.56 inches. In order to ensure that the design is follow the standards or not, the dimensions for the Wellhead Housing has been done and has been shown in Figure 4.1. The unit of the dimensions is in inch.

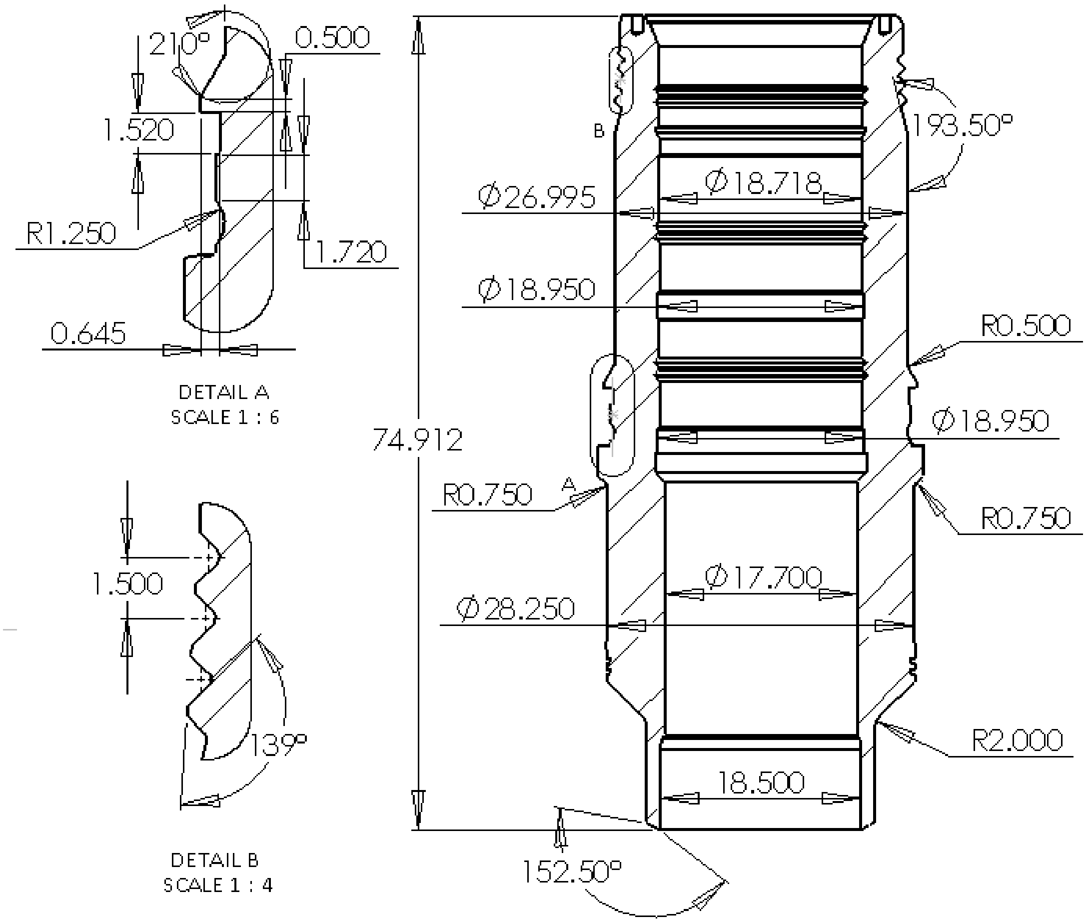

Figure 4.1: Dimensions of Wellhead Housing

Based on Figure 4.1, it shows that the minimum vertical bore of the design is 17.700 inches, which is exceeding the value for standard minimum vertical bore. Therefore the design is acceptable.

The thickness of the Wellhead Housing also need to follow the standands that has been put in API 6A (refer to *Equation 4*).

$$t = pR / (S - 0.5\,p) \qquad \text{(}\textit{Equation 4)}$$

According to the design, one part of the thickest wall has a radius of 8.85 inch and its thickness is 5.275 inch. The calculation below shows that the value of thickness that needed for a given radius when working and test pressure applied is less than thickness that has been state in the design. Therefore, the thickness is acceptable.

At working pressure, $P = 10{,}000$ psi

` Thickness, $t = 10{,}000\ (8.85) / (0.83*66{,}717 - 0.5*10{,}000)$

$= 1.757$ inch < 5.275 inch

At test pressure, $P = 15{,}000$ psi

Thickness, $t = 15{,}000\ (8.85) / (0.83*66{,}717 - 0.5*15{,}000)$

$= 2.773$ inch < 5.275 inch

4.2 Experimentation/Modeling

For this analysis, the working conditions will consists of stress analysis of Wellhead Housing with its test pressure, 15000 psi.

4.2.1 Stress Analysis of Wellhead Housing with test pressure of 15,000 psi

The test pressure is applied at the whole contact point in the Wellhead Housing as shown in Figure 4.2. In order to run the simulation and enable stress distribution being seen, the model needs to be meshing first. Figure 4.3 is shown the model after meshing.

