Effect Of Residual Bend In Coiled Tubing Buckling For Horizontal Wells

by

Junalou Resquites Molde

14722

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Petroleum)

January 2015

Universiti Teknologi PETRONAS
32610, Bandar Seri Iskandar
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Engineering Programme
Universiti Teknologi PETRONAS
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(PETROLEUM)

Approved by,

____

(Dr. Sonny Irawan)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2015

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.

JUNALOU RESQUITES MOLDE

ABSTRACT

Coiled tubing has been continuously used successfully around the world. Various of companies has proven its advantage during drilling operation which cause this advance drilling technology a very important part specially on drilling underbalance well, workover, slimhole drilling and re-entry wells. Drilling with coiled tubing saves time and cost of operation thus increases profit. Selection of which how long coil tubing string shall be used in drilling varies with depth of the reservoir. However, in the life of coiled tubing string a residual bend exist. Initially coiled tubing is not straight tubing when placed inside a wellbore as it has a certain residual bend which is bound to happen. This paper's aim is to explain how this residual bend that is present in coiled tubing affect on string maximum length before lock-up occurs on tubing.

In this thesis, the buckling of the tubing associated with different load application was studied. For the analysis, widely known industry standard software, Ansys Workbench, was used. The results are in line with the new modeling technique/ experimental works documented in literatures. The overall simulation analyses are summarized. In addition, list of recommendations as future work are proposed.

ACKNOWLEDGEMENT

The thesis work is to fulfil the requirement in the Bachelor of Science degree in Petroleum Engineering at Universiti Teknologi PETRONAS, Department of Petroleum Engineering.

First of all, I would like to especially give the biggest warmth of thanks to my faculty supervisor Dr. Sonny Irawan (Senior Lecturer), for giving me the opportunity to work for the thesis under his supervision, and also for his advice, guidance, kindness and support.

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I am pleased to acknowledge those people who directly or indirectly supported me and guided me upon completing this project and to Mechanical Lab technicians, who has given all the support to me to finish my work during the lab sessions.

Lastly, I would also like to express my sincere gratitude to my beloved family and friends for their support, encouragement and endless love throughout my studies

Above all, this project would have never been worth it without the infinite blessings of the Most Highest and Graceful, the Almighty God.

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Nomenclature

E= young’s modulus, m/Lt^2, psi

F= axial compressive force, m/Lt^2, lbf

Fh= critical helical buckling force, m/Lt^2, lbf

Fo= axial compressive force applied at tubing downhole end, m/Lt^2, lbf

I= bending moment of inertia, $L^{4,}$ in^4

L*= lockup depth, L, ft

Lloc= lockup depth (theoretical upper limit) for a given residual bend radius R, L, ft

L^*_{loc}= lockup depth (theoretical upper limit) for a straight coiled tubing (R→infinity), L, ft

L_s= section length of straight tubing L, ft

r= tubing radial clearance, L, in

R= residual bend radius of curvature, L, in

w= coiled tubing buoyancy weight per unit length, m/t^2, lbf

K= apparent friction coefficient

CHAPTER 1

INTRODUCTION

The focus of this study is to address the specific issues associated with coiled tubing drilling (CTD) with its arising development applications to bring significant improvements to drilling area in increasing both the productivity and recovery of hydrocarbons from existing fields. Specifically, a study on the lockup length of the coiled tubing (CT) string with the consideration of residual bending present in the string in penetrating horizontal wells to when accessing the resource.

1.1 Background

The increasing advancement of technology in drilling industry with the purpose of bypassing challenging drilling environment and economic climate is yielded. Coiled tubing is one of its rapid growing technologies drilling operation. Nowadays, Coiled- tubing drilling has its various applications such as drilling underbalance wellbore, sidetracking, well intervention, re-entry applications, drilling shallow new wells, and the rest of modern wellbore configurations rely on CT conveyed techniques as shown in figure 1.

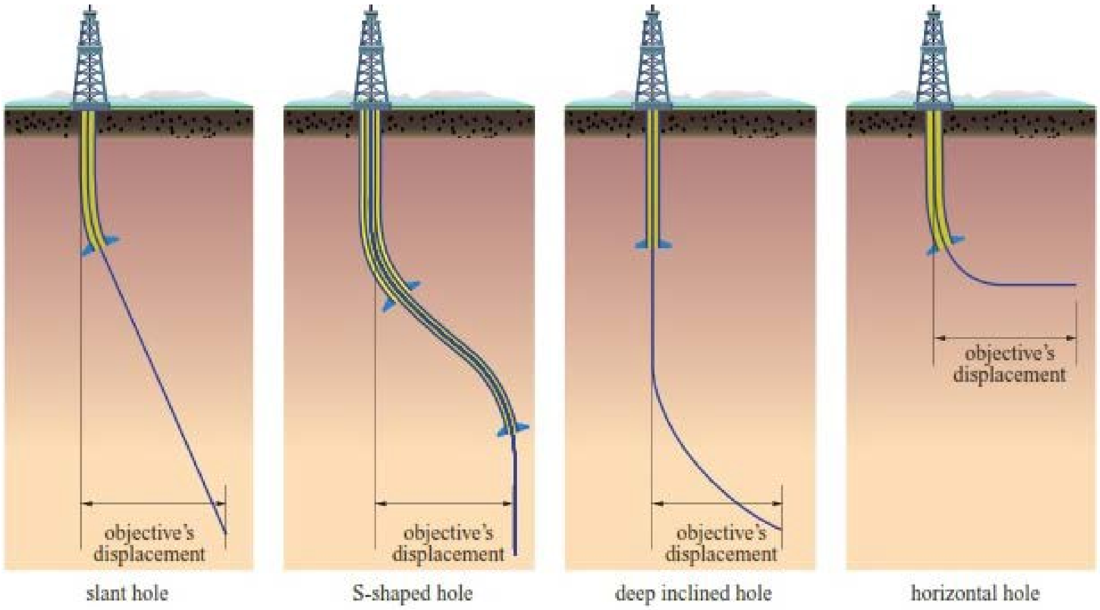


Figure 1: Main configuration of a directional or horizontal well, (Encyclopedia of Hydrocarbons, ND)

In coil tubing drilling, drilling on extended reach wells has bending which existed in every coiled tubing string. With this kind of limitation, it actually gives off a problem towards reaching the lockup depth.

1.2 Problem Statement

Coil Tubing Drilling (CTD) technology is progressing rapidly in the oil and gas industry for slim hole well drilling, re-entry drilling programs and horizontal or extended reach wells. The development in CTD is predominantly driven by the increasing focus on well cost reduction and operation efficiencies. Despite ever increasing interest on CTD, the current available technology comes with limitations in its mechanical parts to use for drilling.

Drilling horizontally using CTD, applies the limitation on the string of the coiled tubing. It has been found that when pushing coiled tubing downhole with the applied force, tubing gradually form sinusoid inside the well and a further pushed creates more compression on the string till a second buckling mode continues forming a helix inside the well. And with the presence of residual bend does affect more of the helical buckling on the string. This would result on decrease of the maximum horizontal penetration.

Thus, the ability to relate drilling parameters and the possibility to analyse it with mathematical methods provide the best ways to analyse the effect on drilling operation.

1.3 Relevancy of the Project

Importance of coiled tubing with its limitation been discusses by the previous studies of the researcher’s is important in the innovative competence of oil and gas industry. As coiled tubing has a great advantage in oil and gas market.

In analysing the effects would give an idea on how far can coiled tubing be pushed in horizontal wells which would help in determining the length and types of coiled tubing to use in drilling any kinds of wells with the range of depth, so as to drill the target.

1.4 Objectives

i) To examine the effect of straight initial configuration tubing (no residual bend consideration) to its lockup depth in horizontal well.

ii) To interpret the effect of tubing with residual consideration to its lockup depth in horizontal well.

iii) To analyse the effect of residual bend in coiled tubing on extended reach ratio (lockup length ratio) in horizontal wellbore.

1.5 Scope of Study

The study concentrates on three-related objectives which are:

i) First is to construct a desired geometry on Ansys,, create mesh to develop a finite element model and use static structural model.

ii) By that, critical helical buckling load (Fh) of the model will be predicted using Ansys software with the inputs: K, w, R, E, I, r, F, Fo. The inputs are to be taken depending on the type of coiled tubing string to be used.

iii) The critical helical buckling load will be used to get calculate the lockup depth using the available equation. Then a simulation conducted to analyse the result and plot the graph of residual bending radius vs. lockup depth.

CHAPTER 2

LITERATURE REVIEW AND/OR THEORY

2.1 History of Coiled Tubing Drilling

According to (Gantt et al., 1998), the first development of coiled tubing services were for workover market as coiled tubing running with casing and completion are not efficient enough to run, that is why re-entry drilling were the CTD techniques first application in conjointment with workover rig.

Previously, the available tubing size of CT services was 1 inch with relative short strings lengths. (Kumar, Raj, & Mathur, 2011) stated that early CT operation were limited in terms of diameter of tubing and length due to tubing mechanical properties as requirement to yield suitable string length are in the means of consistent quality of the tubing and fewer butt welds which was delivered in late 1960's. However, in 1990's, (Byrom, 1999) and (Kumar et al., 2011) cooperated with the argument of development in tubing sizes of 2 inch diameter was introduce in this era. From this time main focuses of CT innovation were reduction of cost, larger diameters and higher strength steel. From that point of view, increment supply of CT OD sizes for well-servicing applications had produced 2-3/8, 2-5/8, 2-7/8, 3-1/2 and 4-1/2 inches (Kumar et al., 2011).

Moreover, (Kumar et al., 2011) declared that the original development of coiled-tubing (CT) for economically safe work-over operations without the means to kill the well were in live well intervention tool. As continued growth of underbalance drilling in the industry, CT technique is a great help to lessen horizontal and vertical wells damage. Such characteristic advantages of CTD capabilities are continuous circulation during pipe tripping, portability, decrease in crew levels, no connection, faster trips and etc.

2.2 CT configuration and its physical theory

According to (Zheng & Adnan, 2007) , coiled tubing string is not initially straight configuration but rather a residual bend is existed as coiled tubing spooled on a reel on its storage and transportation has already been plastically deformed (bent).During drilling operations using CTD, tubing is unspooled from the reel and bent on the gooseneck before entering into injector and the wellbore as shown in figure 2. After leaving the injector, coiled tubing has a range of residual bend radius of 150-400 inches. This residual bending curvature stays even after entering into the wellbore that is why its initial configuration is not straight.

