STUDY OF FLUID-STRUCTURE INTERACTION (FSI) ON BENFIELD SOLUTION (BS) LINE USING ANSYS

by

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the requirement for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
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BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

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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 reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(NURUL HAZWANI AHMAD SHOKRI)

ABSTRACT

This research work investigates the fluid-structure interaction between Benfield Solution (BS) fluid and Benfield Solution (BS) vertical pipe. The study involved static and dynamic characteristic of BS Pipe when pipe subjected hydrodynamic load. The static load modeling determines the frequency at the highest deformation by using baseline velocity of fluid. The dynamic loading is exerted to the pipe to see the effect of flow velocity to the severity to the pipe. The dynamic characteristic of pipe is done at three different fluid velocity magnitude based on plant operating mode. The problem identified in this research is when there is an excessive vibration which suspected caused by fluid-induced vibration (FIV) had caused the pipe trunnion support to have a crack at its trunnion support. The crack propagates and caused BS fluid leakage at the weldment between pipe and the trunnion. From visual inspection, the pipe is vibrating horizontally with high magnitude and low frequency with natural frequency higher than 10Hz. The vibration by FIV had caused the trunnion support hit the base frame excessively and exceed it tolerance value which is 10mm. This research is to study the interaction of fluid dynamics and the pipe structure for the determination of the fatigue life of the Benfield pipe. This pipe is modeled using ANSYS Structural Analysis and solved by Modal Analysis to see the highest deformation and maximum stress profile at the fractured trunnion. The simulation result will be validated using Caesar II by Group Technical Solution(GTS) report. In a nutshell, when the BS pipe vibrates approaching to 36.741Hz, the highest deformation of Benfield pipe by 13.01 mm is recorded since the acceptable tolerance between trunion and base frame is 10 mm, mode 4 exceeds this value and cause trunnion deterioration after $2.565e^{+}4$ cycles. The area of deformation is occurred at the lower part of the pipe, which resulting the actual pipe leakage area of the project. From that point, maximum stress exerted onto the pipe is validated with GTS data. There is slightly lower value in ANSYS stress analysis due to some reasons, which mainly caused by different scope of study.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

A typical modern ammonia-producing plant first converts natural gas such as methane or LPG (liquefied petroleum gases) such as propane and butane into gaseous hydrogen. The method for producing hydrogen from hydrocarbons is referred to as Steam Reforming. The hydrogen is then combined with nitrogen to produce ammonia.

Starting with a natural gas feedstock, the processes used in producing the hydrogen are simplified into a few processes. There are desulphurization, reforming section, CO conversion, CO_2 Conversion, CO_2 Removal Section, Methanol Synthesis Section, Methanation, Methanol Distrillation, Ammonia Synthesis Section and Ammonia Refrigeration Unit.

Benfield Solution (BS) Unit in ammonia plant is functioned for the carbon dioxide removal process. Carbon dioxide is removed by absorption in hot aqueous potassium carbonate solution containing 30 wt% potash (potassium carbonate). The reason of keeping the solution hot is to increase the rate of absorption and keep the bicarbonate dissolved. Another advantage is the temperature is approximately same in the absorber and in regenerators.

The CO_2 absorption occurs according to the following reaction mechanism.

1. $\mathbf{CO_2 + H_2O \rightarrow HCO_3^- + H^+}$
2. $\mathbf{CO_3^{--} + H_2O \rightarrow HCO_3^- + OH^-}$
3. $\mathbf{CO_3^{--} + CO_2 + H_2O \rightarrow 2HCO_3}$ **(Benfield Solution)**

In Benfield Solution (BS) 3 wt% of diethanolamine (DEA) is used as an activator to increase the mass transfer rate of CO_2 from gas phase to the liquid phase. It also decreases the CO_2 vapor pressure. Furthermore BS contain 1 wt% of vanadium pentoxide, V_2O_5 which acts as a corrosion inhibitor.

The absorption takes two stages in CO_2 Absorber, C-15-02 which is presented in Figure 1.1. In the first stage (the lower part of C-15-02), the bulk of CO_2 is absorbed at the high temperature. In the second stages, a stream of strongly regenerated solution is utilized. The solution leaving the absorber bottom is loaded with CO_2 and will be called rich solution.

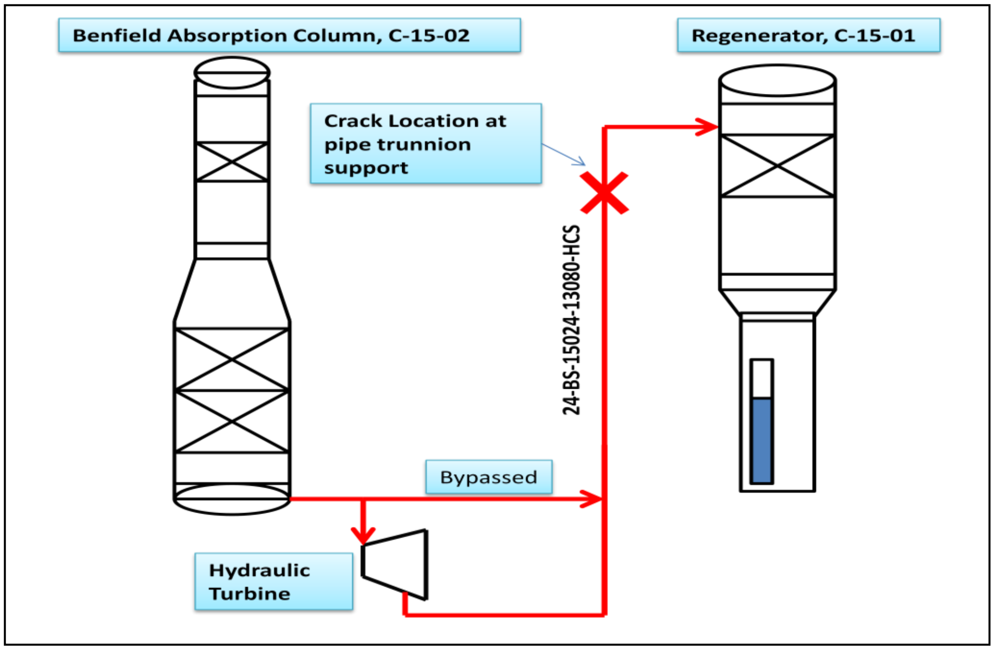


Figure 1.1: Benfield Solution process flow diagrams

The rich solution of Benfield Solution has two modes of operations and it flows within three lines. These three lines have same pressure value and temperature but different in volume flow rate magnitude. Thus, pressure and temperature will not be the variable in this study except for velocity fluctuation. The lines are listed as follows:

A. 24-BS-15023-13080-HCS:

This line indicates the flow of Benfield Solution (BS) fluid from exit CO_2 Absorber (C-15-02) directly to Regenerator and **bypassing** the hydraulic turbine. Table 1.1 shows the flow properties of BS fluid. Both maximum and normal volume flow rate is used as variable in determining dynamic characteristic of BS Pipe under hydrodynamic load.