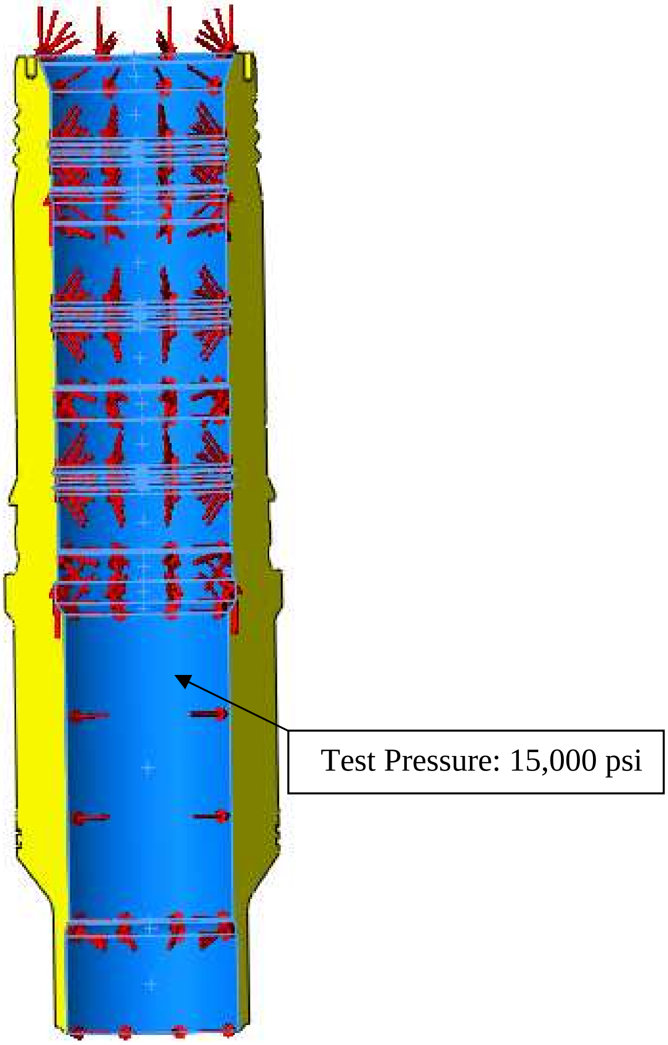

Figure 4.2: Test Pressure

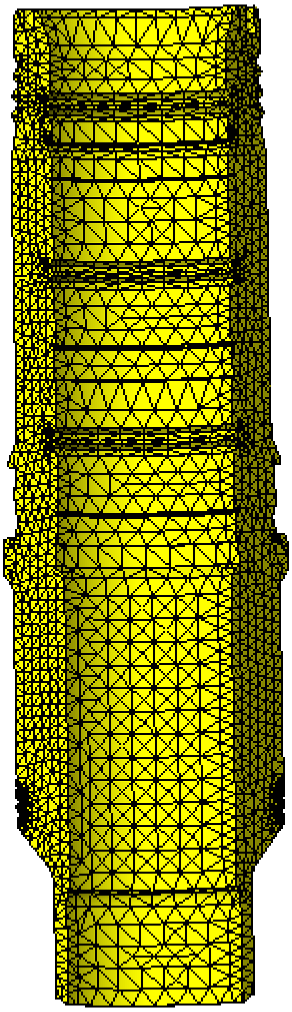

Figure 4.3: Meshing

4.2.1.1 Nodal Stress and Element Stress

Since the approach to average stresses is different for the nodal and element stress, the maximum stresses in the stress plot will be different. The degree of difference in the values is a reflection of the coarseness of the mesh, and hence the convergence of stress results. If the values are very different, it is a reflection of the mesh being too coarse at the high stress location.

Therefore, comparing nodal stresses and elemental stresses is a way of understanding if the mesh is fine enough, and if the results have converged at the highest stress location in the geometry. The stresses should approach one another as the element size gets smaller. The elements sizes are reduce at the area that has higher stress which is at the end of the Wellhead Housing, as shown in Figure 4.4. While Table 4.4 and Figure 4.5 shown the outcome as the element size reduced.

