LATERAL VIBRATION ANALYSIS OF DRILLSTRING USING FINITE ELEMENT METHOD

BY:

PIRAWIN A/L VADEVELOO

15042

Dissertation submitted in partial fulfillment of the requirements for the

Bachelor of Engineering (Hons)

(Petroleum Engineering Engineering)

(APRIL 2015)

Universiti Teknologi PETRONAS

Bandar Seri Iskandar, 31750 Tronoh,

Perak Darul Ridzuan, Malaysia.

CERTIFICATION OF APPROVAL

LATERAL VIBRATION ANALYSIS OF DRILLSTRING USING FINITE ELEMENT METHOD

By

PIRAWIN A/L VADEVELOO

Dissertation submitted in partial fulfillment of the requirements for the

Bachelor of Engineering (Hons)

(Petroleum Engineering Engineering)

Approved by,

____

(DR. TAMIRU ALEMU LEMMA)

Universiti Teknologi PETRONAS

Bandar Seri Iskandar, 31750 Tronoh,

Perak Darul Ridzuan, Malaysia.

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.

PIRAWIN A/L VADEVELOO

ABSTRACT

This project investigates lateral vibration of a drillstring under the action of weight on bit and drillstring rotation. The dominant cause of drillstring and bottom hole assembly's failures, shocks and severe damages to borehole wall is recognized to be the lateral vibration. Thus, lateral vibration is chosen to be the only factor of interest and focused in this project. Lateral vibration manifests itself from the increased speed of rotary drilling. This study presents a finite element model using ANSYS software to investigate the lateral vibration of drillstring in a vertical well. The analysis proceeds in two stages. Firstly, modal analysis is performed to determine the natural frequencies of the drillstring and the second stage is to carry out harmonic analysis to obtain the frequency response at a varying length of drill pipe. Simulation is first carried out by simulating benchmark problem before proceeding to deal with the actual case studies by carrying out parametric study (drillstring length, weight on bit, rotational speed). The results show that increase in weight on bit increases the natural frequencies and hence changing the location of maximum amplitude in the harmonic analysis.

ACKNOWLEDGEMENT

An endeavor over a period can be successful only with the advice and support of well-wishers. The author would like to take this opportunity to express his profound gratitude to Universiti Teknologi PETRONAS for providing the platform for the research project to be conducted.

The author also take this opportunity to express a deep sense of gratitude and regards to his supervisor, Dr.Tamiru Alemu Lemma, Lecturer, Mechanical Engineering, Universiti Teknologi PETRONAS, for his cordial support, valuable information and exemplary guidance, which help the author in completing the final year project. The blessing, help and guidance given by him time to time shall carry the author a long way in the journey of life on which the author about to embark.

The author would like to thank Almighty, his parents, brother, sisters and friends for their constant encouragement without which this report would not be possible.

Thank you.

TABLE OF CONTENTS

CHAPTER 4: RESULT AND DISCUSSION

CHAPTER 5: CONCLUSION AND RECOMMENDATION

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND NOMENCLATURES

3D	*Three Dimensional*
BHA	*Bottom Hole Assembly*
DQM	*Differential Quadrature Method*
FYP	*Final Year Project*
NP	*Neutral Point*
UTP	*Universiti Teknologi PETRONAS*
WOB	*Weight On Bit*

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Drilling operation is a major part in finding and developing new hydrocarbon reserves. It is also the process by which tubing is bored through the surface of the Earth and a well is established. Drilling is done using rotary drilling rig which uses drill bit to penetrate through the different formations down the earth, Figure 1 shows the rotary drilling rig used for drilling operation. As the well gets deeper, pipe is added to the drill bit and continues for further penetration. Drillstring is the combination of drill pipes, bottom hole assembly (BHA) tools and other tools used to make the drill bit turn at the bottom of the wellbore. In this operation, drillstring is a major part that is involved. In an economical point of view, drilling operation is very costly and thus efficient drilling need to be prioritized. According to Arizona Geological Survey, operation of oil drilling in Arizona costs between $400,000 to $1,000,000, depending on its location and depth of the well. Based on the similar survey, it states that a typical rig capable of drilling costs $8000 to $15,000 per day. Therefore, imagine the huge loss in economy to be faced if drilling operation is stopped due to some problems.

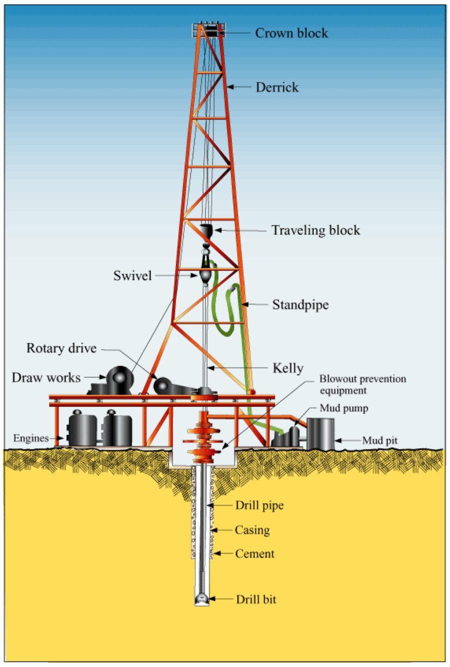


FIGURE 1. Rotary Drilling Rig [4]

Hydrocarbon well drilling operations are usually interfered by few problems from drillstring itself that lead to failures of drilling tools and bottom hole equipment. The most influential problem identified is the vibration of drillstring. As shown in Figure 2, drillstring vibration consists of three main types which are known to be axial vibration, lateral vibration and torsional vibration and all these vibrations are generally quite complex in nature. Besides, these vibrations can promote failures and abrasive wear of tubular and bring damage to both drill bit and the borehole wall. In addition, lateral vibrations are the most destructive type of vibration and can create huge impact as the BHA impacts the wellbore wall. Lateral vibration manifests itself from the increased speed of rotary drilling. Thus, a proper understanding of drillstring dynamics is necessary to achieve a safe range of drilling speeds.

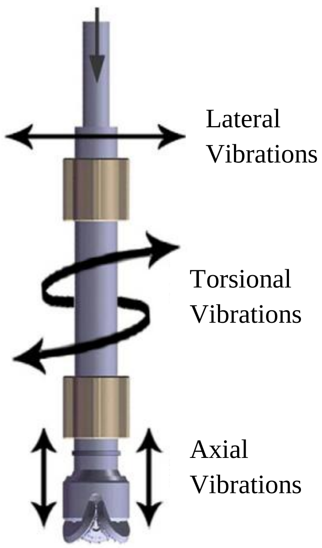


FIGURE 2. Three forms of drillstring vibration. [4]

The interaction between BHA and the drillstring contacts points may, in certain circumstances, lead the system into whirling. As a consequence, the drilling operation turns out to be inefficient and also costly. Moreover, drillstring contact-impact interaction with the borehole results in high frequency excitations, which further deteriorate the drilling performance and eventually may cause damages to the BHA. Hence, drillstring lateral vibrations must be fully apprehended and its effects should be minimized in any approach to optimize drilling performance.

1.2 Problem Statement

Drilling operation will induce vibrations which can only be sensed at the rotary table. These vibrations may be caused from factors such as bit rock interaction, drill cutting flow and wrong operation settings (rotary speed and weight on bit settings). Thus, in this project the problem that being identified here is how lateral vibration of a drillstring will affect the vibration signature pattern recorded at rotary table. Optimization of drilling process requires a reliable model and real-time data processing tool. Main aim of this project will be to contribute to the modeling part by producing a simplified model to study drillstring dynamics. Later, the model will be used to assess the effect of weight on bit, rotation, and pipe length to system frequencies and harmonic response. The following hypothesis has been considered to expedite the project.

- ❖ ANSYS based finite element modelling for in depth study of lateral vibration of drillstring would be considered a suitable choice to model the system.
- ❖ Frequency domain based analysis of the drillstring response to a harmonic input would be an appropriate choice to reveal key aspects of the drillstring dynamics.

1.3 Objectives

The objectives of this project are:

i. To develop a finite element based model in ANSYS Workbench.
ii. To investigate the effect of weight on bit, drillstring length, and rotational speed to modal frequencies and harmonic response.

1.4 Scope of Study

The scope of study is limited to the following:

i. A drillstring defined by light weight pipes and BHA only.
ii. Mud flow effect is not to be included.
iii. The bit-rock interaction or friction force at the bit is not to be included.