Table 1.1: Flow properties of bypassing hydraulic turbine

Density	1242 kg/m^3
Pressure	31.5 barG
Temperature	117 °C
Volume flow rate (m^3/kg) – Max	1435 m^3/kg
Volume flow rate (m^3/kg) – Normal	1350 m^3/kg

B. 24-BS-15025-13080-HCS

This line indicates the flow of Benfield Solution (BS) fluid when it **passed through** hydraulic turbine. The rich solution is depressurized through hydraulic turbine, PT-15-01-AT through momentum transfer. The shaft power from hydraulic turbine is used to drive the semi-lean solution pump, P-15-01A. From hydraulic turbine, the rich solution enters the top of Regenerator, C-15-01. Table 1.2 shows the flow properties of BS fluid when it passed through hydraulic turbine. The volume flow rate is slightly lower that the magnitude of flow bypassed the turbine.

Table 1.2: Flow properties of across hydraulic turbine

Density	1242 kg/m^3
Pressure	31.5 barG
Temperature	117 °C
Volume flow rate (m^3/kg) – Normal	1248 m^3/kg

C. 24-BS-15024-13080-HCS

This line is connecting rich solution from both line; either bypassed of across the hydraulic to the top of Regenerator. This line was found leakage and have serious vibration problem since two years back. Thus, this line is taken as case study. This volume flow rate is varies indicating fluctuation of hydrodynamics loadings from bypassed or passed BS lines. Benfield Solution pipe line (24-BS-15024-13080-65HCS) used in this project as pipe model to transport Benfield Solution from hydraulic turbine (PT-15-01-AT) to Regenerator (C-15-01). Detail pipe specification and operating parameter is tabulated in Table 1.3. The pipe is used The ASTM standard type 304L stainless steel. Table 1.4 is presenting the specification for this pipe. This specification is used when verifying dimension and material properties in ANSYS modeling.

Table 1.3: Benfield Solution Pipe Dimension and Operating Parameter

Specification	Details
Type of Pipe	A-358-304L EFW
Benfield Line	24-BS-15024-13080
Operating Pressure	7.4 barG
Operating Temperature	122 °C
Design Pressure	9.6 barG
Design Temperature	150 °C
Pipe Diameter	24 inch
Nominal Thickness	5.44m

The engineering data of the pipe are as follows:

Table 1.4: Benfield Solution Pipe Specifications

Specification		Details
Piping Class	[redacted]	13080
Pipe Material	[redacted]	ASTM API 5L Gr. B
System Class	[redacted]	Class 600
Pipe Size	[redacted]	8”Sch. 80, 12” Sch. 80,

Corrosion allowance	[redacted]	1.0 mm
Mechanical Properties	Min Tensile Strength	413.793 MPa
	Max Tensile Strength	241.379 MPa
Physical Properties	Density	8027.20kg/m^3
	Young's Modulus at 19 ^{0}C	203.39 x 10^3
	Young's Modulus at 73 ^{0}C	200.08 x 10^3
Allowable Stress	Sustained (21 ^{0}C)	137.89 MPa
	Stress range (21 ^{0}C to 73 ^{0}C)	206.8 MPa

The BS pipe is attached to the trunnion support by electric fusion welding (EFW) at four side to give structural support and allow pipe movement. The trunnion support data are tabulated in Table 1.5 :

Table 1.5: Trunnion Support Specifications

Specification	Details
Type	Guide
Support No	A31 1231
Pipe Material	Carbon Steel
Pipe Size	6 inch
Plate Material	Carbon Steel
Plate Size	300200 x 12t

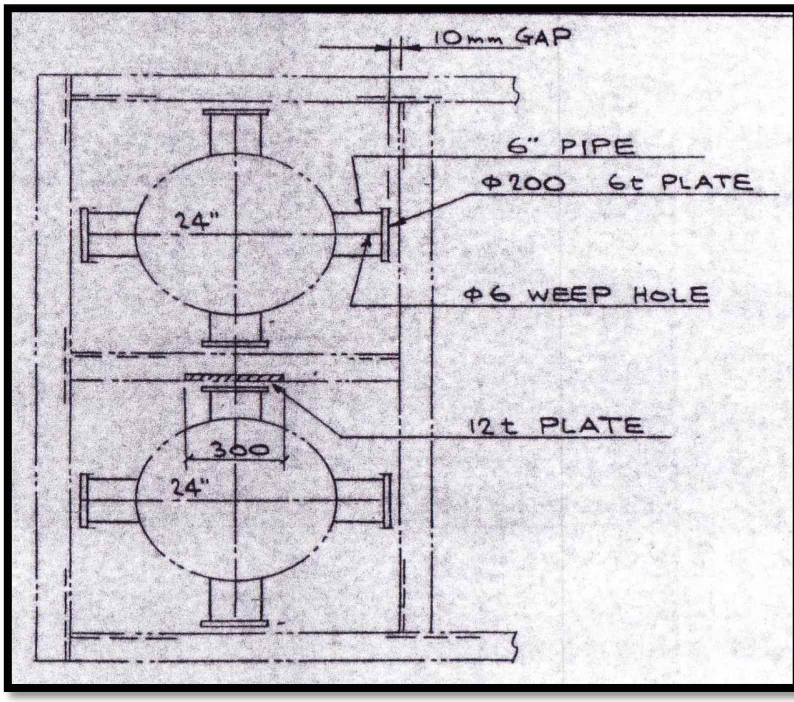


Figure 1.2: Trunnion Support Top Side View

Figure 1.2 shows that the trunnion support drawing from top side view. It supports the Benfield solution pipe at four sides with the designed tolerance of 10mm between each base frame of the building. The tolerance is important to permit allowable pipe vibration due to its internal flow.

From the previous history of this pipe, it once leak on March 2010 at upper part of pipe (T-joint) due to crack propagation. It was found leak again on November 2011 at different spot. The incident happened during plant operating hours and the plant personnel had identified it is due to the crack propagation between the pipe and its welded trunnion support; occurs when the fluid induced the pipe and it vibrates and swing and hit the base frame of the building. From inspection conducted on March 2012, the excessive vibration issues were found. The root cause of the incident was not yet identified.

1.2 **Problem Statement**

From visual inspection, high vibration of BS pipe with high amplitude low frequency was found when Benfield Solution bypassed hydraulic turbine. High vibration occurred at 24-BS-15024 has caused crack to its trunnion support due to excessive vibration induced by Benfield Solution fluid. From visual inspection, the pipe with support sliding longitudinally and hit the base frame of the building and cause the trunnion to crack.

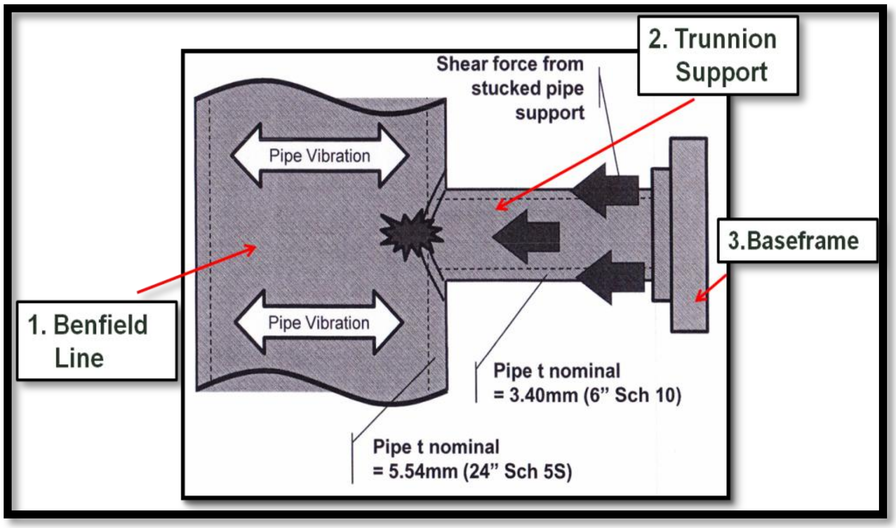


Figure 1.3: Failure of Trunnion Support due to pipe vibration

1.3 **Objectives**

To study the interaction of fluid dynamics and the pipe structure for the determination of the fatigue life of the Benfield pipe.