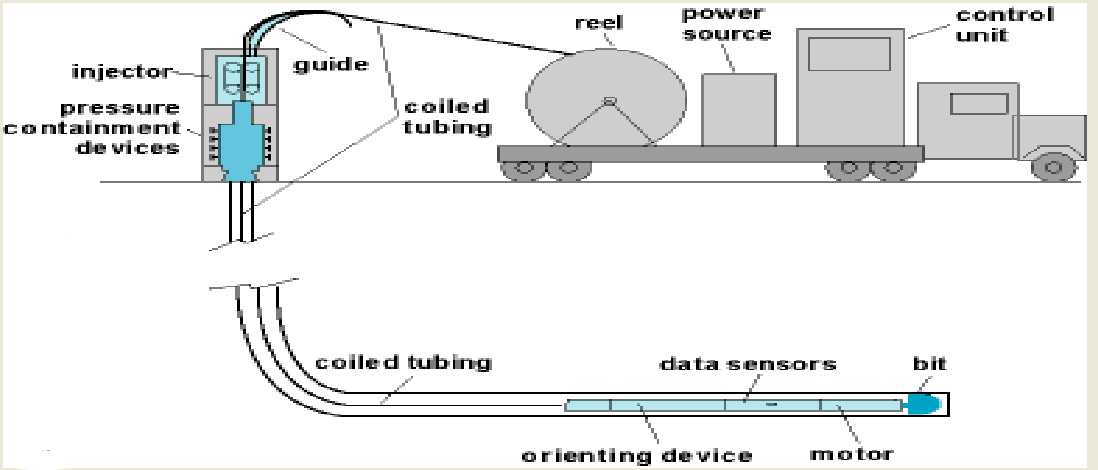


Figure 2: CTD configuration.

Moreover for the life of CT, figure 3 shows that if CT is stretched moderately, steel behaves elastically (returning to its original dimensions once stress is removed). Stress beyond its yield point, it deforms permanently. Stress too much and too frequently, it fails. In highly deviated well, tubing may become compressive (Ackert, Beardsell, Corrigan, & Newman, 1989).

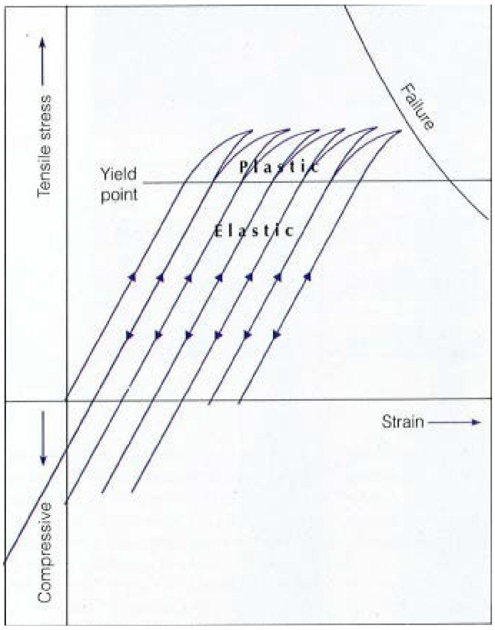


Figure 3: Stress and strain history of coiled tubing as it is spooled in and out of the well, (Ackert et al., 1989).

Another fact on CT is that it first buckles into sinusoidal shape. As the compressive force increases, the tubing will subsequently deform into helical shape as shown in figure 4, (Ackert et al., 1989).

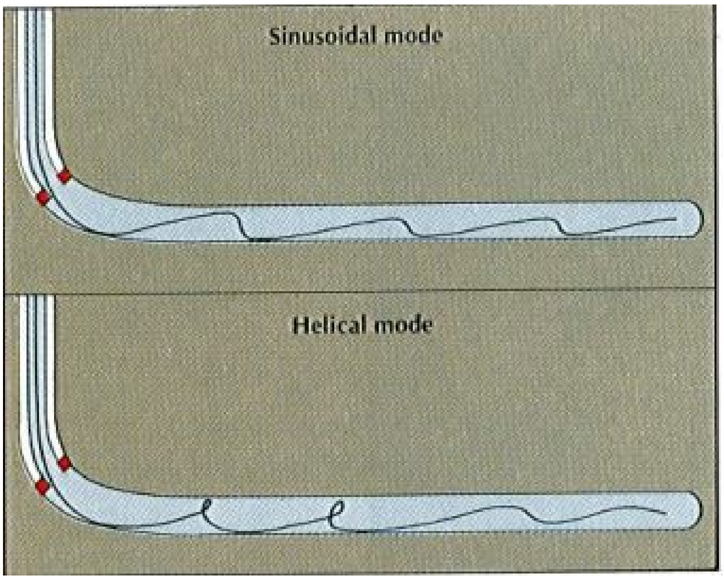


Figure 4: CT string Configuration when applying axial load,
(Ackert et al., 1989).

As more force is applied for the requirement in pushing CT into a well increases rapidly, more frictional drag exponential increases until overcoming insertion forces which resulted in a lock-up condition (where tubing will no longer move further into the well). Such situation, CT may plastically deform or fail from bending, axial thrust and pressurization (Simulia, 2009).

(Lubinski & Althouse, 1962) pioneer the relationship between pitch of helix and the applied forces of helical buckling of a long tubing string in the wellbore. When most of the research was focusing on determining critical buckling loads of a long tubing string in a horizontal wells, Mitchell pioneers the relationship between radial contact forces and the applied axial forces on a helically buckled string. All of them assumed a straight tubing string.

Later on, (Qiu & Miska, 1999) established a new model on evaluating effect of tubing’s initial configuration which is a curvature on sinusoidal and helical buckling.

2.3 Buckling in horizontal sections

As mentioned, first buckling mode would be sinusoidal shape and a further increase of axial compressive loads will result a helix form of the tubing, thus reaching helical buckled tubing. For analytical solution, here are the equations for both buckling points.

Sinusoidal buckling in a horizontal wellbore occurs:

Fs= $2(\frac{EIx\,w}{r})^{0.5}$ ---eqn. 1

Helical buckling in a horizontal wellbore occurs:

Fh= $2\,(2\sqrt{2}-1)\,\sqrt{\frac{EIx\,W}{r}}$ ---eqn. 2

Where:

Radial clearance:

r = $\frac{1}{2}$ (Dhole- ODtubing) --eqn.3

Moment of inertia:

I= $\frac{\pi}{64}(ODtubing^{4}-IDtubing^{4})$--eqn.4

2.4 Coiled tubing with residual bend in horizontal wells

To calculating the lockup depth,here is the formula of the length of helically buckled tubing with residual bend (R): $L_{loc} = L^{S} + L^{*}$ = (Fh/uw)+(2R/K) ln(rRFh+2EI)/rRFh-------------------------------eqn. 5

Looking into the figure 5, shows the consideration of coiled tubing being pushed into a horizontal wellbore in determining how far the coiled tubing can be pushed into the well (lockup depth).

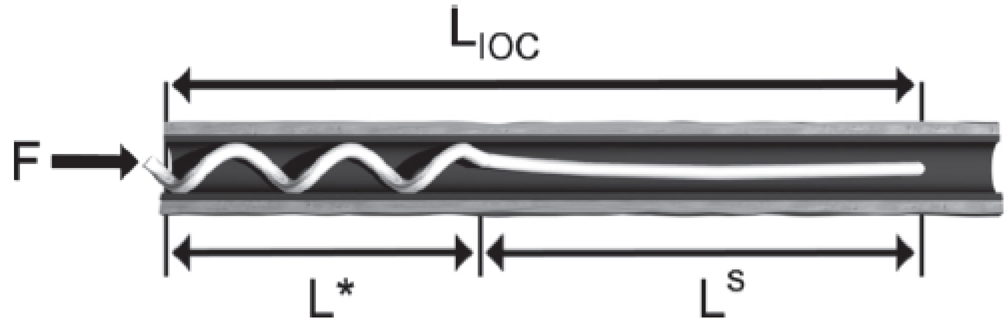


Figure 5: Maximum length of coiled tubing being pushed into a horizontal well, (Zheng & Adnan, 2007).

Since we are to compare the straight tubing from the buckled one, so here's' the section length of straight tubing formula:

$L^s = Fh/Kw$--eqn. 6

Maximum lockup depth in horizontal wells:

$L_{loc} = (3Fh/2Kw) = (3/K)\sqrt{\underline{2EI/rw}}$--eqn. 7

This equation 3 is if the initial configuration of the tubing is straight, where R→ infinity.

CHAPTER 3

RESEARCH METHODOLOGY

In achieving the objectives of the project a method/procedure is to be use in this study. The method that the author used in her project is based on ANSYS simulation software.