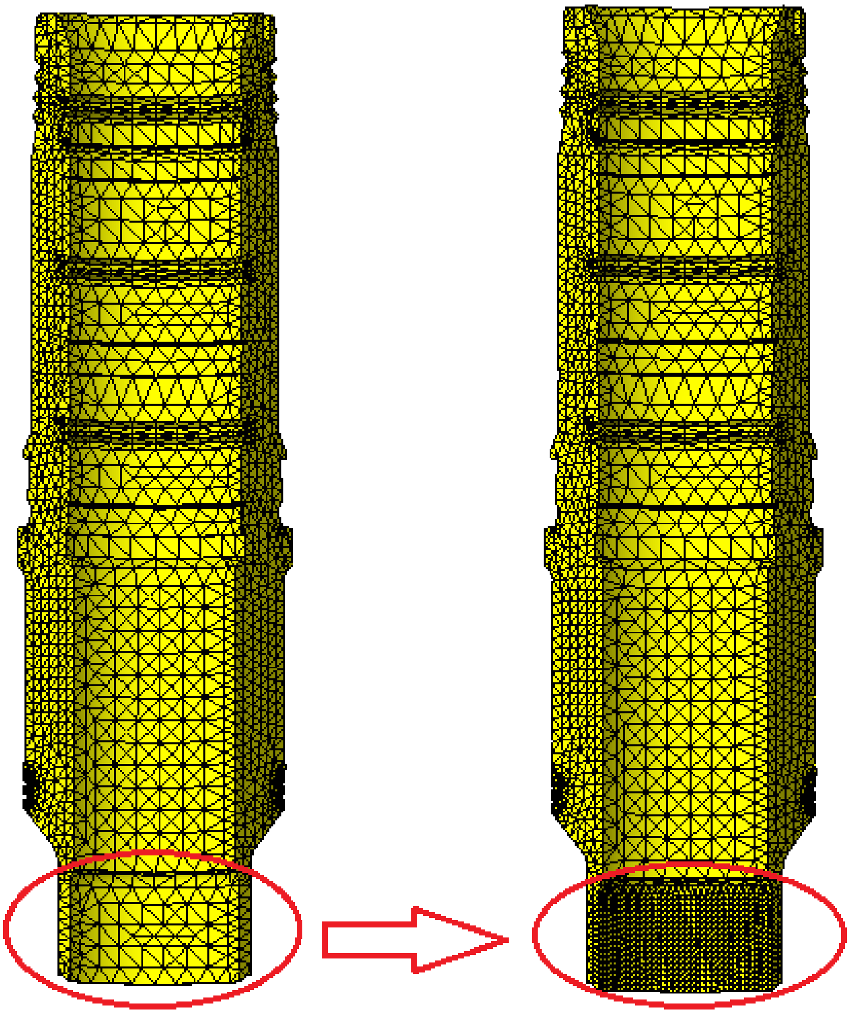

Figure 4.4: Elements sizes reduced

Table 4.4: Percentage Difference between Maximum Stress for Node Values and Element Values

No.	**Element Size (inch)**	**Total Nodes**	**Total Elements**	**Max. Stress Node Values (psi)**	**Max. Stress Element Values (psi)**	**% Difference**
1	1.75	36,663	22,605	164,890	159,474	3.28
2	1.663	36,461	22,467	168,251	163,003	3.12
3	1.575	36,655	22,607	165,076	159,414	3.43
4	1.488	36,525	22,511	166,200	159,402	4.09
5	1.400	36,610	22,574	165,264	159,434	3.53
6	1.313	36,698	22,586	165,111	159,424	3.44
7	1.225	36,730	22,597	165,017	159,404	3.40
8	1.134	36,708	22,600	165,162	159,612	3.36
9	1.050	36,941	22,747	166,032	161,956	2.45
10	0.963	37,053	22,790	164,690	160,432	2.59
11	0.875	37,019	22,761	164,326	159,781	2.77
12	0.788	37,169	22,808	164,451	159,909	2.76
13	0.700	37,873	23,250	164,370	160,323	2.46
14	0.613	38,249	23,409	164,876	160,481	2.67
15	0.525	39,259	23,929	164,622	160,817	2.31
16	0.438	40,822	24,759	165,283	161,994	1.99
17	0.350	43,241	26,040	164,858	161,723	1.90