CHAPTER 2

LITERATURE REVIEW

2.1 Drillstring Dynamics

In a drilling environment, it is a common problem for drillstring to experience vibrations during rotary drilling. Drillstring vibration is one of the major causes that leads to poor drilling performance and may be detrimental to its whole drilling process. According to Ahmad Ghasemloonia, Geoff Rideout, and Stephen (2014), drillstring vibration is not simply independent axial, torsional and lateral vibration. There are 3 major coupled modes : lateral-axial, lateral-torsional and axial-torsional which are typical drillstring modes. Some examples of drillstring vibrations are known as bit bouncing (axial vibration), stick-slip (torsional vibration) and whirling (lateral vibration).

2.2 Lateral Vibration

Lateral problems such as backward and forward whirling are caused when the rotary speed is increased. This eventually impacts with parametric instabilities and the borehole wall (Yigit&Christoforou, 1998). Moreover, it is studied that if a rotating drill bit abruptly halted, rapid whirling of the drillstring will occur. This consequently leads to a catastrophic collision of drillstring with borehole wall due to the energy change in the motion(Tucker & Wang, 1999). Jamal, Seyed, and Gholamreza (2011) performed static analysis in order to determine the effective length of drillstring where it is free to experience lateral vibration. A finite element dynamic model was developed using ANSYS software to study in details about the characteristics of vibration occurring in a rotating drillstring. It is clearly shown that this model indicates the critical rotary speeds at which drillstring vibration can go extreme.

2.3 Modeling of Drillstring Vibrations

Christoforou and Yigit (1997) came up with a model derived for BHA, assuming that motion of the drill collars is confined to the borehole and supported at the location of stabilizer. The impact was modelled by Hertzian contact law. Hakimi and Moradi

(2009) analysed drillstring vibration in a near vertical hole using the approach of Differential Quadrature Method (DQM). DQM is capable of predicting the natural frequencies of drillstring accurately.

2.4 Contact Models

Ahmadian, Nazari, and Jalali (2007) developed the contact force model between drill collar and borehole wall and also investigated its behaviour through equation of motions. External forces are taken into considerations while developing the equation of motion. Hertzian contact law is used to define the contact force between borehole and the drill collar.

$$F_N = \begin{cases} -K_h(r - D_c)^{\left(\frac{3}{2}\right)} & if\ |r| \geq D_c \\ 0 & if\ |r| < D_c \end{cases}$$

Where,
F_N = Contact force
K_h = Hertizan stiffness
D_c = Borehole clearance
r = Borehole radius

Khulief, Al-Sulaiman, and Bashmal (2008) had used continuous force-displacement law in order to develop a dynamic model of the drillstring and borehole contact as shown in Figure 3. This continuous force-displacement law indicates the impulsive force during short period interval of impact. By using energy balance relations, the material compliance and damping coefficients at the contact zone are identified. This contact-impact model is further enhanced into a finite element equation of motion for the drillstring.

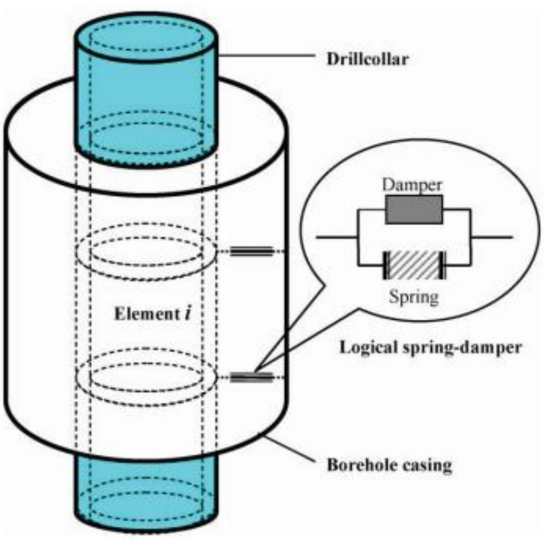


FIGURE 3. The compact-impact model [6]

2.5 Drillstring Whirl

On the other hand, a Stick-slip Whirl Model was introduced by Leine and Campen (2002) which aims to explain the complicated behaviour of drillstring motion when both lateral and torsional vibrations are involved. This model shown in Figure 4 also potrayed the observed phenomena in experimental drillstring data could be affected by fluid forces of drilling mud. Whirling occurs at the same period of time when the drillstring experienced lateral movement while it is in rotational state of movement.

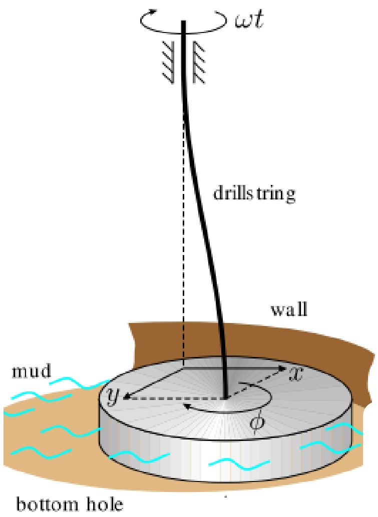


FIGURE 4. Stick-slip Whirl Model. [7]

2.6 Summary

Drilling performance is affected when drillstring experienced dynamic motion such as vibrations. Different types of vibrations had been highlighted and this project will mainly focus on lateral vibration. Lateral vibration occurs when rotary speed of the drillstring is high. To study in depth, it is crucial to understand types of modelling of drillstring vibrations and also contact models. Hertzian Contact Law and contact-impact model are examples of contact model used in previous research. Moreover, the whirling of drillstring can be studied by taking into account rotation and lateral vibration of drillstring.

CHAPTER 3

METHODOLOGY

This project is done step by step as per shown in flowchart in Figure 5. It starts with literature review and once adequate amount of understanding regarding the topic is acquired, selection of identified case is done. Using this selected case, its data and results acts like a benchmark. Then, finite element model will be developed with the aid of ANSYS software before proceeding to the next step. Once completed, using the benchmark data, simulation will be run to obtain similar results as in case selection. Next, once the results matched, another simulation need to be run which will only be based on a single setting. Parametric study is required to be carried out as a next step after this simulation. In this study, various important parameters will be identified and studied in detail. A final simulation is run after that and analysis of results will be done. Finally, a complete report will be written out to be pass to examiner for evaluation.