In order to obtain the objective, following activities will be conducted:

- To define mechanical properties of Benfield pipe based on ASME Code for Pressure Piping, B31
- To model the critical part of Benfield pipe using ANSYS Structural Analysis and the dimension is derived from isometric drawing from plant.
- To calculate velocity of the flow based on the volume flow rate variation.

- To manipulate hydrodynamic forces to see the deformation and stress point of the pipe to perform the dynamic analysis of the pipe.
- To perform stress analysis
- To estimate fatigue life of Benfield pipe.

1.4 Scope of study

The project involves:

- Numerical/Analytical Modelling and simulation only. Experimental work is excluded for the scope of study
- Type of loading involved is hydrodynamic loading only; type of flow regime is not implemented.
- Residual stress due to fabrication process will be considered has been relieved during construction because no data collection.
- Wind load is negligible as it conveys minor impact to the structure.
- Validation of results will be based on mathematical calculation and GTS report

1.5 Significance of the project

- Apply theoretical concepts of fluid dynamics in determining deformation of trunnion based on exact simulation software
- Solve engineering problem by applying relevant analysis gained from mechanical course.
- Analyze result and findings based on previous researches and interpret them as a way to provide recommendation to the problem.

CHAPTER 2

LITERATURE REVIEW

2.1 Fluid- Structure Interaction (FSI)

In ANSYS, FSI applications involve coupling of fluid dynamics and structure mechanics disciplines. Fluid flow exerts hydrodynamic forces on a structure and deforms and/or translates the structure

- Fluid flow can also modify thermal stresses within the structure
- Deformed or translated structure imparts velocity to the fluid domain and changes its shape and thus changes the fluid flow

Erath W. use KEDRU, a finite difference program for water hammer and other pressure wave calculations and EASYPIPE, a structural dynamic program, have been coupled in his investigation of FSI in water hammer. With this program it is possible to take the fluid structure interaction (FSI) into account.

Daneshmand use Finite Element Method (FEM) to study fluid structure interaction of hydraulic engine mount (HEM). He models HEM using 3D solid and fluid elements in ANSYS software. The study is conducted by considering fully coupled fluid structure interaction. The aim is to determine HEM dynamic characteristics and area of deformation.The 3D solid and fluid elements are used to model HEM (Solid 45 and Fluid 30 element). The effects of inclusion the bell system in HEM is compared in two different models. The model is considered for two loadings; a high amplitude low frequency (10000N, 100-200Hz) and Low Amplitude High Frequency (1000N, 1200-1300 Hz). Daneshmand consider the fully coupled fluid structure interaction in investigation of the dynamic behavior of HEM. This was included using 3D finite element modeling with pressure and displacement.

Robert tends to develop a finite element method model to simulate the impact process, and presents investigations using the model to determine the influence of the geometry and velocity of the impacting object. He studied the influence of the pipe diameter, wall thickness and concrete coating thickness along with internal pressure. The FEM Model discretization has been developed by using LS-DYNA explicit FEM software utilizing shell and solid elements and pre-stressing due to internal pipeline pressure is applied using ANSYS software. Parametric studies will be presented relating the dent size to pipe diameter, wall thickness and concrete thickness, internal pipe pressure and impacting object geometry. The concrete coating is modeled using eight-node constant-stress solid element because of stability and numerical efficiency. The pipe is discretized using Hughes-Liu formulation shell elements (3D) with five through-thickness integration point.

2.2 Static Structural and Modal Analysis of Benfield Pipe

A static structural analysis determines the displacement, stress, strains and forces in structure or component caused by loads that do not induce significant inertia and damping effects. Steady loading response conditions are assumed; that is the load and the structure's response to vary slowly with respect to time. Modal analysis is used as solver to static structural problem which determines the vibration characteristic (natural frequencies and mode shapes of a structural).

The formulation used in ANSYS Modal Analysis is used for vibration dynamic fluid-structure problems linear system with time integration methods. The problem of interest is to compute the response of linear system subjected to an imposed acceleration, in this case hydrodynamic load by BS fluid. The hydrodynamic load on the system is described by acceleration profile a(t) in given direction D and the system response is defined by evolution of its degree of freedom, X(t) (in FSI problem structure displacement field and fluid pressure and displacement potential fields) in the moving frame, M, C and K denoting, respectively, the system mass, damping and stiffness matrices. The system dynamic is described by the following equation.

$$\mathrm{MX}\,(\mathrm{t}) + \mathrm{CX}(\mathrm{t}) + \mathrm{KX}(\mathrm{t}) = -\mathrm{MD}y(t)$$

The system dynamic behavior can be viewed as the superposition of elementary mass-spring system with mass mn and spring stiffness kn, each system oscillating at frequency fn given by

$$fn = \frac{1}{2\pi}\sqrt{\frac{kn}{mn}}$$

Baseline velocity taken is at normal operating parameter of BS fluid as baseline of the result. The deformation is compared between velocities from both cases based on the most critical/selected mode shapes which meet criteria set by GTS report. Fauziah (2011) investigate the effect vortex shedding frequency and internal flow on response to riser. The hydrodynamic force of sea wave and current is calculated using Morison equation. The model is simulated using MATLAB Code. The result shows as velocity of internal flow increases, the riser response is higher.

CHAPTER 3

METHODOLOGY

3.1 Process flow chart

Figure 3.1 shows the overall FYP flow chart. Each procedure will be discussed further in the next topic.