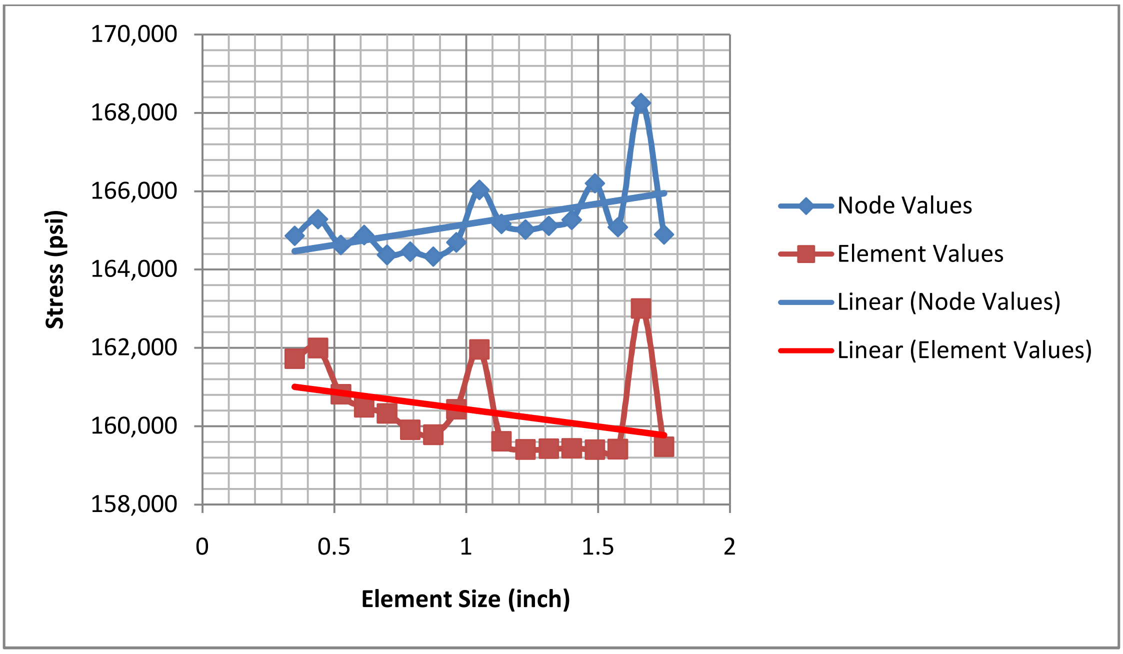

Figure 4.5: Graph of Stress versus Element Size

The element size has been reduced by 5 until 80 percent from the starting or initial element size, 1.75 inches in an increment of 5 percent. The percentage difference has been reduced from 3.28 percent to 1.90 percent. This shows that the meshing has become finer and produced more accurate result. But, as can be seen in the maximum stress column for both node values and element values, the values are higher than yield strength and the tensile strength of the material, AISI 4130. This is because, the Wellhead Housing should be attached to Pup Joint and that area will be covered by cement, which will assist it to withstand the internal pressure. As this report is only consist and focus on Wellhead Housing without any equipment attached to it, the pressure load will not be applied at the region. Besides, the meshing will also focus on the region other than the previous region which is at the end of the Wellhead Housing. Figure 4.6 show that the area of the Wellhead Housing that has been applied the load pressure while Figure 4.7 show the stress distribution at the area by applying meshing with the finest element size which is 0.350 inches.

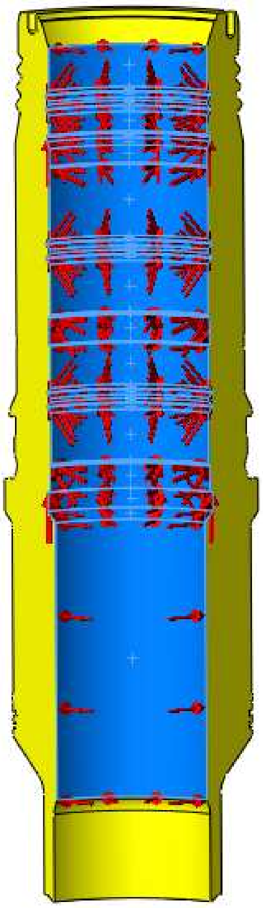

Figure 4.6: Load Pressure

Figure 4.7: Stress Distribution

Element size of 0.350 inch is used due to it given very small difference in value between nodal stress and element stress. From Figure 4.7, it can be seen that the maximum stress due to the load pressure is 56,511.6 psi. The value is less than the yield strength of AISI 4130 which is 66,717 psi. Therefore, it can be concluded that this if AISI 4130 is used as the material for Wellhead Housing, this component will not deform or yield which means it is safe to operate.

4.2.1.2 Hoop Stress

Hoop Stress is the circumferential loading of a cylindrical mechanical body and must be kept well below the yield strength of the material. The hoop stress in the Wellhead Housing would tend to make the pipe diameter or circumference increase. Figure 4.8 and Figure 4.9 below represent the value of hoop stress at node 115922. That node is one of nodes that situated in the region of the Wellhead Housing that has internal diameter of 17.7 inches and thickness of 5.275 inches.