3.1 Project Flow Chart

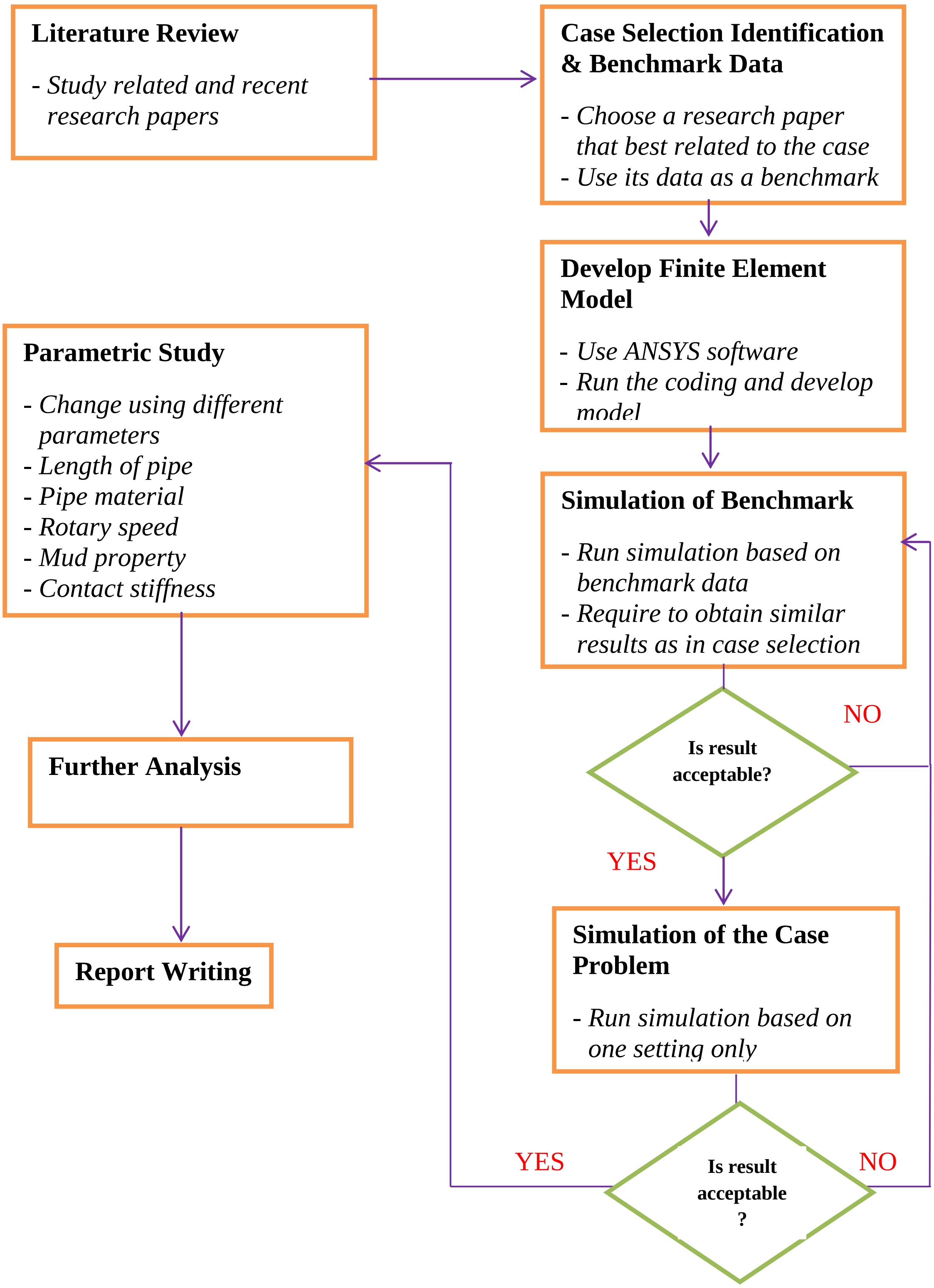


FIGURE 5. Project Flow Chart

3.2 Tools and Equipment

Tools and equipment used in this project are ANSYS Workbench and MATLAB.

3.3 Benchmark Problem

As per the methodology, case selection identification has been done by choosing a related case problem to this project and finite element model has been developed in ANSYS software. The paper that was chosen as benchmark problem is "*Finite Element Dynamic of Drillstring Analysis*" by Hussein A.Alnaser published in the year 2002.

This paper had analysed the vibrations of rotary oil well drilling assemblies by developing a finite element system that represents the drilling assembly. This paper also had performed modal analysis for different rotational speeds and drillstring configurations.

TABLE 1. Benchmark Drill Pipe Specification

Parameter	**Symbol**	**Unit**	**Value**
Drill pipe	L_p	m	1000
Drill pipe outer radius	R_{po}	m	0.127
Drill pipe inner radius	R_{pi}	m	0.095

TABLE 2. Benchmark Drill Collar Specification

Parameter	Symbol	Unit	Value
Drill collar	L_c	m	200
Drill collar outer radius	R_{co}	m	0.2286
Drill collar inner radius	R_{ci}	m	0.0762

TABLE 3. Benchmark Material Specification

Parameter	Symbol	Unit	Value
Drillstring density	ρ	kg/m^3	7850
Modulus of elasticity	E	N/m^2	210 x 10^9
Shear modulus	G	N/m^2	7.6923 x 10^{10}

3.4 Case Study: K421 Block

After the completion of benchmark simulation in ANSYS software, simulation of case study is carried out using the real data obtained from the field. This case study data was given by supervisor and these data came from a real oil field well and thus they are highly confidential. There are three subsets of case study namely Case Study 1, Case Study 2 and Case Study 3. For each case, two graphs were generated that shows the relation of frequency versus amplitude and also frequency versus phase angle. To study and compare more in depth about this finite element model, different range of pipe length were selected; minimum length, medium length and maximum length of drill pipe for respective case.

TABLE 4. Case Study Data

Parameter	Symbol	Units	Case Study 1 (Value)	Case Study 2 (Value)	Case Study 3 (Value)
Length of Drill Pipe	L_p	m	232	1940	3154
Length of BHA	L_{bha}	m	224	173	352
Internal Diameter of Drill Pipe	D_{pi}	m	0.10861	0.10861	0.10861
External Diameter of Drill Pipe	D_{po}	m	0.127	0.127	0.127
Internal Diameter of Drill Collar	D_{ci}	m	0.07325	0.07325	0.0762
External Diameter of Drill Collar	D_{co}	m	0.127	0.127	0.16764
Weight on Bit	WOB	N	11315.40	34670.33	70356.19

3.5 Equation of Motion

A harmonic analysis is used to determine the response of the structure under a steady-state sinusoidal (harmonic) loading at a given frequency. This analysis considers loading at one frequency only. Loads may be out-of-phase with one another, but the excitation is at a known frequency. This procedure is not used for an arbitrary transient load.

To better understand a harmonic analysis, the general equation of motion is as follows:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \{F\} \longrightarrow \text{(Equation of Motion)}$$

Where, [M] = Mass Matrix

[C] = Damping Matrix

[K] = Stiffness Matrix

$\{F\} = F_{max} e^{j(\Omega\emptyset + \Psi)}$

$\{x\} = x_{max} e^{j(\Omega t + \emptyset)}$

For harmonic analysis, the complex response {x} is solved from the matrix equation:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \{F\}$$

$j^2 = \sqrt{-1}$, $j^2 = -1$ $= F_{max} e^{j(\Omega\emptyset + \Psi)}$

Steady state response is calculated assuming:

$\{x\} = x_{max} e^{j(\Omega t + \emptyset)}$

Frequency response calculation:

Let $\{x\} = x_{max} e^{j(\Omega t + \emptyset)}$

$\{\dot{x}\} = j\Omega\, x_{max} e^{j\Omega t}$

$\{\ddot{x}\} = -\Omega^2 x_{max} e^{j\Omega t}$

$(-\Omega^2 M x_{max} + j\Omega C x_{max} + K x_{max}) e^{j\Omega t} = F_{max} e^{j\Omega t}$

$\forall_t , e^{j\Omega t} \neq 0$

$[-\Omega^2 M + j\Omega C + K] x_{max} = F_{max} - 1$

$x_{max} = [-\Omega^2 M + j\Omega C + K] F_{max}$

There are important assumptions that needed to be taken into account in performing harmonic analysis simulation. The assumptions are as follows:

- [M], [C], and [K] are constant matrices.
- Linear elastic material behaviour is assumed.
- Small deflection theory is used, and no nonlinearities included.
- Damping [C] should be included. Otherwise, if the excitation frequency W is the same as the natural frequency ϖ of the structure, the response goes to infinite a condition called resonance.
- The loading {F} (and response {x}) is sinusoidal at a given frequency ϖ, although a phase shift may be appear.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Model Validation of Benchmark Problem

A model similar to benchmark model was developed as shown in Figure 6. Using modal analysis, natural frequencies of the model are obtained and graph of first 10 modes for different location of neutral point (NP) along the drill pipe versus its frequencies were plotted. Figure 7 shows the actual graph from the benchmark problem while Figure 8 shows the simulation model graph carried out to match the actual graph. Based on the comparison shown in both Figure 8 and Figure 9, it is clearly shown that similar pattern and values managed to be generated in the graph. Based on the result generated through simulation, it is proven that the result obtained is reliable and valid to proceed with case study simulation.

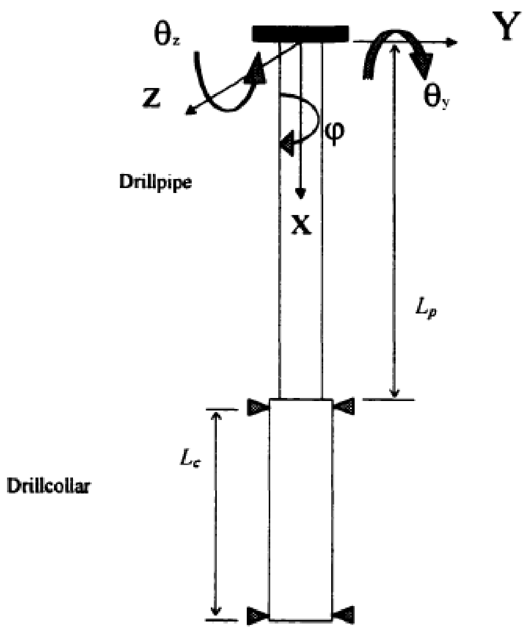


FIGURE 6. Schematic Diagram of the Benchmark Problem [5]