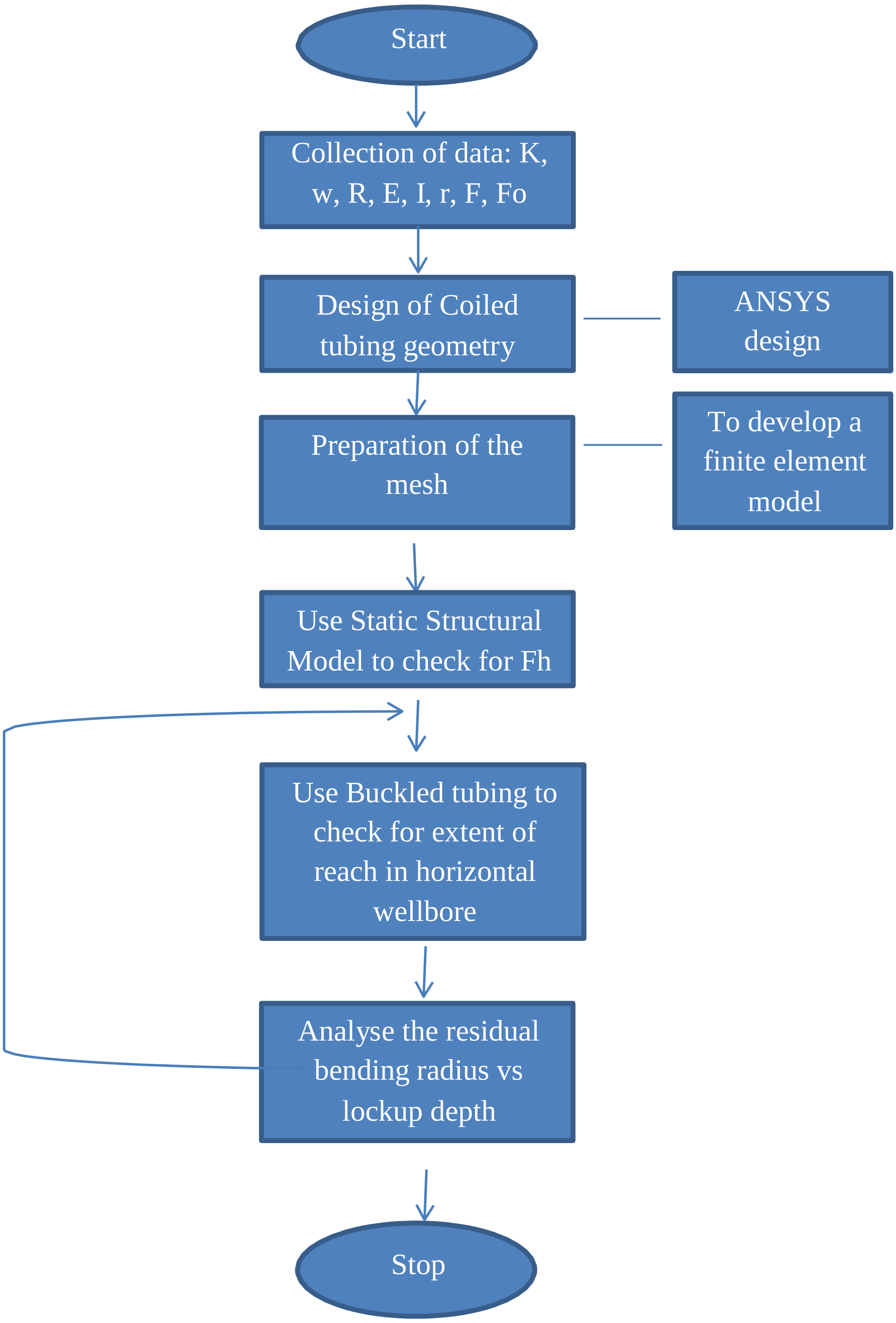
This software is world-widely used by the organization over the world to design a process required in any field of engineering simulation. Ansys is a reliable software in delivering the best value for an engineering simulation software investment.

Finite modeling with ansys considers geometric details, structural analysis, including linear, nonlinear and dynamic studies. The engineering simulation product provides a complete set of elements behavior, material models and equation solvers for a wide range of mechanical design problems. Ansys simulation software enables organizations to predict how a product operates in real world.

From that, in relating to the studies in this paper, a modeling of straight tubing and helical buckled string behavior is to be prepared for analysis on the effects of residual bend towards wells' lockup depth.

Moreover, a table was operated in excel for the plots in the graph and build results from the data taken in ansys software under simulation process and data management software. And to model the geometry of tubing with and without residual bend under geometry interfaces. From that then a comparison of design was imposed.

3.1 Methodology

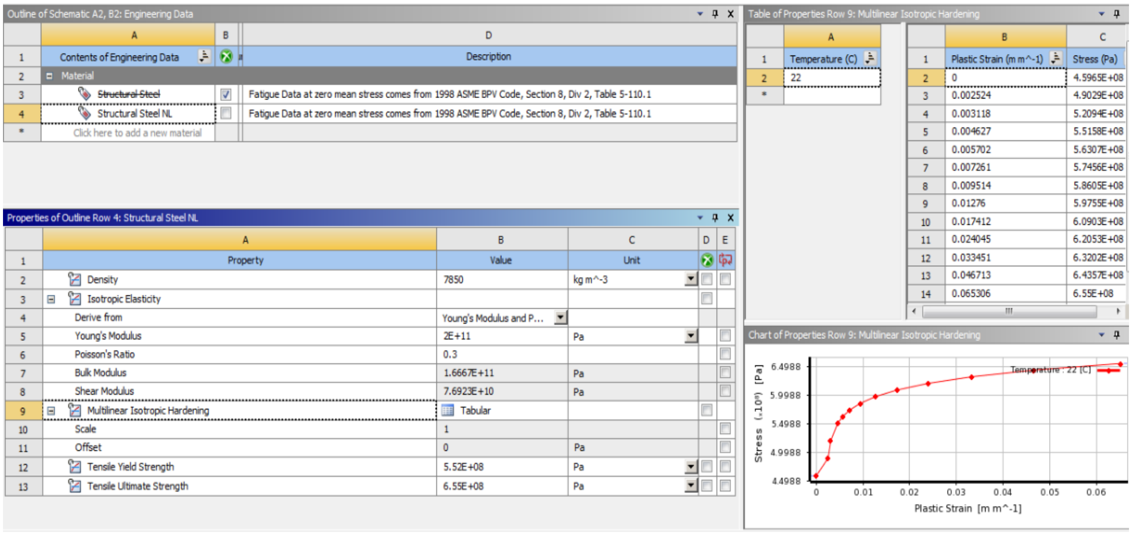


3.1.1 Steps-by-steps ANSYS workbench software execution

To develop and do analysis for our tubing using static structural system of Ansys.

Figure 6: Static Structural Step 1

From the engineering data section, set of parameters prepared were being input. Material used is a non-linear structural steel grade 90 was selected for the tubing. Parameters as such: density, young modulus, Poisson's ratio, bulk and shear modulus. Various materials will be taken into account in future design for comparison purposes of the results.


Outline of Schematic A2, B2: Engineering Data

	A	B	D
1	Contents of Engineering Data		Description
2	Material		
3	~~Structural Steel~~	☑	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
4	Structural Steel NL	☐	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
*	Click here to add a new material		

Properties of Outline Row 4: Structural Steel NL

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	7850	kg m^-3	☐	☐
3	Isotropic Elasticity			☐	
4	Derive from	Young's Modulus and P...			
5	Young's Modulus	2E+11	Pa		☐
6	Poisson's Ratio	0.3			☐
7	Bulk Modulus	1.6667E+11	Pa		☐
8	Shear Modulus	7.6923E+10	Pa		☐
9	Multilinear Isotropic Hardening	Tabular		☐	
10	Scale	1			☐
11	Offset	0	Pa		☐
12	Tensile Yield Strength	5.52E+08	Pa	☐	☐
13	Tensile Ultimate Strength	6.55E+08	Pa	☐	☐

Table of Properties Row 9: Multilinear Isotropic Hardening

	A
1	Temperature (C)
2	22
*	

	B	C
1	Plastic Strain (m m^-1)	Stress (Pa)
2	0	4.5965E+08
3	0.002524	4.9029E+08
4	0.003118	5.2094E+08
5	0.004627	5.5158E+08
6	0.005702	5.6307E+08
7	0.007261	5.7456E+08
8	0.009514	5.8605E+08
9	0.01276	5.9755E+08
10	0.017412	6.0903E+08
11	0.024045	6.2053E+08
12	0.033451	6.3202E+08
13	0.046713	6.4357E+08
14	0.065306	6.55E+08

Chart of Properties Row 9: Multilinear Isotropic Hardening

Figure 7: Static Structural Step 2

This is the 3D geometry of the tubing where a dimension and length of tubing was set. In this thesis, design geometry ranges from length of 10 to 90 meter with the dimension of 0.0445 m OD: 0.037 m ID is analyzed. All the units are in metric system of this software.

For analysis accuracy in accordance to the real environment of the pipe, tubing is design with imperfection (designing non-symmetric tubing) to provide more realistic results.

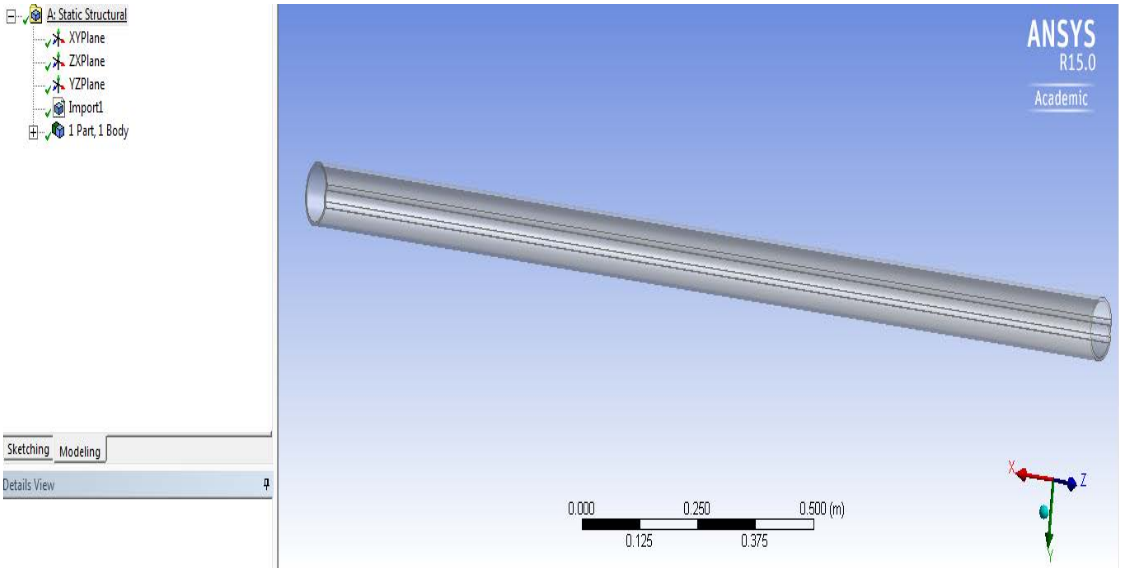


Figure 8: Static Structural Step 3 (1.75 in OD, 1.438 in ID; L = 32.81 ft).

Under model section, a finite element model has been developed through preparing mesh on tubing in 0.25 m scale. Meshing the tubing would give a good result in analyzing the nodes of the whole non-symmetric pipe.