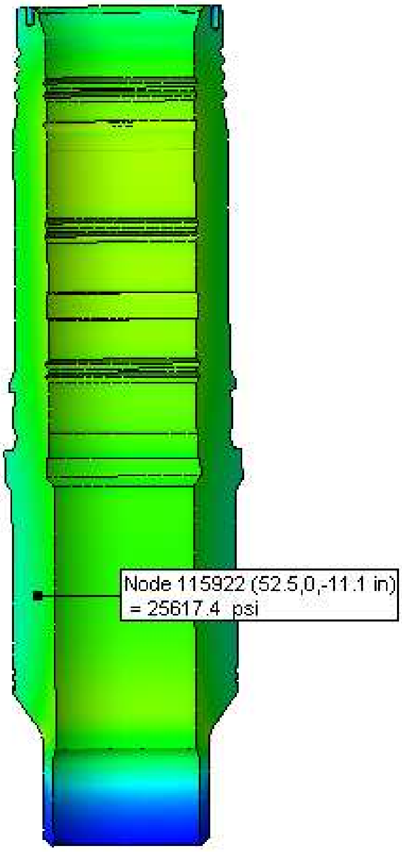

Figure 4.8: Hoop stress at 15,000 psi of internal pressure

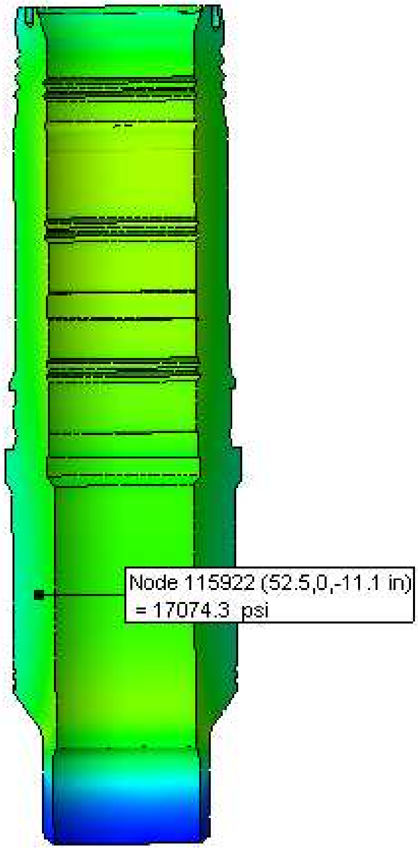

Figure 4.9: Hoop stress at 10,000 psi of internal pressure

The analysis for the hoop stress has been varying by changing the amount of load pressure. The load pressure will start at the working pressure of the Wellhead Housing which is at 10,000 psi until its test pressure which is 15,000 psi. Table 4.5 and Figure 4.10 show the amount of hoop stress depending to the pressure applied.

Table 4.5: Hoop Stress for different Internal Pressure

Internal Pressure (psi)	Hoop Stress (psi)
10,000	17,074
11,000	18,782
12,000	20,488
13,000	22,195
14,000	23,910
15,000	25,617

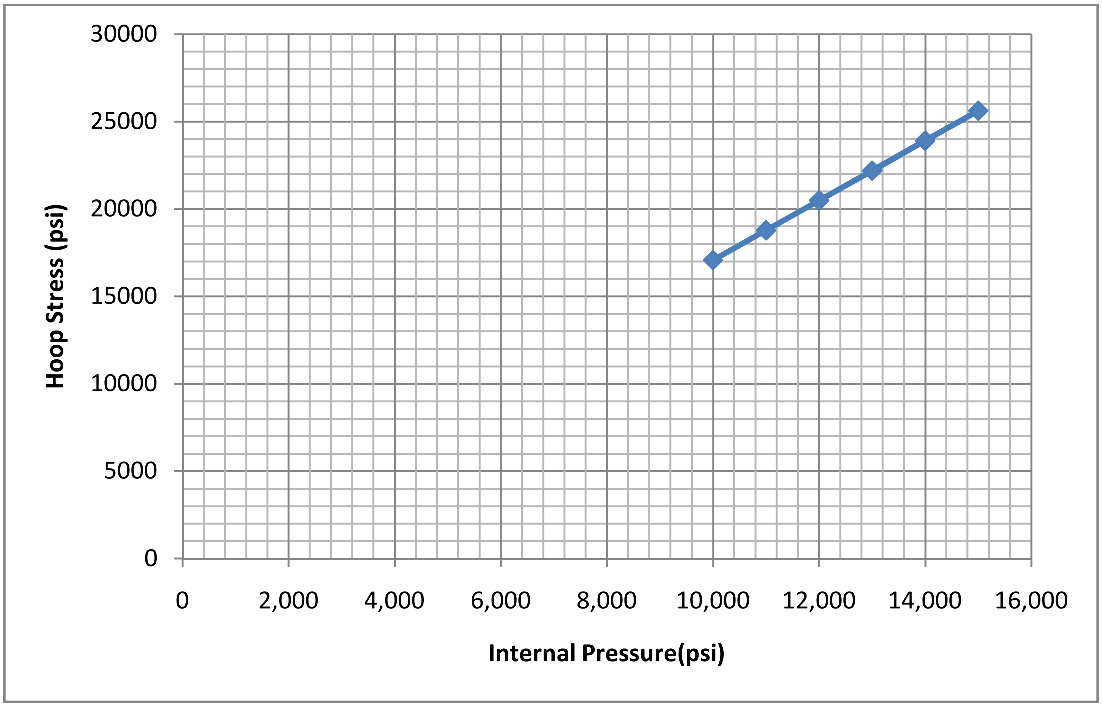

Figure 4.10: Graph of Internal Pressure versus Hoop Stress

At test pressure of 15,000 psi, the hoop stress is 25,614 psi. This simulation has given a positive result as the value of the hoop stress does not exceed the yield strength of the Wellhead Housing which is 66,717 psi.