4.1.1 Benchmark Problem Results

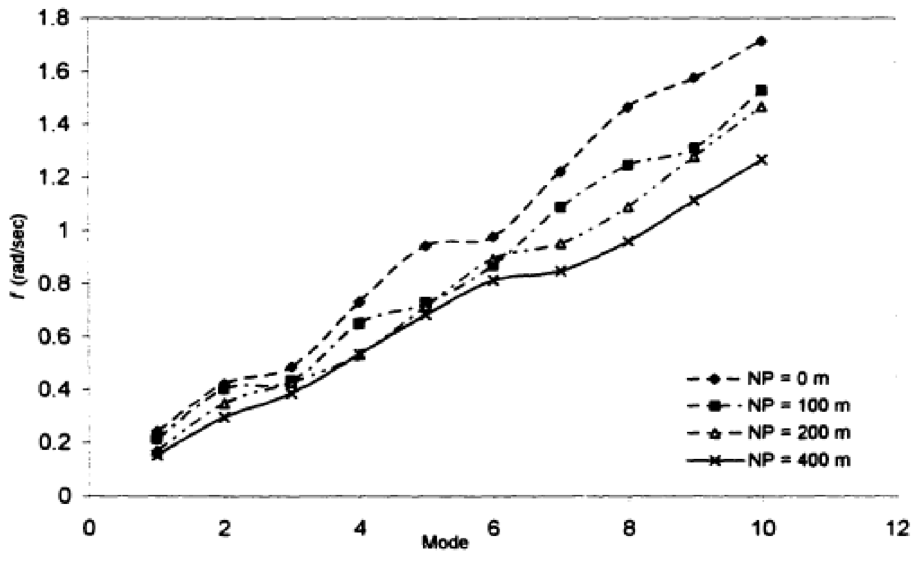


FIGURE 7. Benchmark results for frequencies of first ten modes for different location of neutral point (NP)

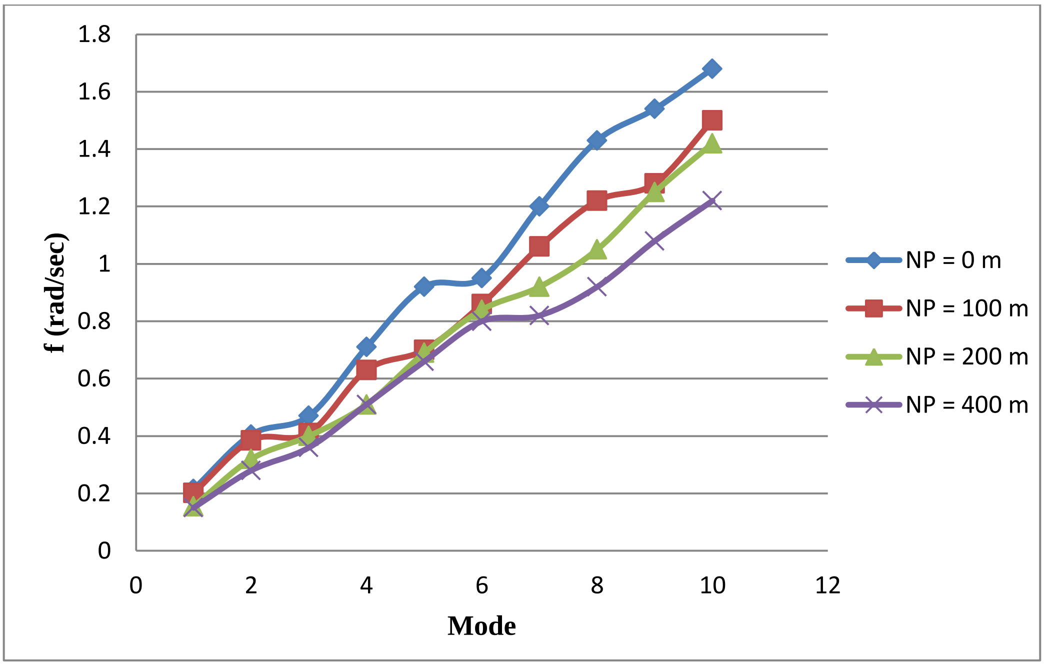


FIGURE 8. Simulation results for frequencies of first ten modes for different location of neutral point (NP)

4.2 K421 Drillstring

Simulation is run based on the data from Table 4 for each case study in ANSYS Workbench. Based on the result data, graphs were plotted using MATLAB software. Parametric study is done by running separate simulation for each case study under different parametric condition. As per highlighted in the objective of this project, the anticipated aim is to investigate the main parameters effect on drillstring dynamics. For Case Study 1, the effect of drillstring length was the chosen parameter to be studied and simulation was carried out. On the other hand, the effect of weight on bit (WOB) simulation was conducted for Case Study 2. Lastly, the third parameter added to this project is rotational speed and this was carried out for Case Study 3. All the simulation for all the case studies were analysed through modal frequencies and harmonic response.

4.2.1 Modal Analysis

The main aim of modal analysis is to specify lateral natural modes and frequencies of the drillstring. If there is external force acting at such frequencies, resonance will occur and hence the amplitude of lateral vibration will increase tremendously. This results the drillstring to hit on the wellbore wall and induces large impacts. The frequency of any external load must be far from the natural frequencies in order to avoid any destructive phenomenon.

4.2.2 Harmonic Analysis

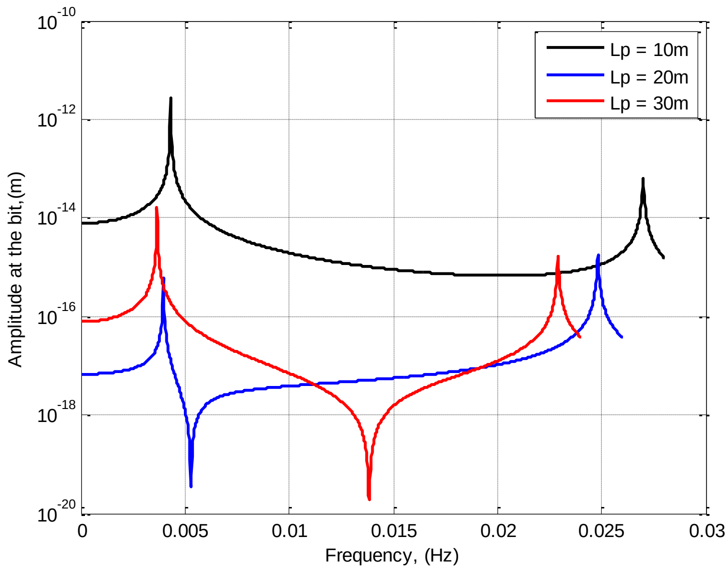
Harmonic analysis is performed to obtain the frequency response of the drillstring. The result of this analysis is depicted for the frequency versus amplitude for different length of drill pipe. The onset of resonance phenomenon is identified by appearance of spikes on harmonic plot. It will be then can be used to interpret which point of drill pipe length is subject to large impact force.

4.3 Effect of Drillstring Length

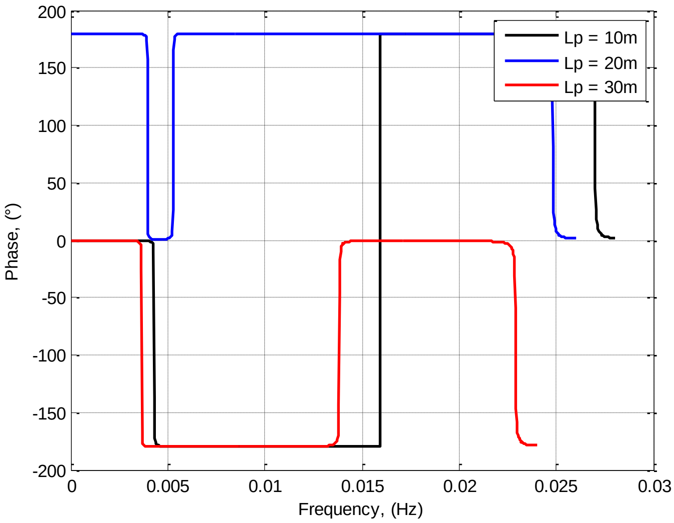
The drillstring length is manipulated by using different length of drill pipe in order to execute simulation for Case Study 1. The range of drill pipe length used are minimum *(10m, 20m, 30m)*, medium *(110m, 120m, 130m)* and maximum *(210m, 220m, 232m)* range. The following results are generated based on modal and harmonic response simulation:

TABLE 5. Minimum Pipe Length (Lp= 10m, 20m, 30m)

Mode	Natural Frequency (Hz)
1	4.3073e-003
2	4.3073e-003
3	2.6993e-003
4	2.6993e-003



(a)