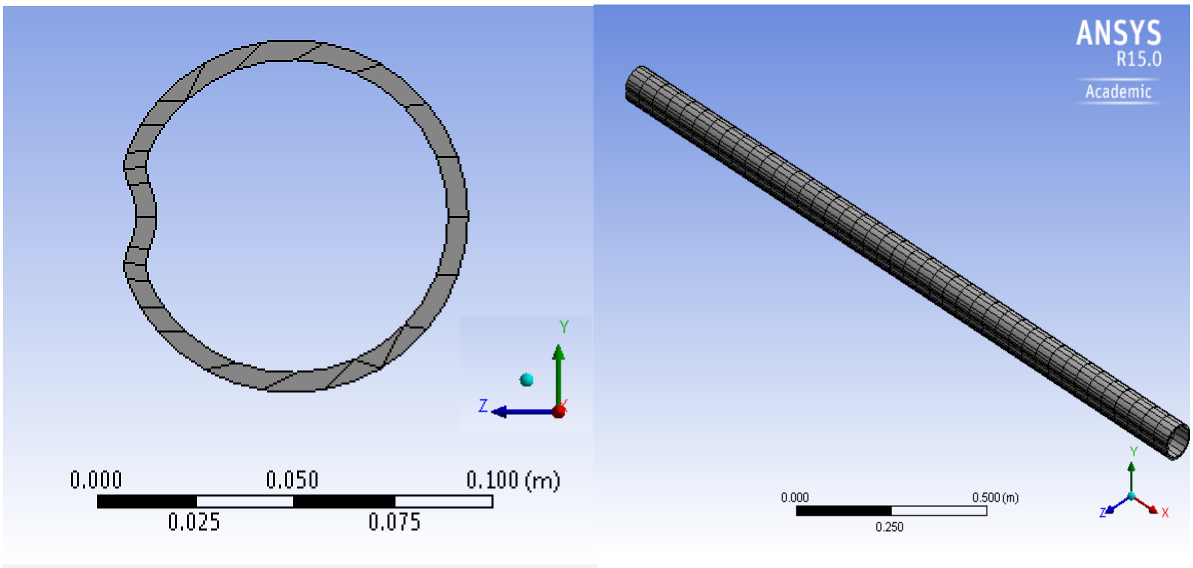


Figure 9: Static Structural Step 4

Part of the setup is applying the boundary condition on the tubing. In this thesis, compressive load applied ranges from 445 to 4005 N (B) and the other end is fixed (A). A different set of values loads is applied to experiment for the analysis on how tubing reacts in order to see the buckling phenomena.

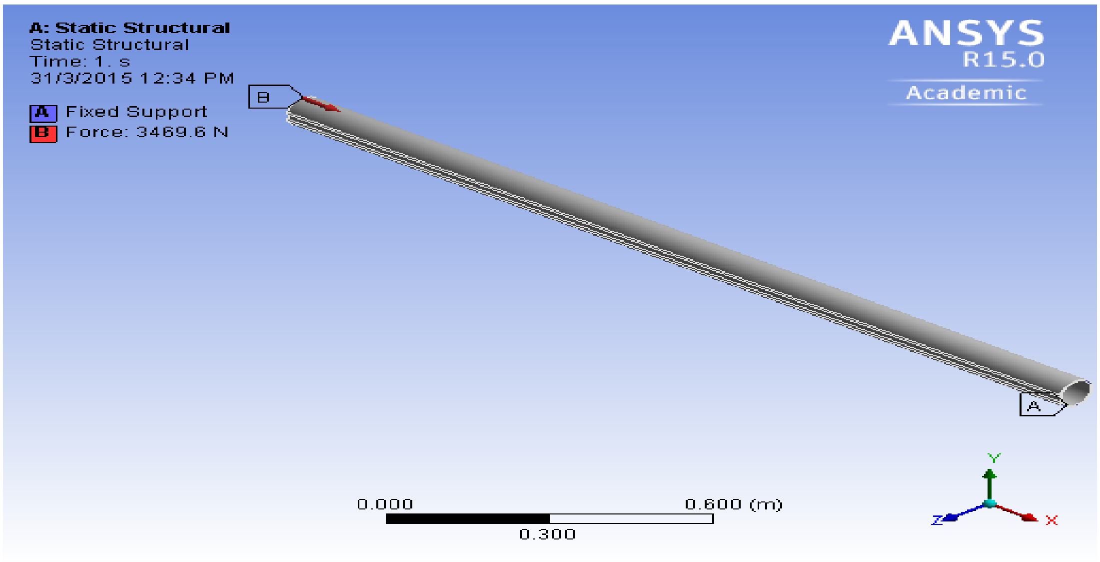


Figure 10: Static Structural Step 5

After the set-up, three analysis are run (solve) to obtain results under solution section for buckling analysis including Total deformation, Equivalent Elastic Strain and Equivalent stress.

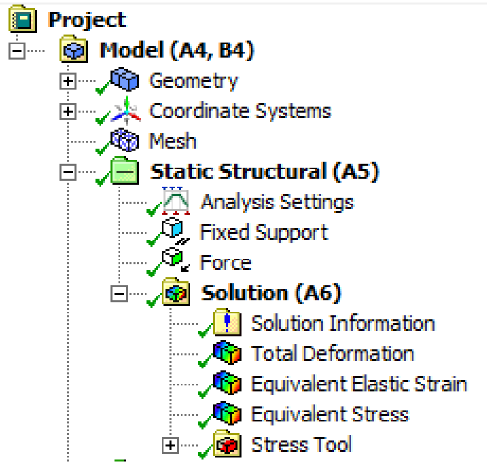
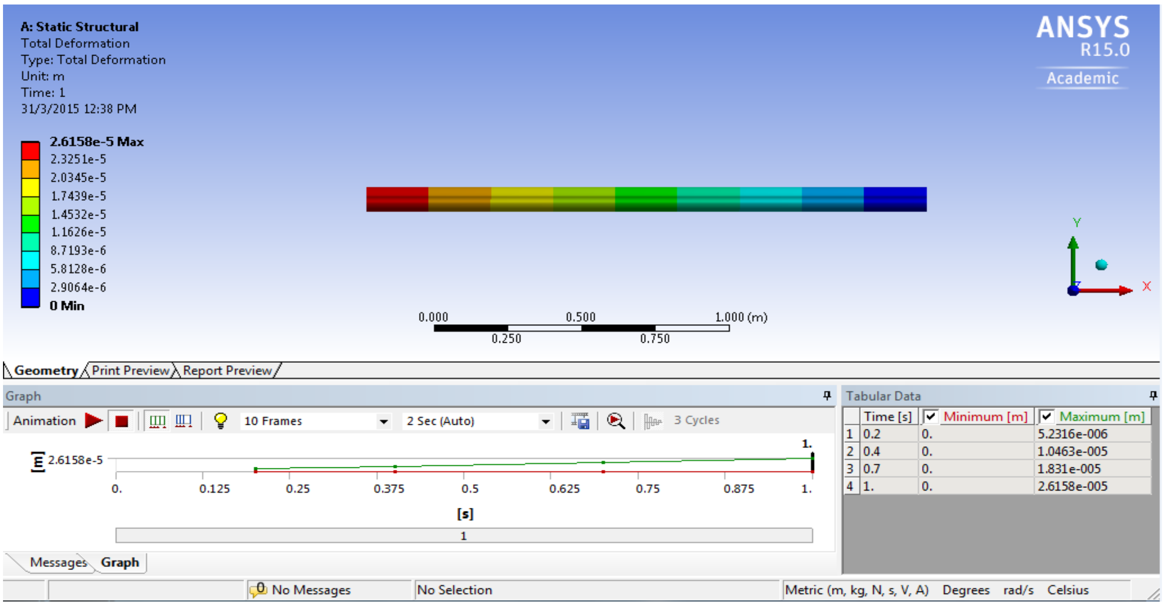


Figure 11: Static Structural Step 6

This result is predicting that tubing is a perfect structure as its linear analysis, therefore the axial load applied is just going to compress the tubing. Thus giving a very slight value of buckling with the minimum value of 0 to maximum of 2.2316e-5.

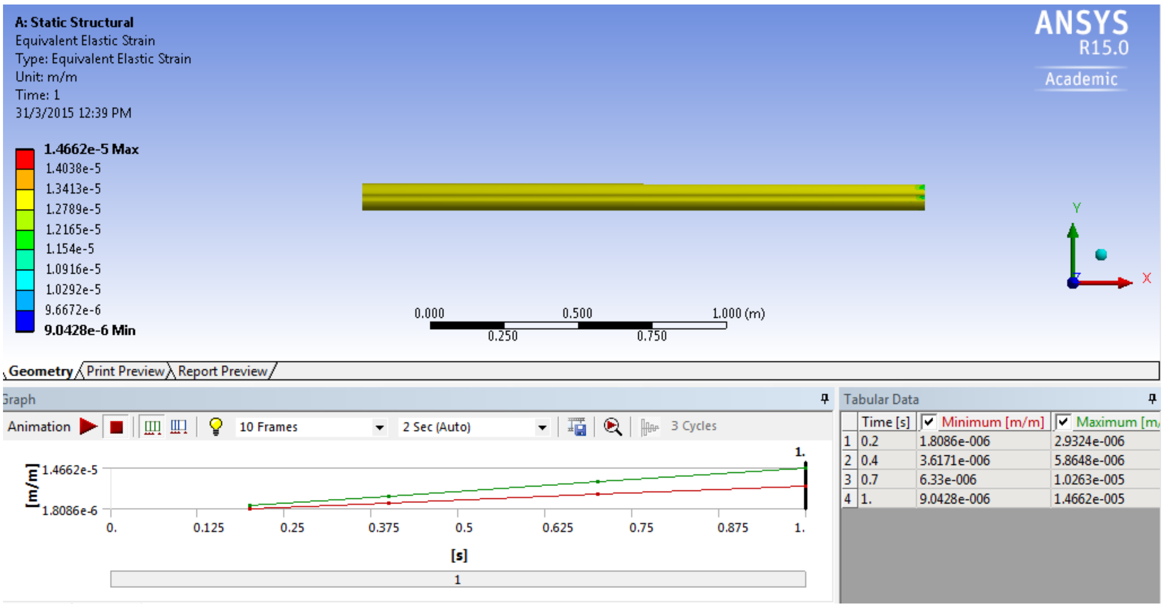


A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
31/3/2015 12:38 PM

	Time [s]	☑ Minimum [m]	☑ Maximum [m]
1	0.2	0.	5.2316e-006
2	0.4	0.	1.0463e-005
3	0.7	0.	1.831e-005
4	1.	0.	2.6158e-005

Figure 12: Static Structural Step 7

This is the quality check of the result in our strain tubing which shows that it's within our strain limits shown from our engineering data. A good engineering practice that makes more accurate and realistic values.