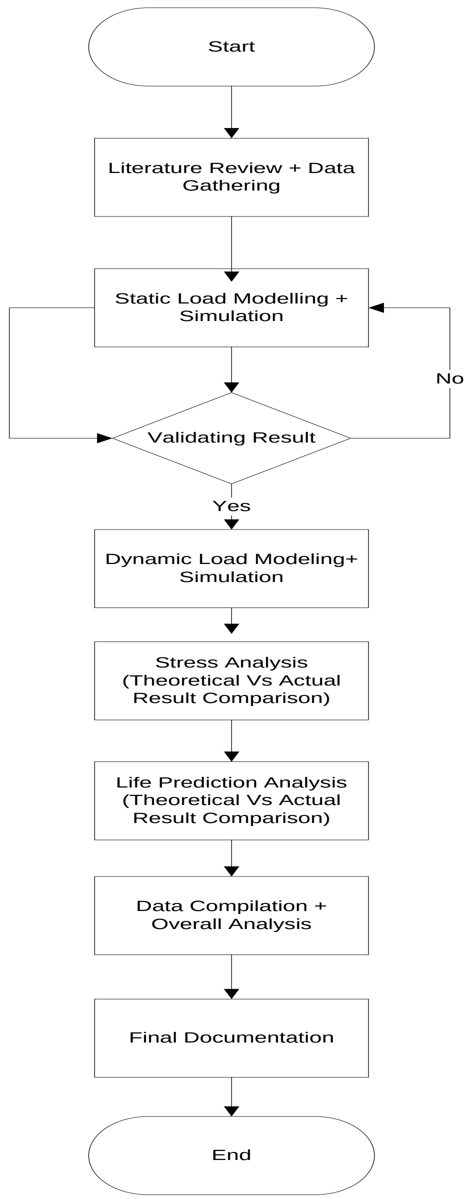


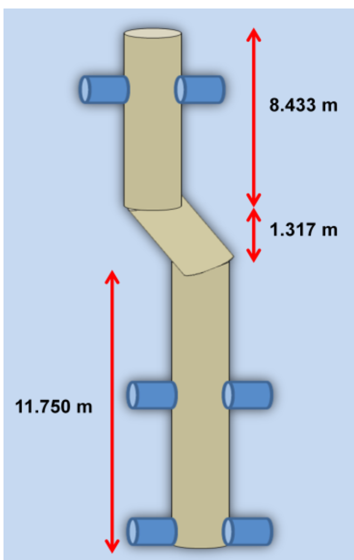
Figure 3.1: FYP Project flow chart

3.2 Static Load Modelling and Simulation

3.2.1 Pipe Modelling

For pipe modeling, ANSYS Workbench is used and the analysis used is Static Structural and Modal analysis as a solver. The dimension and orientation of the pipe in Figure 3.2 is derived from the original isometric drawing. The original drawing is attached in the appendix. In this project, pipe is modeled as fluid element and hydrodynamic force is exerted at the bottom end of the pipe. The input used for hydrodynamic loading calculation in ANSYS is fluid density and fluid velocity. The fluid velocity is calculated using continuity equation. The result will be presented in six mode shapes of deformation of pipe with different area of deformation and the maximum allowable stress at each frequency. For validation, all lines subjected to fluid-induced vibration (FIV) shall obtain a minimal of natural frequency of 10 Hz for the first mode shape. From the result, area of deformation will be identified based on flow fluctuation impact. The deformation should be not exceeding trunnion support tolerance value in order to prevent crack propagation.

3.2.2 Pipe Dimension



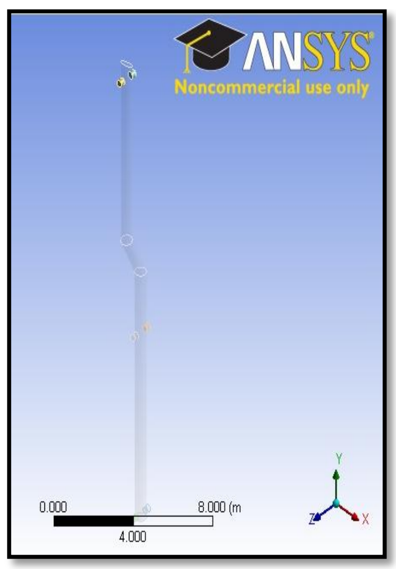


Figure 3.2: Benfield Solution Pipe Dimension and Model in ANSYS

3.2.3 Meshing Control

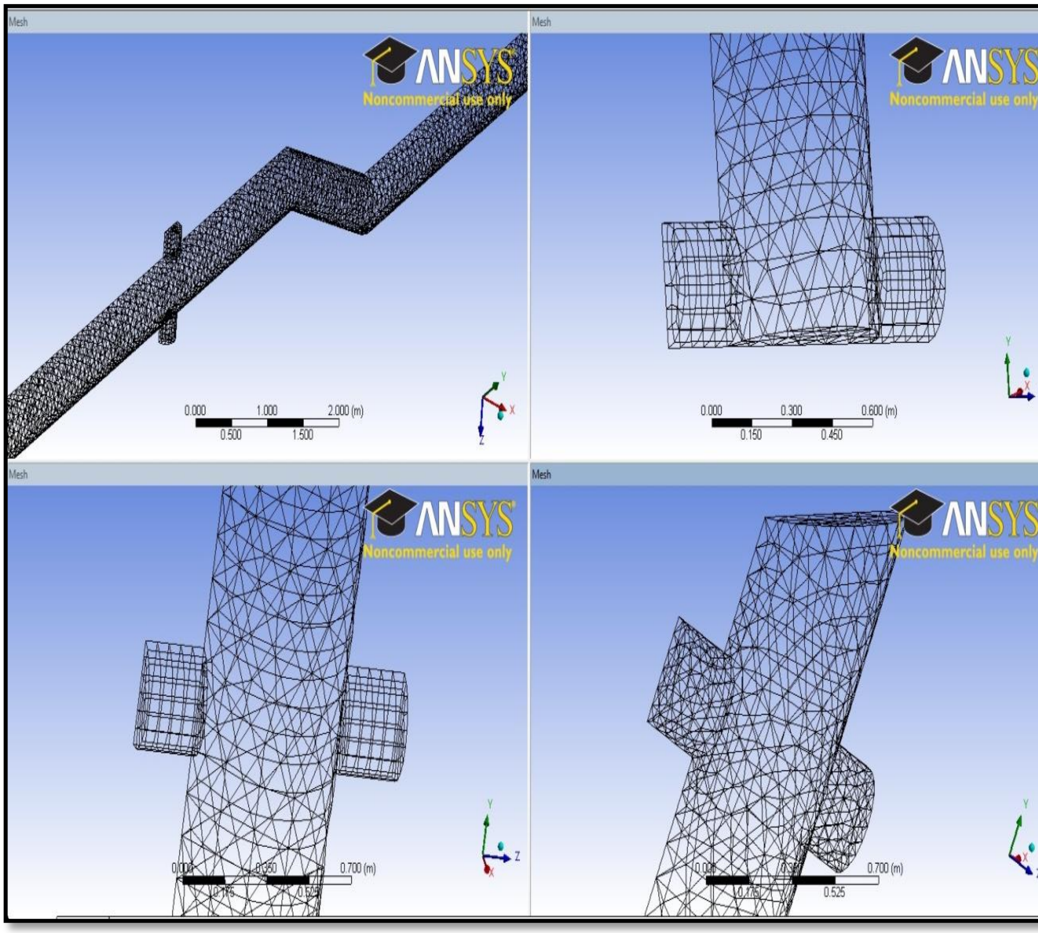


Figure 3.3: Meshing control at the location of trunnion support

Meshing control is spatially discretized into element and nodes of a solid body. This mesh is mathematically represents the stiffness and mass distribution of the structure. In ANSYS mesh size can be controlled manually or program controlled. In order to give better accuracy of the result, mesh size is set to be fine and curvature is on. Figure 3.3 shows the mesh generated at three location of trunnion support.