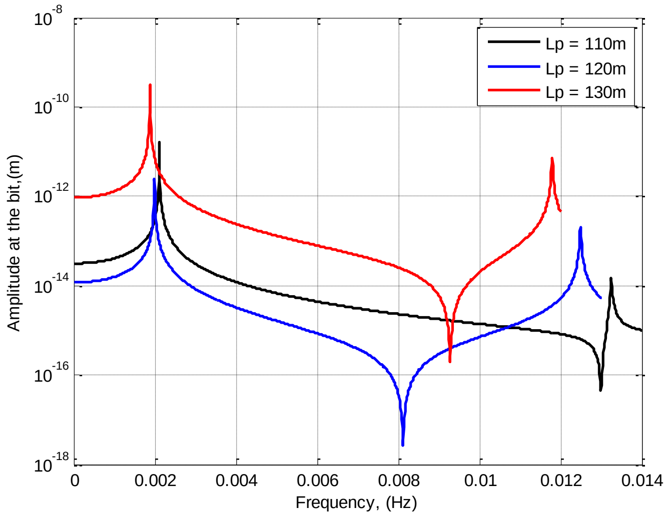
(b)

FIGURE 9. (a) Amplitude Response Graph for Minimum Pipe Length

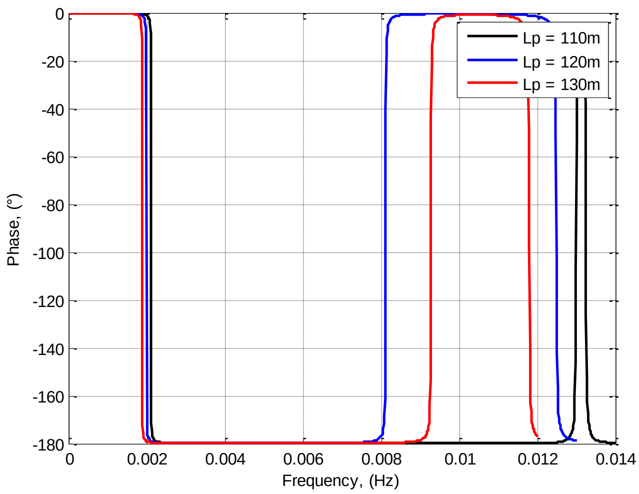
(b) Phase Plot Graph for Minimum Pipe Length

TABLE 6. Medium Pipe Length (Lp = 110m, 120m, 130m)

Mode	**Natural Frequency (Hz)**
1	1.882e-003
2	1.882e-003
3	1.1795e-002
4	1.1795e-002



(a)



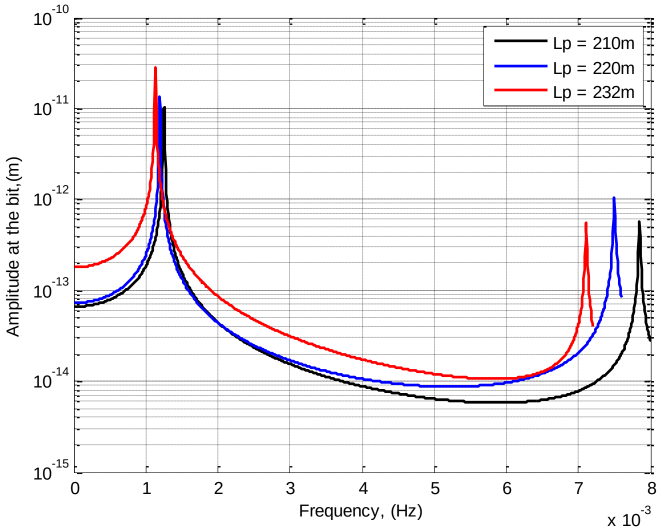
(b)

FIGURE 10. (a) Amplitude Response Graph for Medium Pipe Length

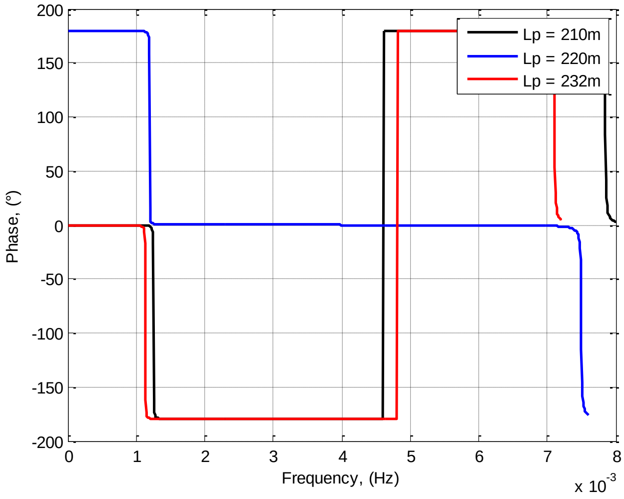
(b) Phase Plot Graph for Medium Pipe Length

TABLE 7. Maximum Pipe Length (Lp = 210m, 220m, 232m)

Mode	Natural Frequency (Hz)
1	1.1342e-003
2	1.1343e-003
3	7.1082e-003
4	7.1082e-003



(a)



(b)

FIGURE 11. (a) Amplitude Response Graph for Maximum Pipe Length

(b) Phase Plot Graph for Maximum Pipe Length

Based on the frequency response graphs above, it is observed that the minimum length of drill pipe (Lp= 10m, 20m, 30m) experiencing a higher initial natural frequency value which is about 0.004Hz. The initial natural frequency value is descending as the length of pipe range goes from medium to maximum range. At the maximum pipe length (Lp= 210m, 220m, 232m), the initial amplitude recorded to be the highest compared to other range of pipe length which is 2.0E-11m. Natural frequencies having the relative maximum amplitude is also known as the resonance frequencies.

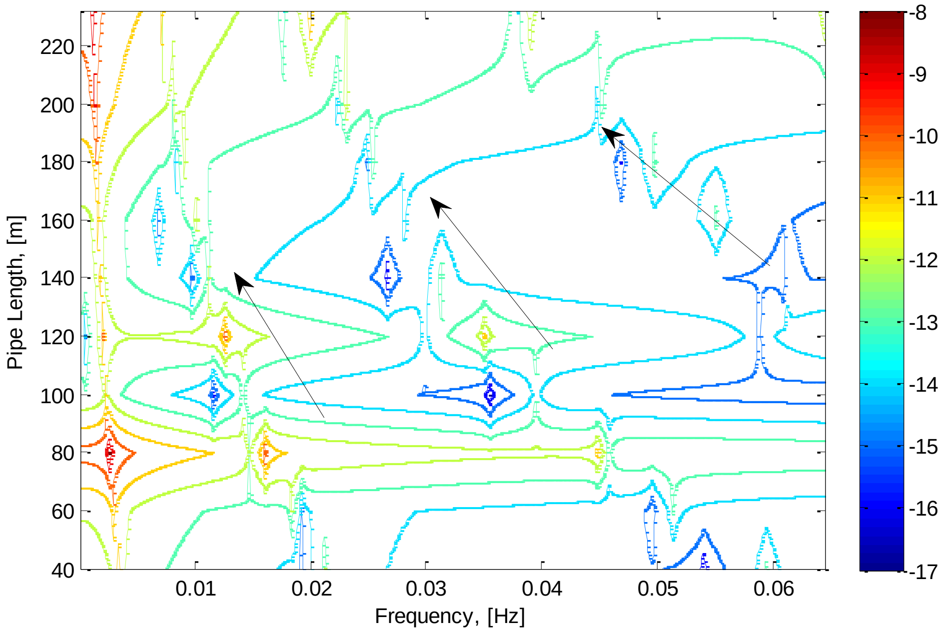


FIGURE 12. Contour Graph of Harmonic Analysis for Case Study 1

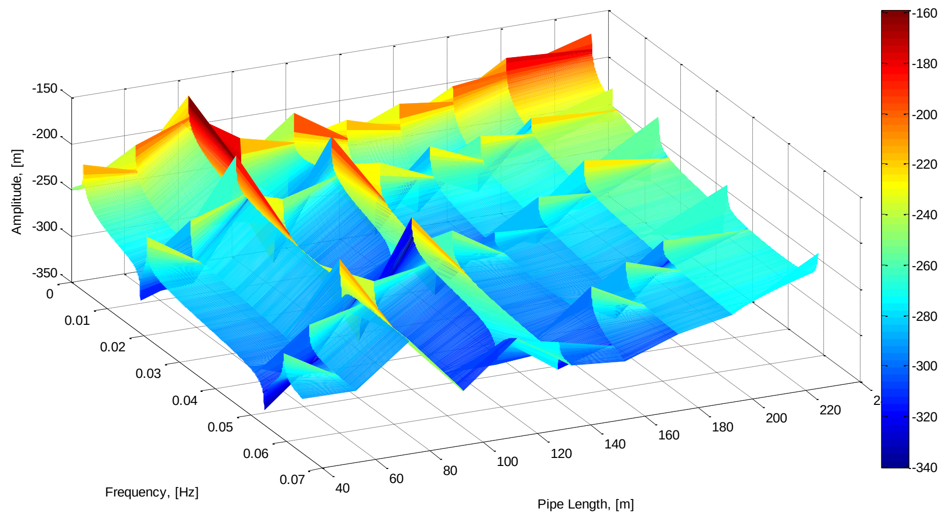


FIGURE 13. 3D Plot Graph of Harmonic Analysis for Case Study 1

Based on Figure 12, it is clearly shown that at the higher drill pipe length of 80m towards 200m and 220m, the amplitude had increased tremendously and resonance occur at those frequencies. The color scale indicates the severity of the resonance presence. Besides, it is also noticed that the trend of the resonance peak is moving in such direction shown by the arrows in Figure 12 which is moving towards left side. Figure 13 was generated to portray the harmonic response result as an alternative way which is 3D view to ease the understanding of the pattern and shape.