The theoretical value of hoop stress of the Wellhead Housing can be calculate using the equation that has been put in API 6A (refer to *Equation 1*).

$$S_h = p.R / t \qquad (Equation\ 1)$$

At internal pressure, p = 10,000 psi

$$S_h = 10{,}000\ (8.85) / (5.275)$$
$$= 16{,}777 \text{ psi}$$

Table 4.6 below show the theoretical values of hoop stress starting from internal pressure, p of 10,000 psi until 15,000 psi.

Table 4.6: Theoretical value of Hoop Stress for different Internal Pressure

Internal Pressure (psi)	Hoop Stress (psi)
10,000	16,777
11,000	18,455
12,000	20,133
13,000	21,810
14,000	23,488
15,000	25,166

Based on the theoretical values, the hoop stress for each internal pressure does not exceed the yield strength of the material which is 66,717 psi. Therefore, as both theoretical and simulation values give positive result, it can be conclude that the material and design specification of the Wellhead Housing can withstand the hoop stress on it.

4.2.1.3 Von Mises and Tresca

Von Mises and Tresca are often used to predict the yielding of ductile materials. The Von Mises criterion states that failure occurs when the energy of distortion reaches the same energy for yield/failure in uniaxial tension. While Tresca criterion states that at any given point in the body, it is considered safe as long as the maximum shear stress at that point is under the yield shear stress. Therefore, in order to ensure that the Wellhead Housing is safe to operate, both Von Mises and Tresca values should be under yield strength of the material. Table 4.7 and Figure 4.11 show the value of Von Mises by varying the internal pressure starting from its working pressure, 10,000 psi, until its test pressure, 15,000 psi.

Table 4.7: Maximum Von Mises Stress at different Internal Pressure

Internal Pressure (psi)	Maximum Von Mises Stress (psi)
10,000	37,742
11,000	41,516
12,000	45,286
13,000	49,060
14,000	52,744
15,000	56,512