3.1.4 Boundary Condition

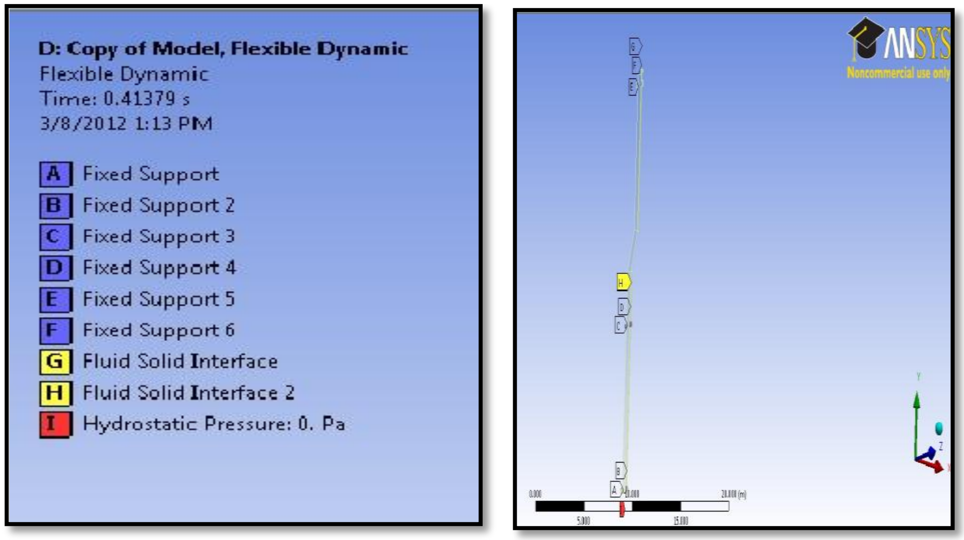


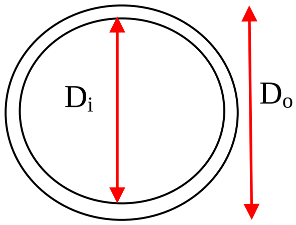
Figure 3.4: Boundary condition setup

From Figure 3.4, in static structural analysis, the boundary condition is set accordingly based on to the real condition of BS Pipe. There are six fixed supports which attached the pipe and the trunnion support. The trunnion supports are set to be fixed support and at the surface between fluid movement and trunnion internal surface, fluid-structure surface function is set. The hydrodynamic load is applied normal to the pipe inlet surface.

3.1.5 Calculations and Assumptions

Table 3.1 indicates the calculation involved in determining the fluid contact area and fluid velocity for normal operating mode. The calculation is based on continuity equation.

Table 3.1: Area and fluid velocity calculation

Surface Area :  $D_o = 0.6096$ m $D_i = 0.60406$ m	$\text{Contact Area, A} = \pi r^2$ $= \pi\left(\frac{Di}{2}\right)^2$ $= \pi\left(\frac{0.3020}{2}\right)^2$ $= 0.2919\ m^2$
Fluid Velocity  $\dot{\upsilon}_a = 1350\ (m^3/hr)$ $\dot{\upsilon}_b = 1435\ (m^3/hr)$ Volume flow rate, $\dot{\upsilon}$	$\text{Velocity, va} = \frac{\text{volume flow rate}}{\text{area}}$ $= \frac{1350\ m^3/hr}{0.2919\ m^2}$ $= 4624\ \frac{m}{hr}$ $= 1.284\ \frac{m}{s}$

Assumptions:

1. The fluid regime used in this project is assumed to be fully-develop laminar flow
2. The cross sectional of the pipe is constant
3. The fluid properties is treated constant at average temperature
4. The friction between fluid particles in pipe is too small and disregarded.
5. Damping is ignored in a modal analysis.

3.3 Dynamic Load Modeling and Simulation

In dynamic modeling, the same approach is used which is static structural analysis coupled with modal analysis. The different is the variation of hydrodynamic force regulated based on three operating modes of BS solution volume flow rate. The simulation takes place at the same frequency for three cases. Table 3.2 shows the volume flow rate variables data that obtained from plant operating parameters. The result deformation and maximum allowable stress is counted at the frequency of static structural result and will be compared in order to solve problem statement of the study.

Table 3.2: Volume flow rate variables

Case	Type of flow	Volume Flow Rate (m^3/hr)
A	Bypassed the hydraulic turbine (normal)	1350
B	Bypassed the hydraulic turbine (max)	1435
C	Across the hydraulic turbine	1248

3.4 Stress Analysis

Stress analysis is done based on dynamic load analysis result. The maximum stress at the highest deformation is counted at the highest volume flow rate; in the case of B. The stress value is generated during the simulation is validated with Caesar II software for piping and GTS Report.

3.5 Fatigue life estimation

Fatigue life conveys the estimated life of trunnion support after hitting the base frame under a few cycles under the ultimate tensile strength of pipe. Fatigue life estimation is done based on stress analysis result. In ANSYS, the alternating stress value is generated and plotted onto S-N curve to determine the number of cycle that caused fatigue; at a point where leaks will occur.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Static Simulation Result

4.1.1 Modal Analysis Animation

Modal Analysis illustration for mode shape 1 and mode shape 2 simulations is shown in Figure 4.1. Six mode shapes at the different pattern of fluid fluctuation is generated inside the pipe at the specific frequency. The deformation contour shows the criticality of pipe, thus provide significant deformation and stress concentration area needed to examine leakage likelihood location.

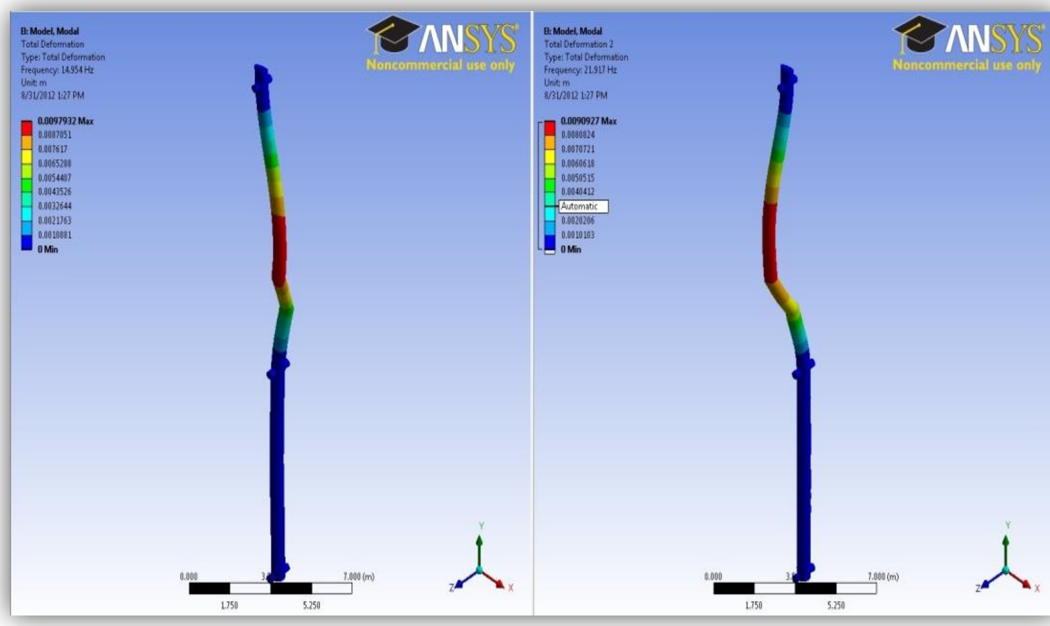


Figure 4.1: The animation shows deformation of pipe at i) Mode 1 at 14.954 Hz and ii) Mode 2 at 21.917Hz