4.4 Effect of Weight on Bit

After running the simulation of case study, a new parameter is added to the model which is Weight on Bit (WOB). The WOB data was given by supervisor and these data came from a real oil field well. The exact case studies run on previous simulation were used for this parametric simulation using WOB. For each case, two graphs were generated that shows the relation of frequency versus amplitude and also frequency versus phase angle. To study and compare more in depth about this finite element model, different range of pipe length were selected; minimum length, medium length and maximum length of drill pipe for respective case. The following are the WOB data used for each case study:

TABLE 8. Weight on Bit Data

Case Study	**Weight On Bit (Newton)**
Case Study 1	11315.40
Case Study 2	34670.33
Case Study 3	70356.19

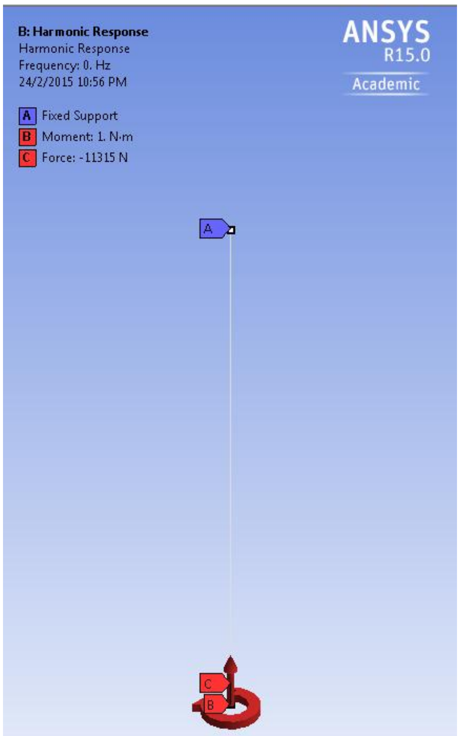


FIGURE 14. Model setup in ANSYS software

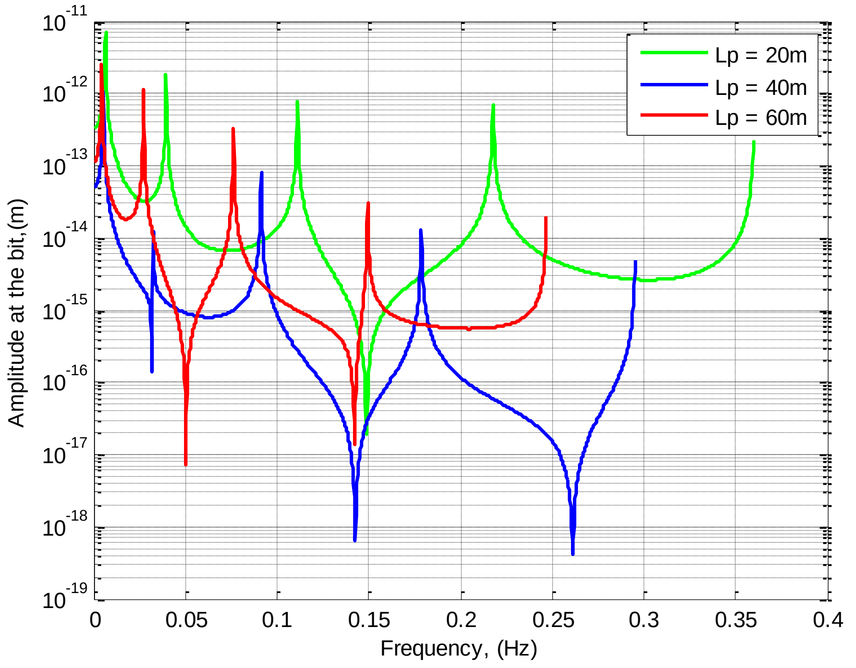


FIGURE 15. Harmonic response for Minimum Pipe Length (Lp = 20m, 40m, 60m)

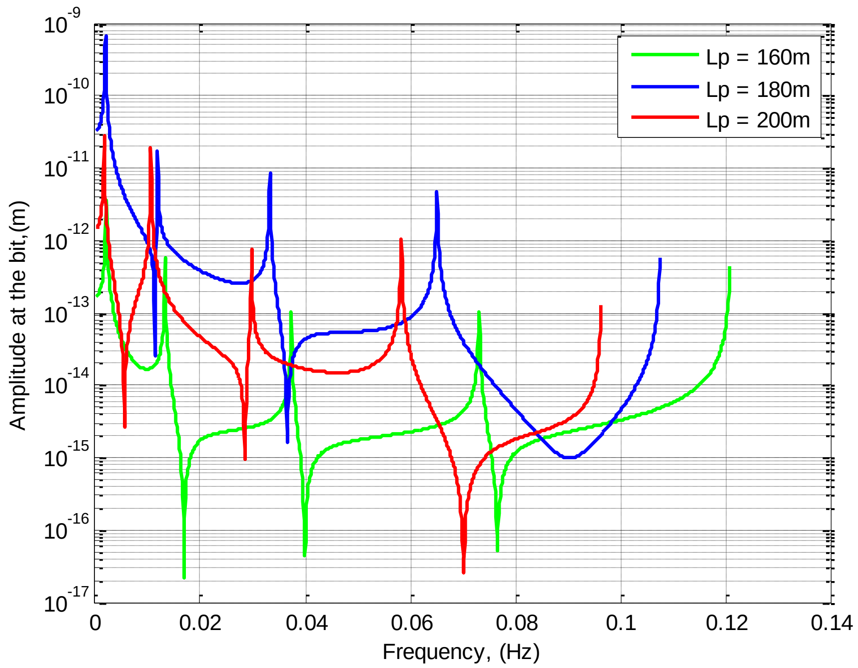


FIGURE 16. Harmonic response for Medium Pipe Length (Lp = 160m, 180m, 200m)

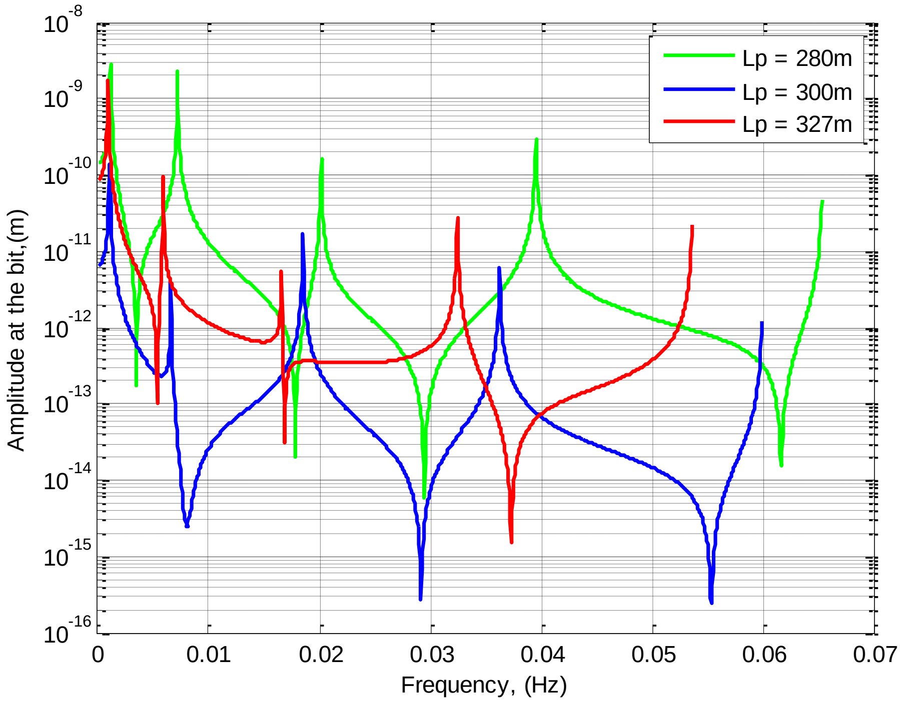


FIGURE 17. Harmonic Response for Maximum Pipe Length

(Lp = 280m, 300m, 327m)