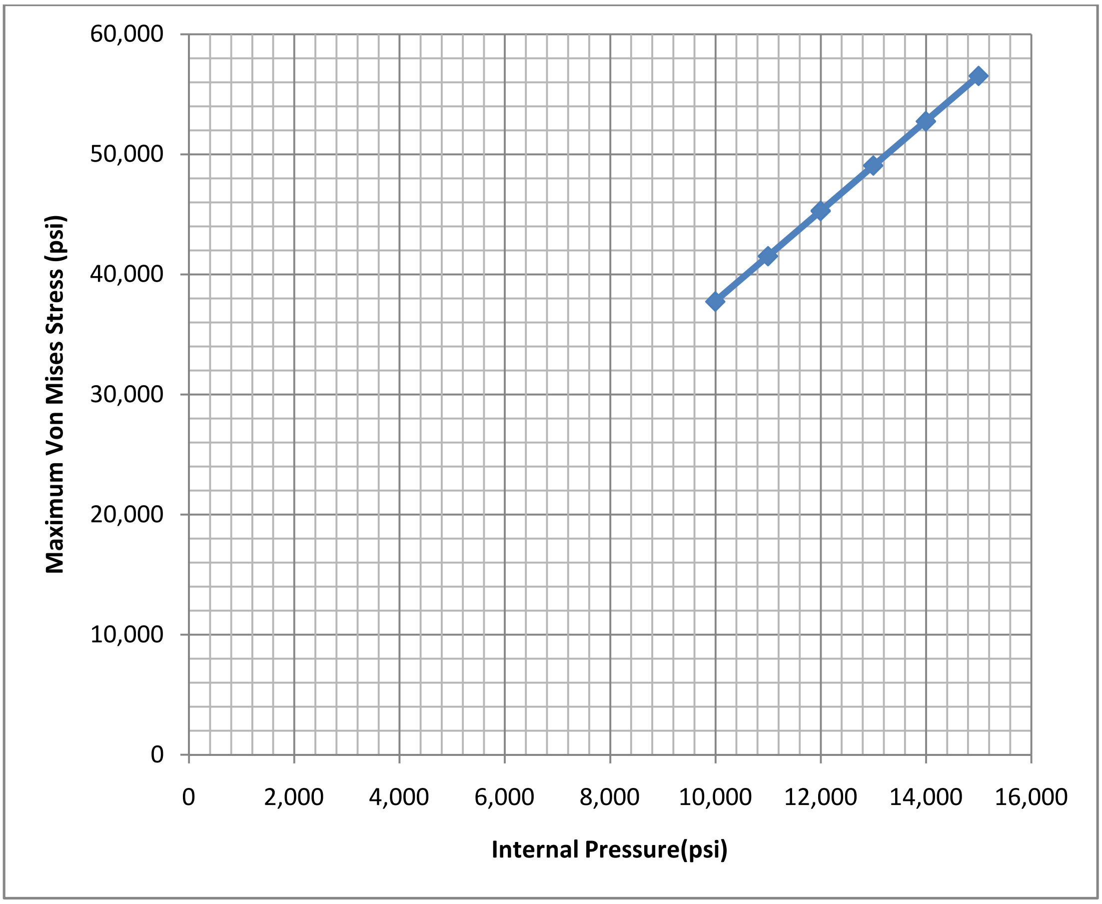

Figure 4.11: Graph of Internal Pressure versus Maximum Von Mises Stress

The value of Tresca cannot be known directly from the simulation using the SolidWorks. It can be found by manipulate the value of stress intensity as stress intensity is twice the value of Tresca stress. Table 4.8 and Figure 4.12 show the value of Tresca stress for different internal pressure.

Table 4.8: Maximum Stress Intensity and Tresca at Different Internal Pressure

Internal Pressure (psi)	Maximum Stress Intensity (psi)	Tresca (psi)
10,000	41,513	20,757
11,000	45,664	22,832
12,000	49,786	24,893
13,000	53,935	26,968
14,000	57,997	28,999
15,000	62,140	31,070

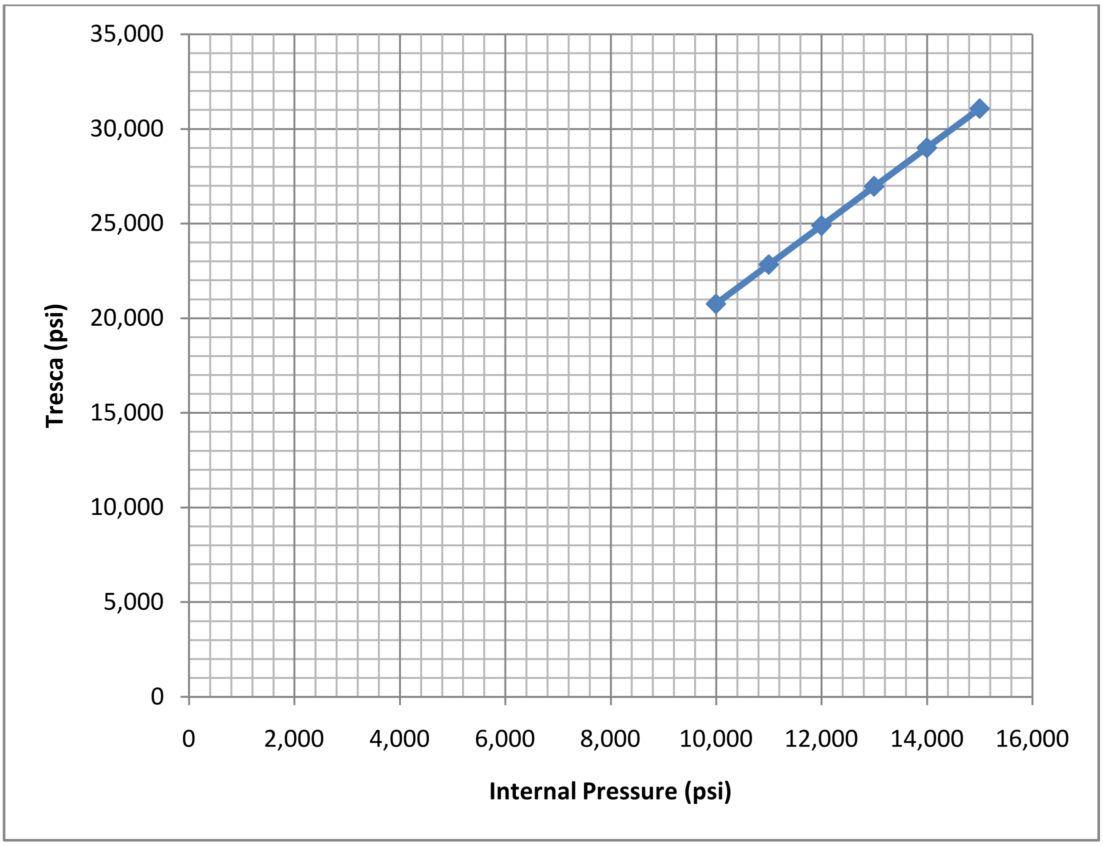

Figure 4.12: Graph of Internal Pressure versus Tresca Stress

The value of maximum shear stress for this material is equal to half of the yield stress, which is:

τ_{max} = 66, 717 psi /2

= 33,359 psi

As the failure of the material will only occur if the Tresca stress is exceeding the maximum shear stress, it can conclude that the Wellhead Housing is safe to operate. This is because, based on the stress analysis, the highest value of Tresca stress is only 31,070 psi.

4.2.1.4 Overall / Compilation

Figure 4.13 show the hoop, maximum von mises, and tresca stress for the Wellhead Housing working internal pressure until its test internal pressure.