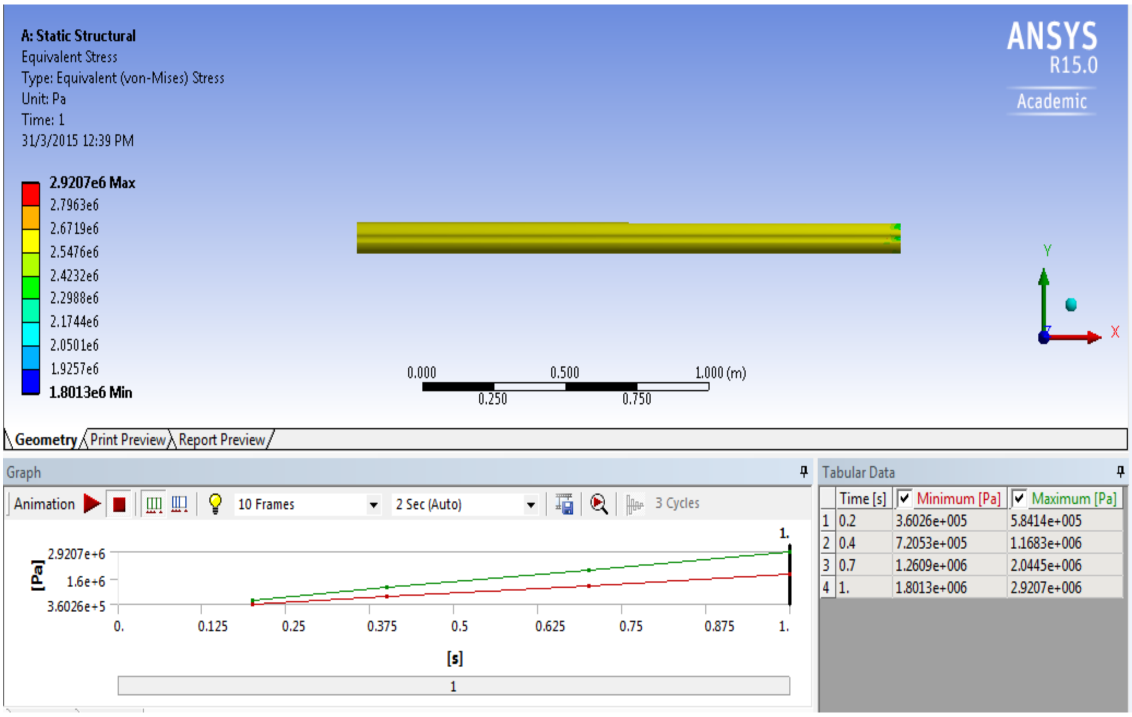


A: Static Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: m/m
Time: 1
31/3/2015 12:39 PM

	Time [s]	☑ Minimum [m/m]	☑ Maximum [m/
1	0.2	1.8086e-006	2.9324e-006
2	0.4	3.6171e-006	5.8648e-006
3	0.7	6.33e-006	1.0263e-005
4	1.	9.0428e-006	1.4662e-005

Figure 13: Static Structural Step 8

This is the quality check of the result in the stress of the tubing which shows that it's within the limits of stress and strain chart in engineering data → material properties. A good engineering practice to make more accurate and realistic data.



A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
31/3/2015 12:39 PM

Tabular Data

	Time [s]	☑ Minimum [Pa]	☑ Maximum [Pa]
1	0.2	3.6026e+005	5.8414e+005
2	0.4	7.2053e+005	1.1683e+006
3	0.7	1.2609e+006	2.0445e+006
4	1.	1.8013e+006	2.9207e+006

Figure 14: Static Structural Step 9

Application of buckling were generated to see the tubing buckles and check for Fh.

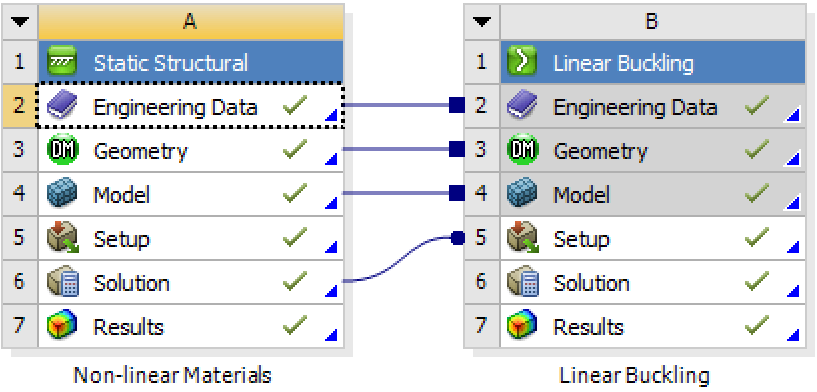
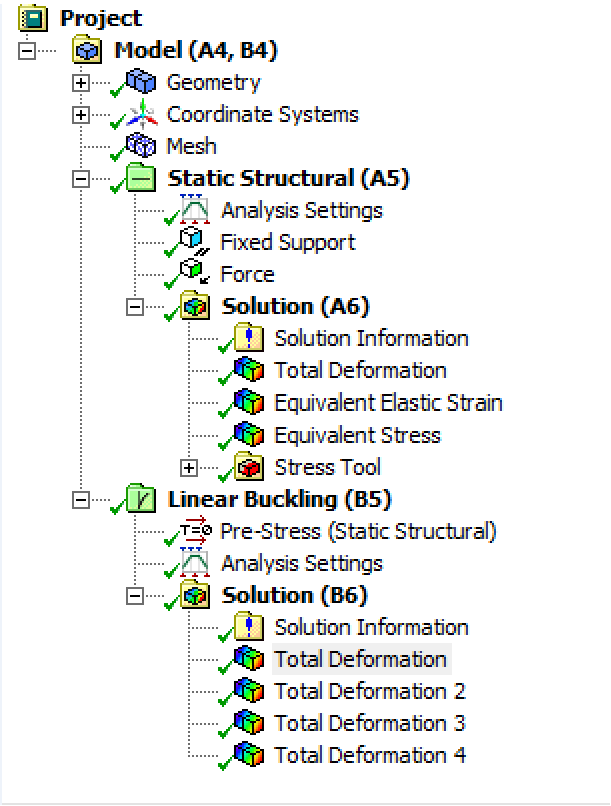


Figure 15: Static Structural Step10

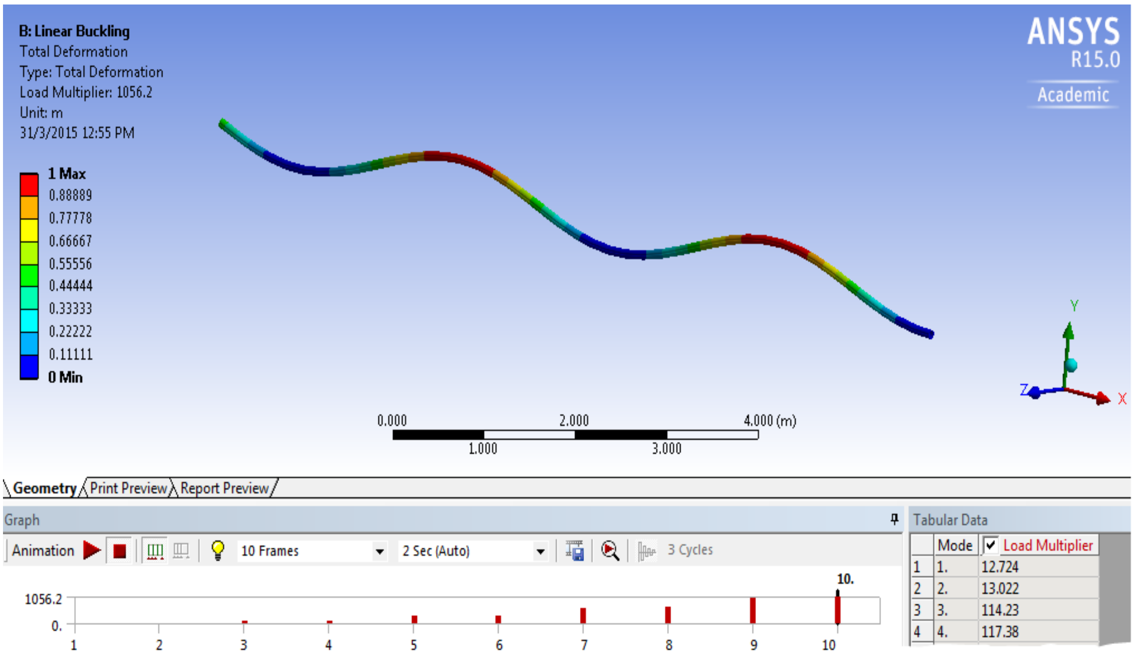
After static structural data's are dropped to linear buckling system, Figure16 is the complete execution of buckling analysis using Ansys and a final total deformation in different set of modes is solved under linear buckling section→ solution. This is to know the theoretical lowest buckling factor. It automatically shows pre-stress that defines the compressive load is set to static structural analysis.



- **Project**
  - **Model (A4, B4)**
    - Geometry
    - Coordinate Systems
    - Mesh
    - **Static Structural (A5)**
      - Analysis Settings
      - Fixed Support
      - Force
      - **Solution (A6)**
        - Solution Information
        - Total Deformation
        - Equivalent Elastic Strain
        - Equivalent Stress
        - Stress Tool
    - **Linear Buckling (B5)**
      - Pre-Stress (Static Structural)
      - Analysis Settings
      - **Solution (B6)**
        - Solution Information
        - Total Deformation
        - Total Deformation 2
        - Total Deformation 3
        - Total Deformation 4

Figure 16: Static Structural Step 11

This is the buckled shape shown in figure 17 from applying an axial load. It is clearly seen that at load given, buckles occur on the tubing. A minimum of 0 m to maximum 1 m length of buckling is observed on tubing in 1.0 m scale. The animation for this result shows in 2 second time out of 0 frames. Modes here are based on the height versus the radius of the tubing. The software has only until maximum of 4 modes that is applicable in analyzing buckling. The load multiplier shown here is the buckling factor of safety for the applied load.