This simulation shows the effect of different length of drill pipe with given respective weight on bit (WOB) on the vibration behaviour of a drillstring. As the length of drill pipe increases from minimum until maximum, the maximum amplitude peak also increases. The frequencies having high amplitude peak are also known as resonance frequencies. At this state of resonance frequency, the tendency for the drillstring to encounter damages will be high. Thus, these results of harmonic response act as a guide indicating the possible danger zone upon reaching a certain value of frequencies. Weight on bit is essential factor in drilling process, which can affect the rate of penetration as well as natural frequencies of the drillstring. It is obvious that in the presence of large amount of axial force, natural frequencies decrease in compression and increase in tension. As the WOB approaches the buckling load, the first natural frequency nears zero.

4.5 Effect of Rotational Speed

One of the most important parameter involved in drillstring dynamics is rotational speed. Three different rotational speeds are chosen which 400rpm, 800rpm and 1200rpm were used for a total of 10 modes in this simulation. The rotational speed factor is added to the simulation for Case Study 3 and results are shown below in Table 9.

TABLE 9. Data of Rotational Velocity versus Frequencies

Modes	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
f(Hz)	1.620 e-5	2.144 e-5	1.197 e-4	1.207 e-4	3.365 e-4	3.369 e-4	6.597 e-4	6.599 e-4	1.091 e-3	1.091 e-3
f(Hz)@ 400rpm	1.620 e-5	2.144 e-5	1.197 e-4	1.208 e-4	3.363 e-4	3.370 e-4	6.592 e-4	6.603 e-4	1.090 e-3	1.092 e-3
f(Hz)@ 800rpm	1.620 e-5	2.144 e-5	1.197 e-4	1.208 e-4	3.361 e-4	3.373 e-4	6.587 e-4	6.609 e-4	1.089 e-3	1.092 e-3
f(Hz)@ 1200rpm	1.620 e-5	2.144 e-5	1.196 e-4	1.209 e-4	3.358 e-4	3.376 e-4	6.582 e-4	6.614 e-4	1.088 e-3	1.093 e-2

Based on the Table 9, it is obvious that increasing the rotational speed of the drillstring increases the frequencies generated across the modes. Every lateral mode of the rotating drillstring produces two distinct modes which are forward mode and backward mode. Forward mode occurs when the frequency increases as the rotational speed increases while backward mode occurs when there is drop in the frequency as the rotational speed increases. It is observed in the table that at odd number modes, the frequencies decrease as the rotational speed increases. At even number modes, the frequencies increase along the increasing rotational speed. Hence, backward mode is experienced by all the odd number modes while forward mode occurs at all the even number modes.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This project has delivered a review of the literature associated with the drillstring dynamics which is the lateral vibration. There are some important conclusions that can be drawn.

- Drillstring dynamics need to be given proper attention and the study of it is necessary to achieve efficient and optimize drilling operation.
- The effect of weight on bit, drillstring length and rotational speed of drillstring are investigated by developing finite element model using ANSYS software simulation.
- Benchmark simulation is completed and simulations of case studies using real data from field were also completed.
- Modal analysis and harmonic response of the drillstring model to be given proper importance in understanding drillstring dynamics.
- When the drillstring rotation speed is increased, the backward bending natural frequencies decrease while the forward bending natural frequencies increases.
- As the length of the drillstring increases, the relative maximum amplitude also increases.
- The presence of weight on bit factor does affect the drillstring dynamics. On a given same length of drill pipe, if WOB is presence the recorded maximum amplitude will be high compared to absent WOB situation.
- The response for one pipe length is different from the response for another or different length. Hence, it is necessary to consider this effect during drilling process optimization.

5.1 Future Work

Several extension to this work can be done and are foreseen to be implemented in the future to develop a comprehensive dynamic model. The following are some suggested future works for improvement:

- Modelling drillstring of an inclined or horizontal well.
- Including drilling fluids in the model.
- Studying the contact impact between drillstring and borehole wall.

REFERENCES

[1] Ahmadian, H., Nazari, S., Jalali, H., 2007. Drill string vibration modelling including coupling effects. J. Mech. Eng. Sci. (IMechE, Vol. 18) No.3-4, 59-66.

[2] Christoforou, A.P., Yigit, A.S., 1997. Dynamic modelling of rotating drillstrings with borehole interactions. J. Sound Vibration, 206), 243-260.

[3] Ghasemloonia, A., Rideout, D.G., Butt, S.D., 2014. Analysis of multi-mode nonlinear coupled axial-transverse drillstring vibration in vibration assisted rotary drilling. J. Petrol. Sci. Eng. 116, 36-49.

[4] Hakimi, H., Moradi, S., 2009. Drillstring vibration analysis using differential quadraturemethod. J. Petrol. Sci. Eng. 70, 235-242.

[5] H. Al-Naser, (2002). *Finite element dynamic analysis of drillstring* (Master's Thesis). Retrieved from ProQuest Dissertations and Theses. (Accession Order No. UMI 1409810)

[6] Khulief, Y.A., Al-Sulaiman, F.A., Bashmal, S., 2008. Vibration analysis ofdrillstrings with string-borehole interaction. J. Mech. Eng. Sci. (IMechE, Part C) 222, 2099-2110.

[7] Leine, R.I., Van Campen, D.H., Keultjes, W.J.G., 2002. Stick-slip whirl interactionindrill-string dynamics. ASME J. Vib. Acoust. 124 (209), 209-220.

[8] Tucker, R.W., Wang, C., 1999. An integrated model for drill-string dynamics. J. Sound Vibration, 224(1), 123-165.

[9] Yigit, A.S. and A.P. Christoforou, 1998. Coupled torsional and bending vibrations of drillstrings subject to impact with friction. J. Sound Vibration, 215: 167-181.

[10] Zare, J., Hashemi, S.J., Rashed, G., 2011. Finite element analysis of drillstring lateralvibration. J. Eng. App. Sci., 6(1), 64-70.