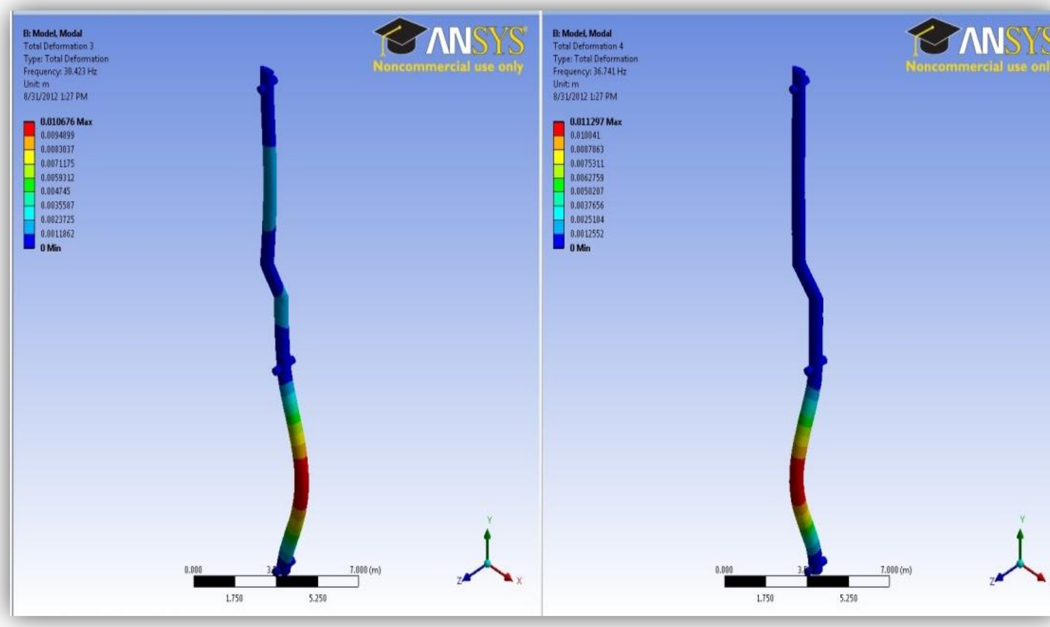


Figure 4.2: The animation shows deformation of pipe at iii) Mode 3 at 30.423 Hz and iv) Mode 4 at 36.741 Hz

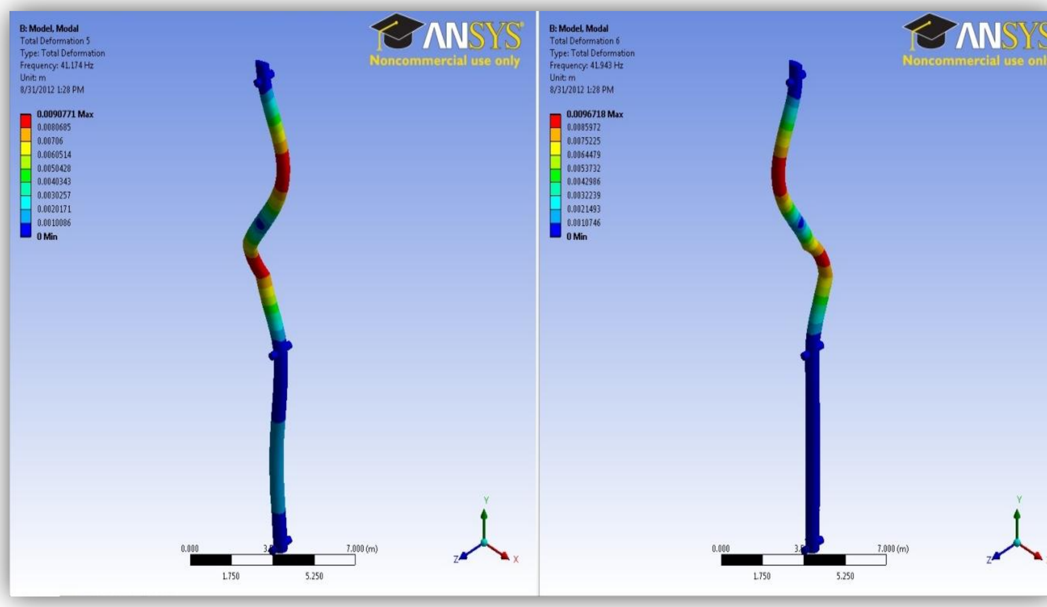


Figure 4.3: The animation shows deformation of pipe at v) Mode 5 at 41.174 Hz and vi) Mode 6 at 41.93 Hz

4.1.2 Discussion

Based on the result, the same area of deformation is detected at mode shape 1, mode shape 2, mode shape 5 and mode shape 6, stress concentration occurs at the upper part of the pipe. At mode shape 3 and 4, the stress concentrated at the lower part of pipe, which indicating at trunnion leakage stated at the problem statement section

The mode shapes frequencies are tabulated in the table 4.1 below.

Table 4.1: Static Load Result

Case A	Mode 1	Mode 2	Mode 3	**Mode 4**	Mode 5	Mode 6
Frequency (Hz)	14.954	21.917	30.423	**36.741**	41.174	41.93
Maximum Deformation (mm)	9.79	9.09	10.6	**11.2**	9.07	9.67

For mode 1, 2, 5 and 6; the stress profile is concentrated at the upper part of the pipe with tolerance less than 10mm. Apart from that, for Mode 3 and Mode 4, the deformation occurs at the lower part of the pipe; which at exact location of leakage happen with highest deformation larger that 10mm. Indeed, Mode 4 has the largest deformation of **11.2 mm** which exceeds the trunnion tolerance. Thus, when the pipe vibrates excessively, it will hit the base frame due to it has exceeding value of tolerance. It caused trunnion to break and Benfield fluid leaks and this will happen at frequency of **36.741 Hz**.

4.2 Dynamic Simulation result

For dynamic analysis, hydrodynamic forces are varies according to different cases of volume flow rate at fixed frequency. The animations are presented in figure 4.4 and figure 4.5 shows the similarities of area deformation of pipe at different cases. As the static result reveals that Mode 3 and Mode 4 occurred at the pipe leakage location, thus, the dynamic load result is analyzed based on Mode 3 and Mode 4 for each cases.