B: Linear Buckling
Total Deformation
Type: Total Deformation
Load Multiplier: 1056.2
Unit: m
31/3/2015 12:55 PM

	Mode	☑ Load Multiplier
1	1.	12.724
2	2.	13.022
3	3.	114.23
4	4.	117.38

Figure 17: Static Structural Step 12

A nonlinear buckling analysis employs a nonlinear static analysis with gradually increasing loads to seek the load level at which a structure becomes unstable. From that producing tubing with a critical helical buckling load (Fh) will be determined.

Considering the equation introduced in the literature review, theoretical prediction of Fh is possible to determine as well and could be used as a reference on the buckling phenomena using the software itself.

Lastly, with regards of the effect on residual bend present on coiled tubing after leaving the injector, equation & is to be used to do the final buckling versus bending analysis.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Analytical solution of straight tubing configuration

This study has been done several applications of compressive loads ranging from 100 to 600lb as shown in table 1. Prediction of buckling loads or the critical load is needed to calculate maximum lock-up depth in horizontal well when ignoring the effect of residual bend, in other words initial configuration of tubing string is straight. Critical load is calculated using the equation below,

Critical load (CL)= applied compressive force x load multiplier

And using the equation below, we will get maximum lock-up depth,

$L^*loc = (3Fc/2Kw)$

Where the thesis work used apparent friction coefficient (k)= 0.3, coiled tubing weight (w)= 2.662 lb/ft.

Table 1: Parameters in getting maximum lockup depth

Compressive force, Fc, (lb)	Critical load, CL (lb)	L*loc (ft)
100	1273.9	187.8287002
200	318.36	375.6574005
300	141.46	563.4861007
400	77.64	751.3148009
500	46.5	939.1435011
600	16.29	1126.972201

Figure 18 shows the effect of buckling on maximum lockup depth where initial configuration of tubing is straight (no residual bend consideration). The graph shows that as load increases, lockup depth in horizontal well decreases quickly until no further pushed can be done at maximum load. This is due to the increment of load applied at the surface causes tubing to buckle at certain depth. Like for this case, CL at 1273.9 lb gave a smaller maximum length of tubing which is 187.83 ft, compared to 16.29 lb gave a slighter decrease in length of 1126.97 ft.

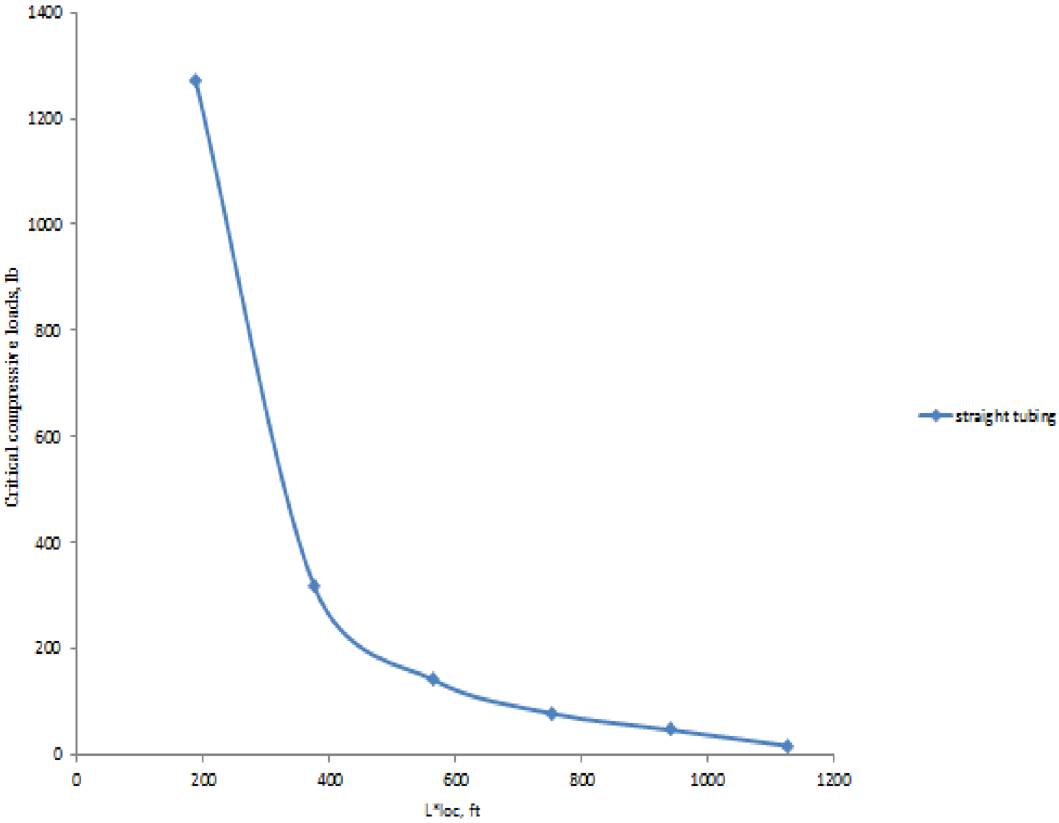


Figure 18: The relationship of buckling load vs. L*loc for horizontal well.

4.2 Analytical solution of tubing with residual bending configuration

This case is again needed to determine critical load to calculate maximum lock-up depth in horizontal well with residual bend effect. This consist of the addition of section length of straight tubing and helical buckled tubing section length as expressed in this equation, Lloc = Ls + L*.
First in calculating the section of straight tubing, Ls= Fc/kw.
And for the buckled tubing length, L*= (2R/K) ln(rxRxCL+2EI)/rxRxCL.

In these sections, we also calculated the helical critical buckling load by this equation,

Fh= 2 $(2\sqrt{2} - 1)\sqrt{\frac{EIx\,W}{r}}$ = 15436 lb

Where the set of parameters are given and computed: young modulus, E= 30, 000, 000 psi for steel;
Bending moment of inertia, I= $\frac{\pi}{64}(ODtubing^4 - IDtubing^4)$ = $\frac{\pi}{64}(1.75^4 - 1.4384^4)$ = 0.251 inch4;
for radial clearance, r = $\frac{1}{2}$ (Dhole- ODtubing) == $\frac{1}{2}$ (4- 1.74)= 1.125 in.

Here different axial load is applied ranging from 100 to 600 lb and various residual bend radius (R) is presented to analyses the effect of buckling where tubing initial configuration is not straight as shown in table 2.

Table 2: Parameters in getting maximum lockup depth

Critical load,CL lb	Lloc with R=100, ft	Lloc with R=300, ft	Lloc with R=500, ft	Lloc with R=750, ft
15436	20841.85	12331.33	22682.13	23171.01
1273.9	4925.337	11074.72	18770.95	26075.79
318.36	4588.955	10393.47	16598.06	22763.05
141.46	4444.361	9947.77	15384.06	20888.57
77.64	4378.289	9631.14	14562.63	19602.85
46.5	4355.242	9396.143	13956.28	18639.68
16.29	4359.409	9217.479	13485.96	17880.46

Figure 19 shows the effect of buckling on maximum lockup depth where initial configuration of tubing with residual bending considered. Different effects have been observed in different values of residual bending radius, R. the graph summarizes the analysis whereby higher residual bending radius leads to decrease in lockup length. This phenomenon is due to the presence of initial bending in the tubing which triggers more to buckle the string easily by increasing the downward force applied.