APPENDICES

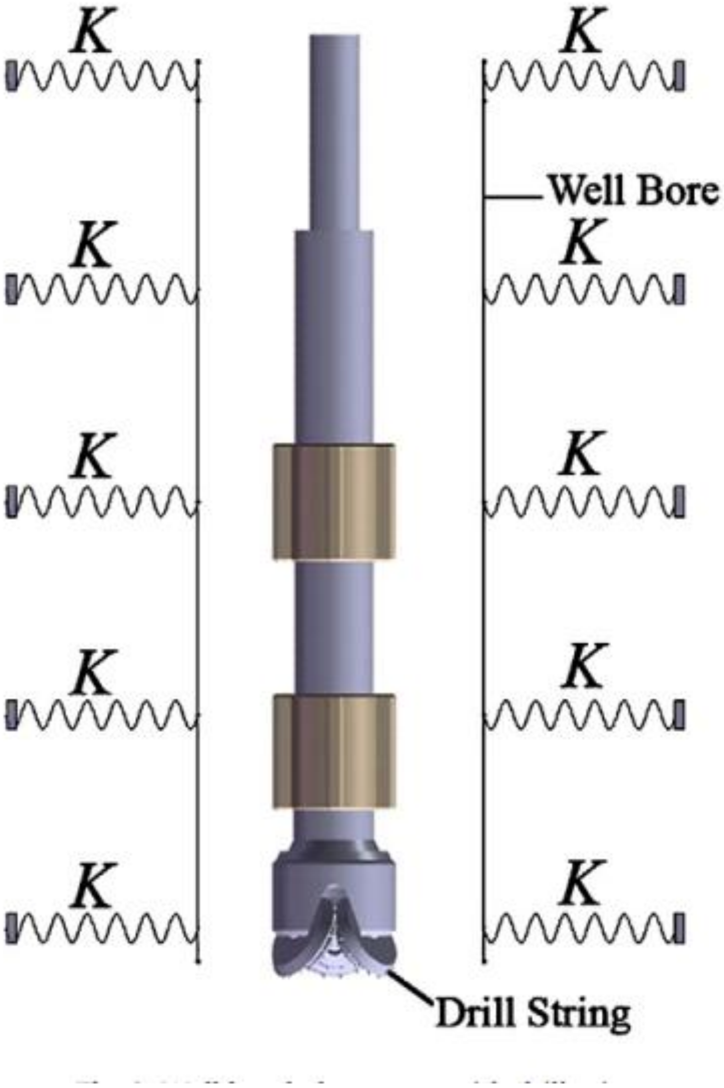


FIGURE 18. Well borehole contact with drillstring

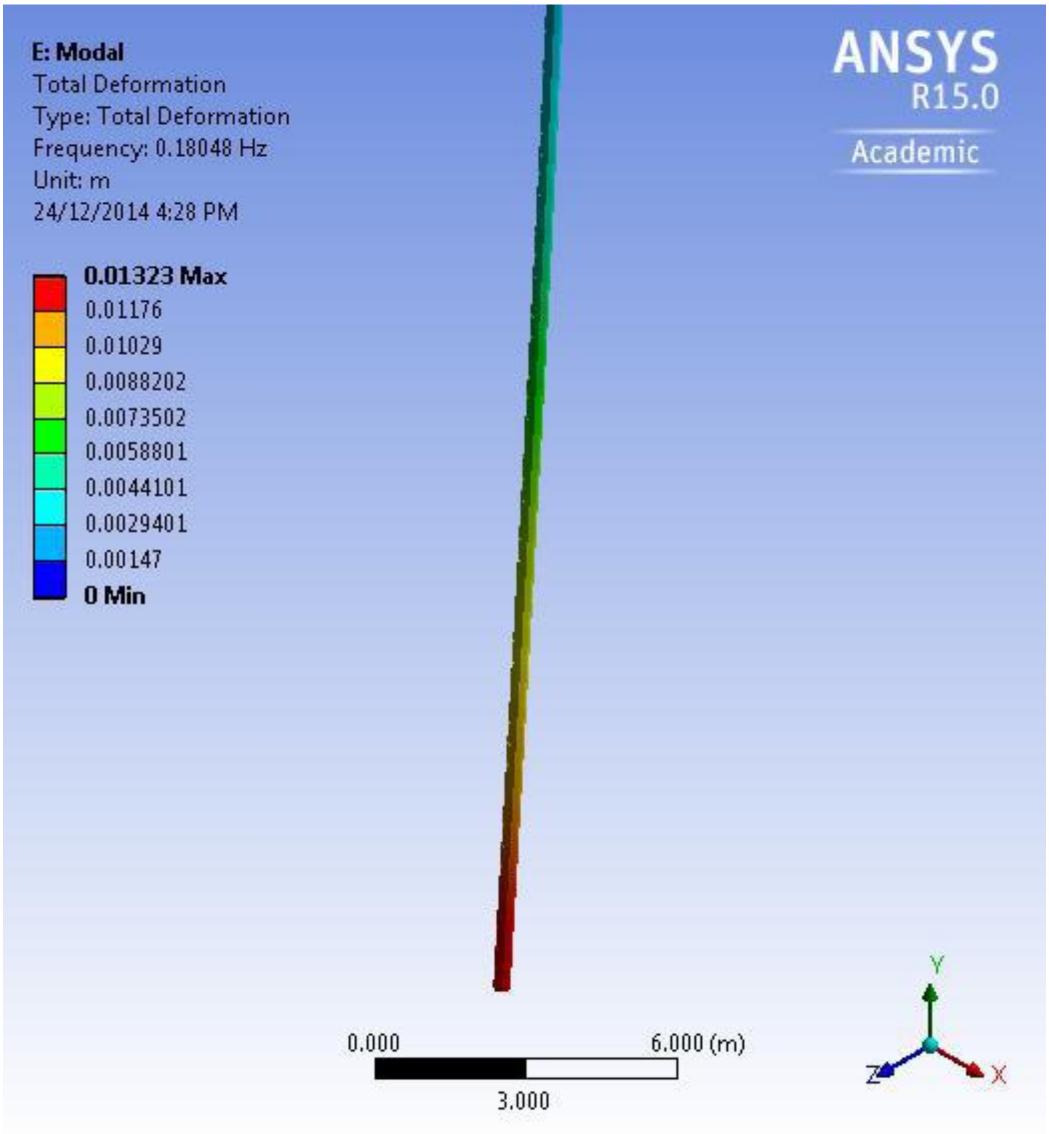
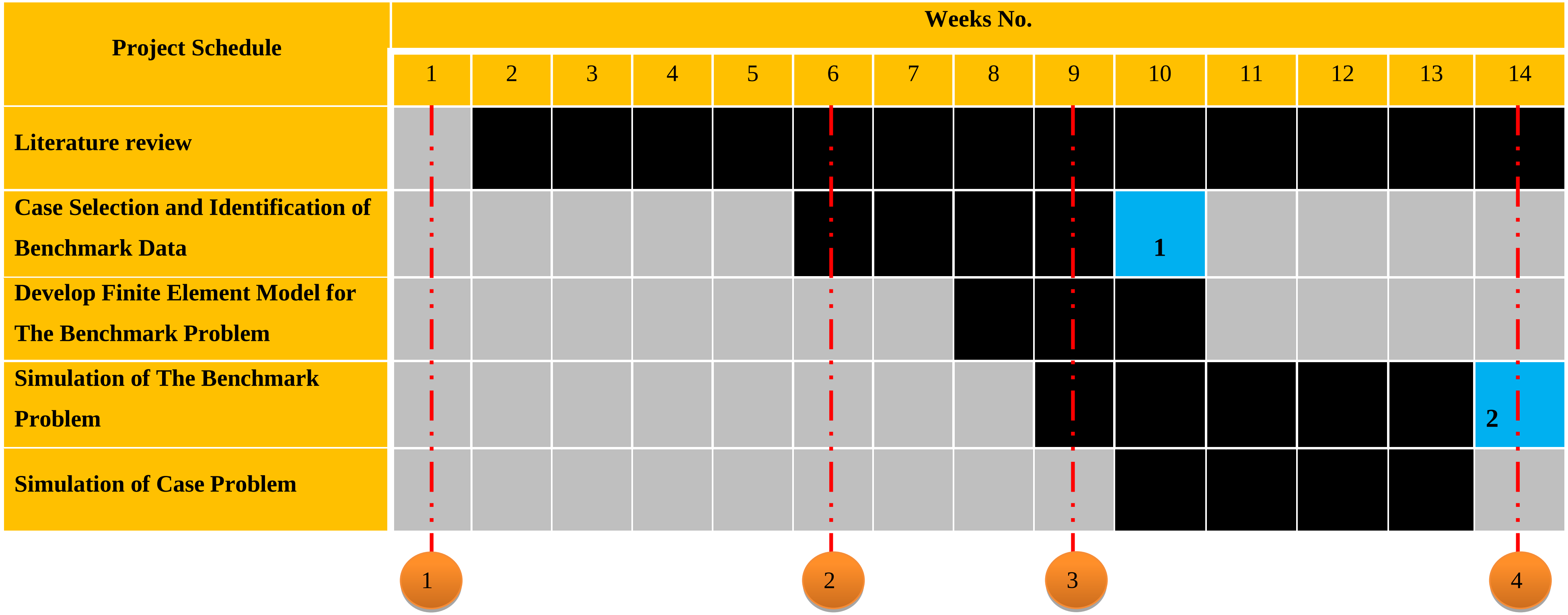


FIGURE 19. Total Deformation of Drillstring

Appendix A3: Gantt Chart and Key Milestone for FYP I



Project Milestones :

1. Completion of benchmark and case problem selection ; Date : (29/11/2014)
2. Completion of FEM and Simulation of the benchmark problem ; Date : (27/12/2014)

Course Related Expectations :

1 : Confirmation of Project Title

2 : Extended Proposal Submission

3 : Proposal Defence

4 : Interim Final Report Submission

Appendix A4: Gantt Chart and Key Milestone of FYP II

Activities/ No. of Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Parametric Study - Variation of string flexibility - Variation of contact stiffness - Variation of damping - Variation of WOB - Variation of rotation													1		
Further Analysis															
Report Writing															2
							1			2	3	4	5		6

1	Submission of Progress Report
2	Pre-SEDEX
3	Submission of Draft Final Report
4	Submission of Dissertation & Technical Paper
5	Viva
6	Submission of Project Dissertation (Hard Bound)

Project Milestones:

1. Completion of Parametric Study
2. Completion of Further Analysis and Report Writing