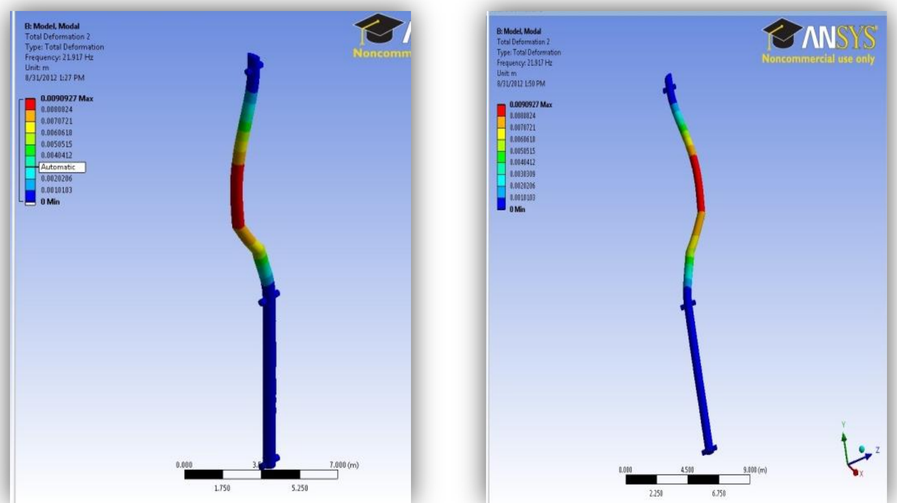


Figure 4.4: Area of deformation for i) Case A Mode 2 and ii) Case B Mode 2

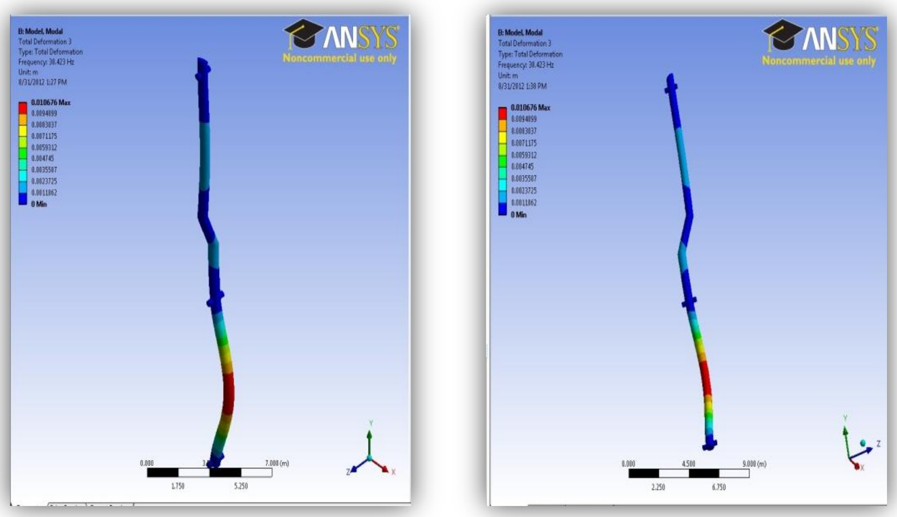


Figure 4.5: Area of deformation for i) Case A Mode 3 and ii) Case B Mode 3

The result shows that when hydrodynamic load is subjected to same frequency, the deformation occurred at the same area. The mode shape 3 and 4 deformation results are tabulated in the Table 4.2 below for each case.

Table 4.2: Dynamic Load Result

	Mode 3 (30.423 Hz)	Mode 4 (36.741Hz)
Case A	10.6 mm	11.2 mm
Case B	11.55 mm	13.01mm
Case C	9.59 mm	9.89mm

For dynamic analysis, hydrodynamic forces are varies according to different cases of volume flow rate. Since mode 3 and 4 gives exact area of deformation, for dynamic analysis, the deformation of pipe is counted at mode 3 and mode 4 only. From the table, we can say that the highest deformation occurs at mode 4 of case B; which is the highest volume flow rate used in the project. It gives the **highest deformation of 13.01mm at 36.741 Hz,** thus, it is the highest point of severity of trunnion support deformation.

This result proved the theory that as the velocity internal flow increased, the BS pipe response is higher. Thus, the severity of BS Pipe against hydrodynamic loading will become crucial and caused pipe leakage with maximum deformation.

4.3 Stress Analysis

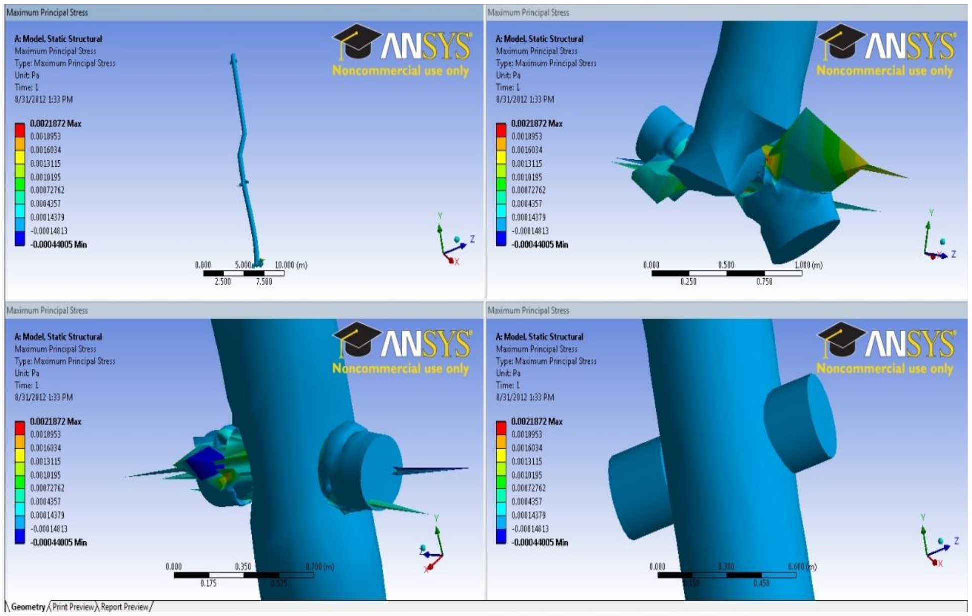


Figure 4.6: Trunnion Support deformations at three different points

Table 4.3: Stress Analysis Result

ANSYS Data	GTS Data
66.979 MPa	87.68 MPa

Figure 4.6 show the trunnion support deformations at three different points lower part, middle support and upper support. Stress distribution at the highest deformation as shown in Table 4.3, is validated with stress analysis simulated using Caesar II by GTS. The maximum allowable stress from ANSYS is slightly less than GTS stress data analysis. It is due to; in ANSYS

- No wind load consideration
- Only critical part of vibration is taken into account.
- GTS report is using Caesar II software that use nodal element to analyze the real application piping problem.