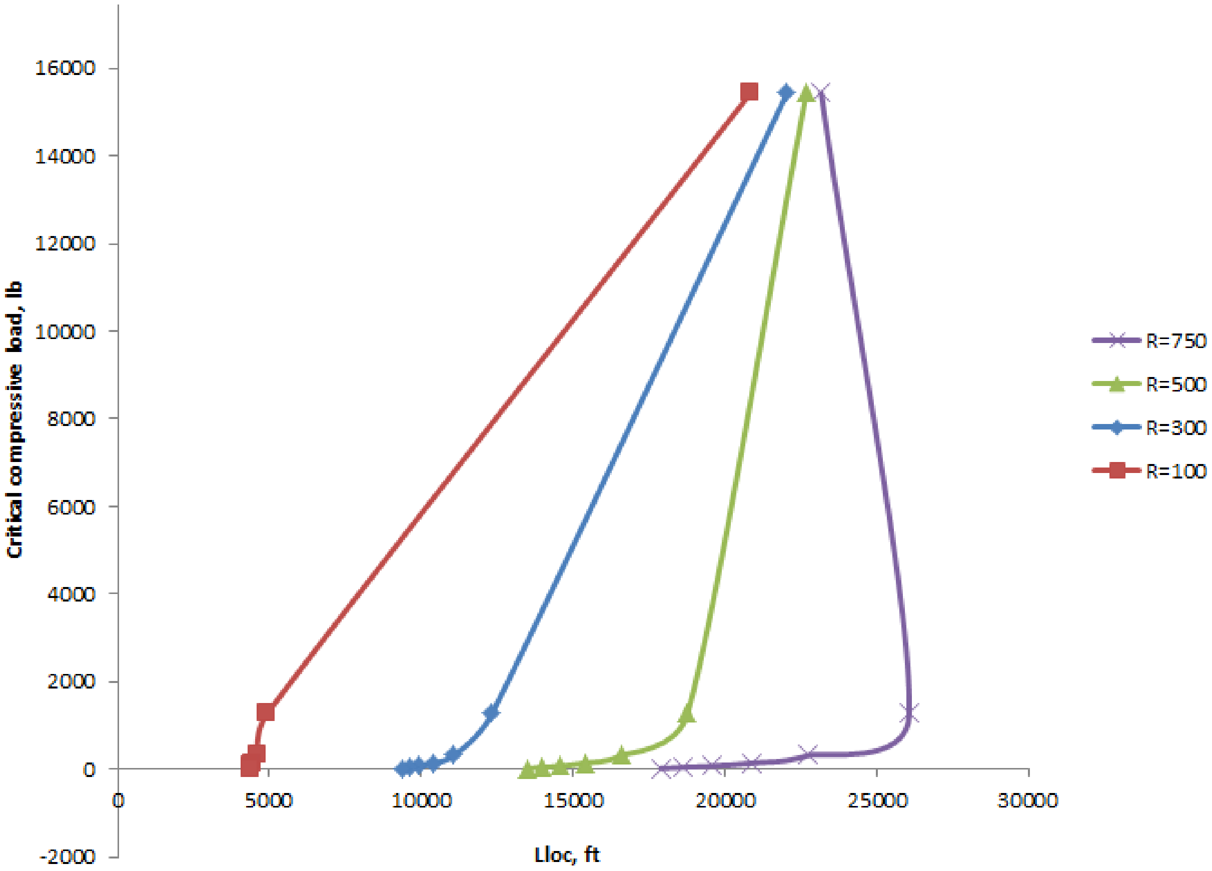
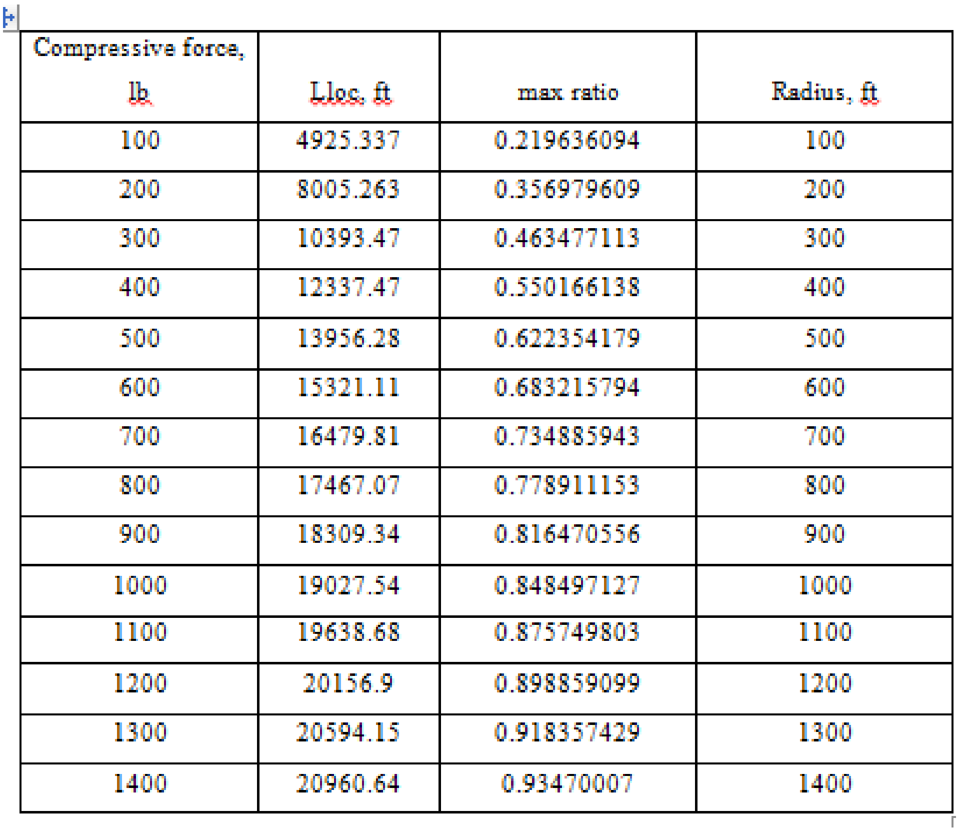


Figure 19: The relationship of buckling load vs. Lloc for horizontal well.

4.3 Analytical solution of tubing with and without residual bending configuration

Using equation 5 and 7, calculation of maximum reach ratio has been executed and tabulated in table 3.

Table 3: Parameters in getting maximum ratio



Compressive force, lb	Lloc, ft	max ratio	Radius, ft
100	4925.337	0.219636094	100
200	8005.263	0.356979609	200
300	10393.47	0.463477113	300
400	12337.47	0.550166138	400
500	13956.28	0.622354179	500
600	15321.11	0.683215794	600
700	16479.81	0.734885943	700
800	17467.07	0.778911153	800
900	18309.34	0.816470556	900
1000	19027.54	0.848497127	1000
1100	19638.68	0.875749803	1100
1200	20156.9	0.898859099	1200
1300	20594.15	0.918357429	1300
1400	20960.64	0.93470007	1400

Figure 20 is the result of our last objective in analysing the effects, this shows the effect of residual bend on maximum lockup depth in horizontal wells (Tubing: 1.75 in. x 0.156 in., 90 grade; 4 in borehole). The graph above shows that when residual bend radius increases, maximum reach depth significantly reduces. This means the depth of the coiled tubing can reach affects the existence of residual bend.

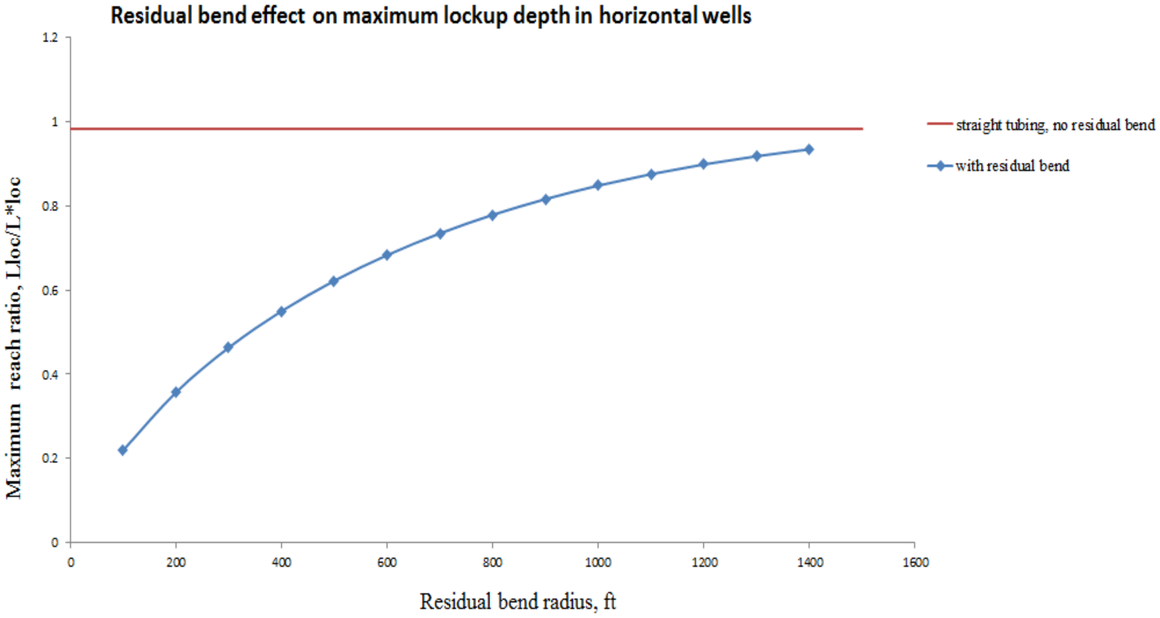


Figure 20: Max. reach ratio vs Residual bend radius

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In this thesis work, an extensive FEM simulation has been presented to aid the material static structural analysis of tubing configuration and linear buckling analysis. Computer based simulation by using ANSYS had aided in the process of FEM analysis for Non-linear Structural Steel. Equivalent Von Mises stress, total deformation, and equivalent elastic strain of the defective tubing had been simulated and produced by using ANSYS.

The results from different analysis of the materials were used to compare the examine of the effect of straight initial configuration tubing (no residual bend consideration) to its lockup depth, tubing with residual consideration to its lockup depth, and the effect of residual bending on maximum reach ratio.

Therefore, analysis summary of the whole study is in the following:

i) As compressive load increases, lockup depth of no residual bend tubing (straight tubing, R→ infinity) in horizontal well decreases quickly until no further pushed can be done at maximum load.

ii) Larger presence of residual bend plus the buckling occurs in tubing when compressive load has been applied, thus, a much greater reduction occurs at tubing lockup length in horizontal wellbore.

iii) When residual bend radius increases, ratio of the maximum reach significantly reduces.

5.1 Recommendation for Further Work

In this thesis work, coiled tubing buckling analysis was discussed in the effect of residual bend as buckle mitigating and triggering technique .This thesis recommends the following suggestions and recommendations for further work:

- Design and analyse buckling with casing environment.
- Use various types of grades to study more of the effects or residual bending in coiled tubing string.
- Use various sizes of CT on the corresponding wellbore geometry.

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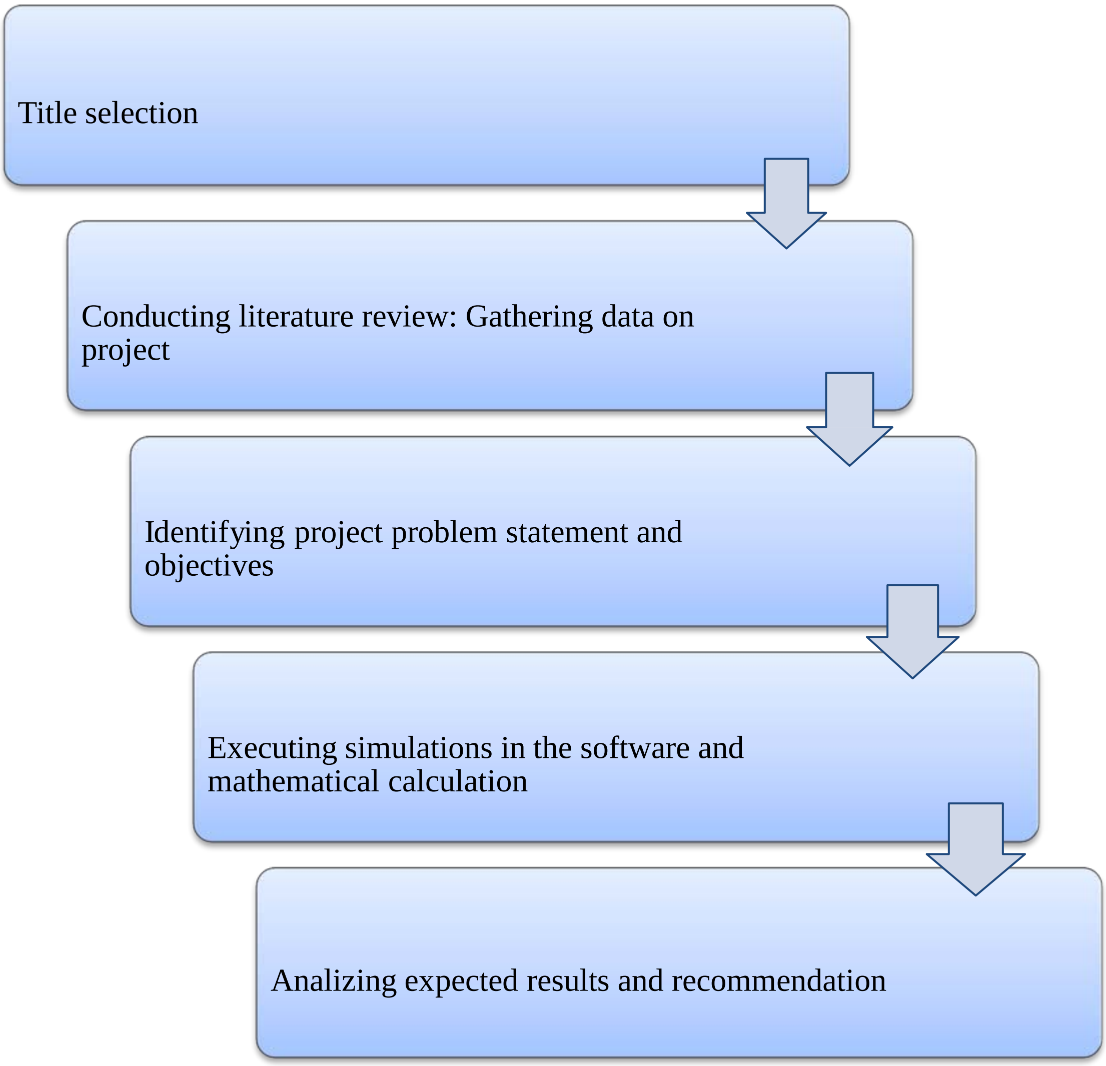
APPENDICES