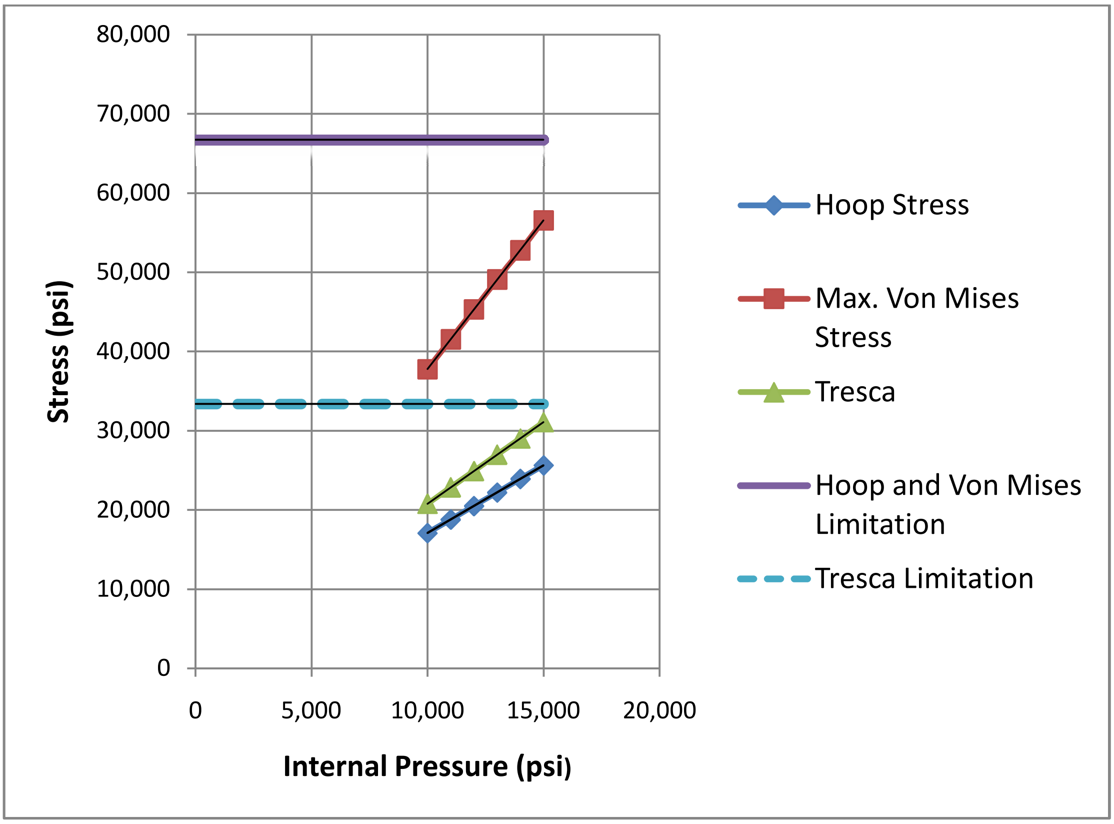

Figure 4.13: Graph of various types of stress versus internal pressure

The limitation lines are the indications for the analysis to decide whether the internal pressure will give deformation to the Wellhead Housing or not.

CHAPTER 5

CONCLUSION AND RECOMMNEDATION

5.1 CONCLUSION

A three-dimensional FEA which is a Stress Analysis of Subsea Wellhead Housing was carried out using SolidWorks Premium software. The material model used for the simulation was AISI 4130. The process simulation has been done by applying an internal pressure to the internal area of Wellhead Housing. The internal pressure was varied from its working pressure, 10 000 psi until its test pressure 15 000 psi.

The results from the simulation consist of Nodal Stress, Elemental Stress, Von Mises Stress, Tresca Stress and also Hoop Stress. Those kinds of stresses are important in order to achieve the objective, which is to know whether the Wellhead Housing is safe to operate at its working pressure or not.

Yield stress of the material is used as the base point to analyze whether the model can withstand the internal pressure or not. From the result, it can be conclude that Wellhead Housing is safe to operate at its working pressure if AISI 4130 is used as its material and the design is following its standard requirement.

5.2 RECOMMNEDATION

Meshing is one of the factors that will affect the result of the stress analysis. Generally, by increasing the resolution of the mesh, the accuracy of the stress analysis can be improved. In this project, the meshing resolution was limited by computer's processor. Therefore, better computer's processor is needed for better resolution. Then, it will lead to better result for this project.

Another way to improve the result of this project is, instead of using only single component from the Wellhead System, the analysis should involve all components which have relationship with the Wellhead Housing. This is because, as Wellhead Housing will be installed together with other components during the installation, it will definitely given different result for the stress analysis if the analysis is not consider other components. In future work, much time should be given for this project as will not able to be accomplished in a short time range.

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