4.4 Fatigue Life Estimation Result

Table 4.4 Alternating stress versus number of cycles

Cycles	Alternating Stress Pa
10.	3.999e+009
20.	2.827e+009
50.	1.896e+009
100.	1.413e+009
200.	1.069e+009
2000.	4.41e+008
10000	2.62e+008
20000	2.14e+008
1.e+005	1.38e+008
2.e+005	1.14e+008
1.e+006	8.62e+007

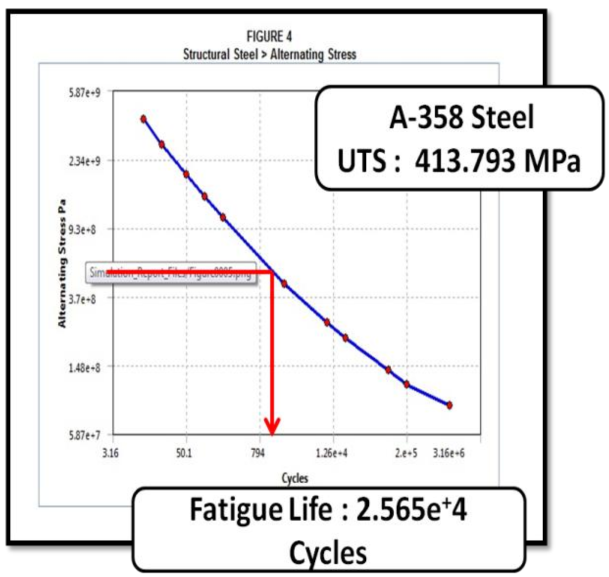


Figure 4.7 S-N Curve

The plotting of alternating stress versus cycles of failure in figure 4.7, shows that all the curve exhibit the power-law behaviour in fatigue life determination.Based on ultimate tensile strength of pipe, the fatigue life of pipe structure after $2.565e^{+}4$ cycles

CHAPTER 5

CONCLUSION

5.1 Conclusion

In a nutshell, when the Benfield Solution pipe vibrates approaching to 36.741Hz, the highest deformation of Benfield pipe by 13.01 mm is recorded. Since the acceptable tolerance between trunnion and base frame is 10 mm, mode 4 exceeds this value and cause trunnion deterioration after $2.565e^{+}4$ cycles. The area of deformation is occurred at the lower part of the pipe, which is resulting the actual pipe leakage area of the project. From that point, maximum stress exerted onto the pipe is validated with Caesar II data and it shows a slightly lower value in ANSYS stress analysis due to some reasons, which mainly caused by different scope of study.

5.2 Recommendation

1. The plant operator personnel should used the minimal mass flow rate in avoidance to reach 36.741Hz and that will cause severe damaged to the BS pipe.
2. Future research need to be done on how to improve vibration problem especially for vertical pipe problem by:
    - Finding the source of vibration
    - Modification of trunnion support design
    - Addition number of trunnion support for extra structural support behavior.

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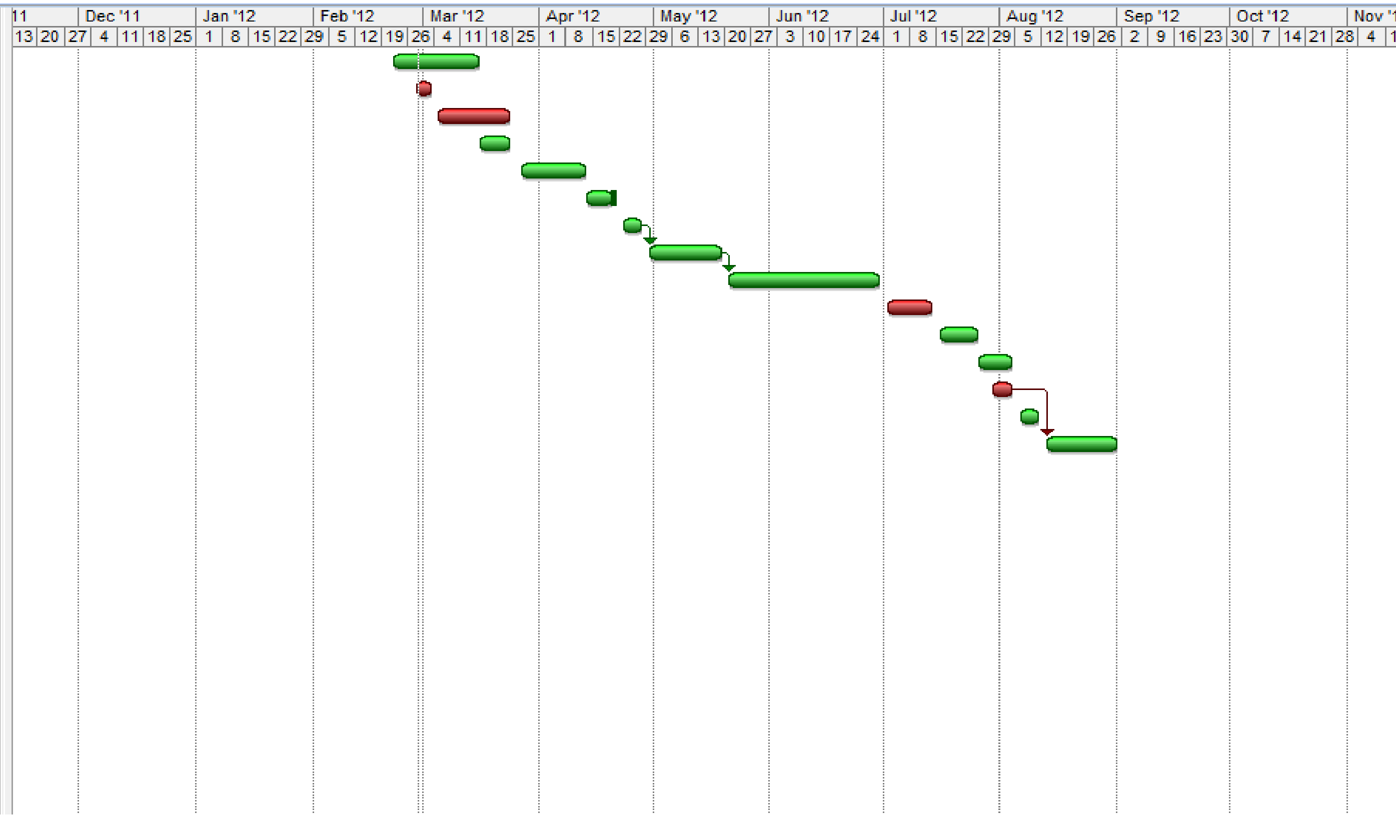
APPENDIX

FYP MILESTONE

	Task Name	Start	Finish
1	Literature Review (Final)	Wed 22/2/12	Thu 15/3/12
2	Extended Report Submission	Tue 28/2/12	Fri 2/3/12
3	Proposal Defense Presentation	Mon 5/3/12	Fri 23/3/12
4	ANSYS Tutorial	Fri 16/3/12	Fri 23/3/12
5	Modelling of Pipeline (Static) with simulation	Tue 27/3/12	Thu 12/4/12
6	Modelling of Pipeline with stuck support (dynamic)	Fri 13/4/12	Fri 20/4/12
7	Simulation (con't)	Mon 23/4/12	Fri 27/4/12
8	Stress Analysis	Mon 30/4/12	Fri 18/5/12
9	Life Prediction Analysis	Mon 21/5/12	Fri 29/6/12
10	Progress report preparation + Submission	Mon 2/7/12	Fri 13/7/12
11	Theoritical Data Vs Operational Data	Mon 16/7/12	Wed 25/7/12
12	Theoritical Data Vs Operational Data (Analysis)	Thu 26/7/12	Fri 3/8/12
13	EDX Poster Presentation	Mon 30/7/12	Fri 3/8/12
14	Project Recommendation to Host Company	Mon 6/8/12	Fri 10/8/12
15	Final Report Compilation + Submission	Mon 13/8/12	Fri 31/8/12



PIPE DIMENSION FROM ISOMETRIC DRAWING