Project Activities & Key Milestone



Appendix-1

Project Timeline (Gantt-Chart)

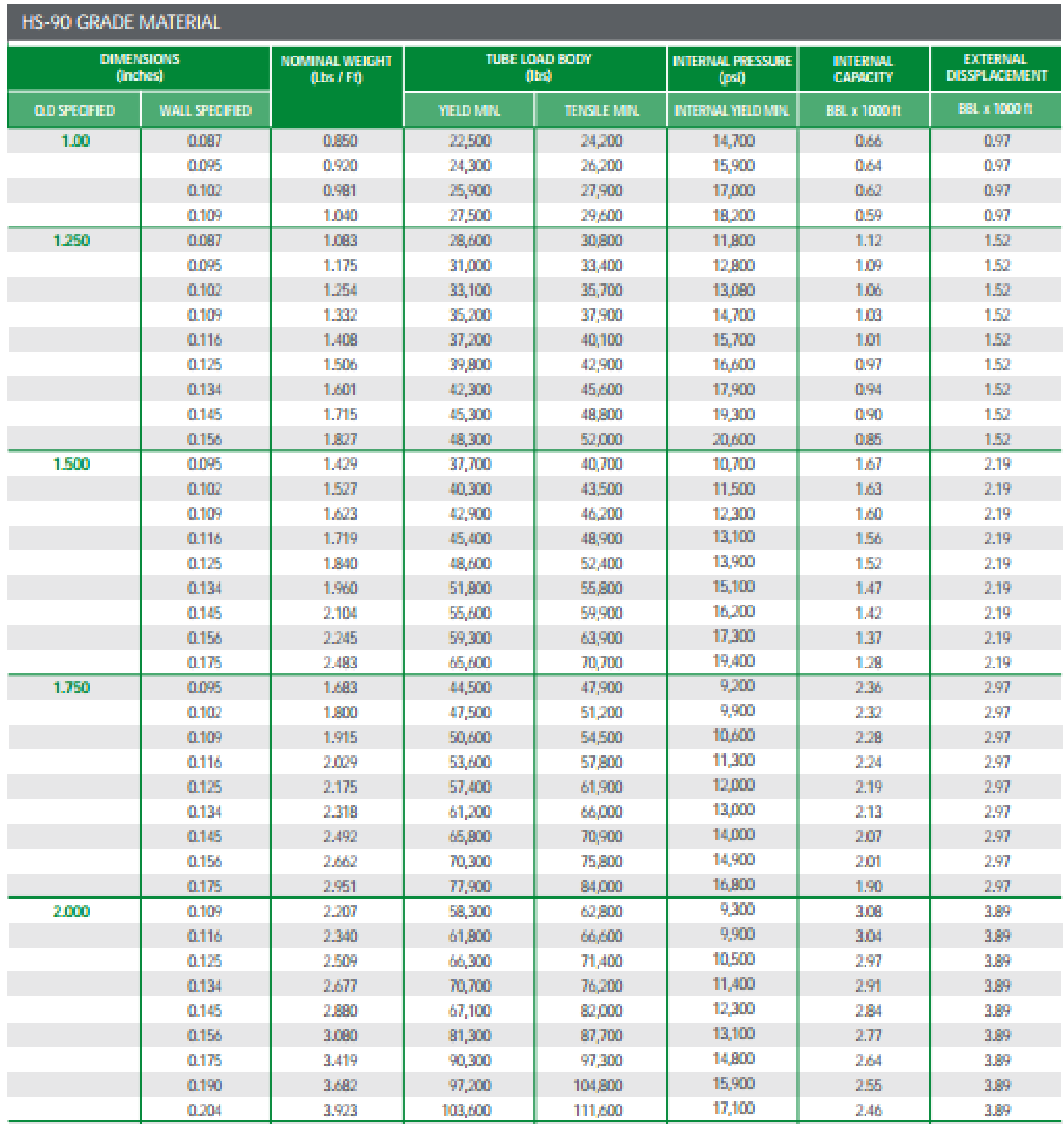
Work/Description	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project topic draft		⬛	⬛											
Research: Data collection				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Extended proposal submission (old topic and new topic)						🟩						🟩		
Discussion with Supervisor			🟪			🟪				🟪		🟪	🟪	🟪
Project work: corrections and change of title selection applied (redoing process of FYP work)										🟨	🟨			
Proposal defence														▨
Project work continues: Research and software												🟧	🟧	🟧
Interim Draft Report Submission													🟦	
Final Interim report submission														🟦

Appendix 2: FYP1 suggested timeline

Project Timeline (Gantt-Chart) Continues

Work/Description	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Continuation of work	■	■	■	■	■	■									
Working with ansys software: familiarization and design making		■	■	■	■	■									
Pre-result						■	■								
Progress report submission							■								
Discussion with Supervisor	■	■	■				■								
Project work continues: Research and software-Result								■	■	■	■	■			
Poster Presentation for pre-SEDEX										■					
Final draft report submission											■				
Project Dissertation Submission in softbound and technical paper												■			
Viva													■		
Project Dissertation Submission in hard-bound															■

Appendix 3: FYP2 suggested timeline



HS-90 GRADE MATERIAL

DIMENSIONS (inches)		NOMINAL WEIGHT (Lbs / Ft)	TUBE LOAD BODY (lbs)		INTERNAL PRESSURE (psi)	INTERNAL CAPACITY	EXTERNAL DISSPLACEMENT
O.D SPECIFIED	WALL SPECIFIED		YIELD MIN.	TENSILE MIN.	INTERNAL YIELD MIN.	BBL x 1000 ft	BBL x 1000 ft
1.00	0.087	0.850	22,500	24,200	14,700	0.66	0.97
	0.095	0.920	24,300	26,200	15,900	0.64	0.97
	0.102	0.981	25,900	27,900	17,000	0.62	0.97
	0.109	1.040	27,500	29,600	18,200	0.59	0.97
1.250	0.087	1.083	28,600	30,800	11,800	1.12	1.52
	0.095	1.175	31,000	33,400	12,800	1.09	1.52
	0.102	1.254	33,100	35,700	13,080	1.06	1.52
	0.109	1.332	35,200	37,900	14,700	1.03	1.52
	0.116	1.408	37,200	40,100	15,700	1.01	1.52
	0.125	1.506	39,800	42,900	16,600	0.97	1.52
	0.134	1.601	42,300	45,600	17,900	0.94	1.52
	0.145	1.715	45,300	48,800	19,300	0.90	1.52
	0.156	1.827	48,300	52,000	20,600	0.85	1.52
1.500	0.095	1.429	37,700	40,700	10,700	1.67	2.19
	0.102	1.527	40,300	43,500	11,500	1.63	2.19
	0.109	1.623	42,900	46,200	12,300	1.60	2.19
	0.116	1.719	45,400	48,900	13,100	1.56	2.19
	0.125	1.840	48,600	52,400	13,900	1.52	2.19
	0.134	1.960	51,800	55,800	15,100	1.47	2.19
	0.145	2.104	55,600	59,900	16,200	1.42	2.19
	0.156	2.245	59,300	63,900	17,300	1.37	2.19
	0.175	2.483	65,600	70,700	19,400	1.28	2.19
1.750	0.095	1.683	44,500	47,900	9,200	2.36	2.97
	0.102	1.800	47,500	51,200	9,900	2.32	2.97
	0.109	1.915	50,600	54,500	10,600	2.28	2.97
	0.116	2.029	53,600	57,800	11,300	2.24	2.97
	0.125	2.175	57,400	61,900	12,000	2.19	2.97
	0.134	2.318	61,200	66,000	13,000	2.13	2.97
	0.145	2.492	65,800	70,900	14,000	2.07	2.97
	0.156	2.662	70,300	75,800	14,900	2.01	2.97
	0.175	2.951	77,900	84,000	16,800	1.90	2.97
2.000	0.109	2.207	58,300	62,800	9,300	3.08	3.89
	0.116	2.340	61,800	66,600	9,900	3.04	3.89
	0.125	2.509	66,300	71,400	10,500	2.97	3.89
	0.134	2.677	70,700	76,200	11,400	2.91	3.89
	0.145	2.880	67,100	82,000	12,300	2.84	3.89
	0.156	3.080	81,300	87,700	13,100	2.77	3.89
	0.175	3.419	90,300	97,300	14,800	2.64	3.89
	0.190	3.682	97,200	104,800	15,900	2.55	3.89
	0.204	3.923	103,600	111,600	17,100	2.46	3.89

Appendix 4: Some of the material properties references