STUDY ON DYNAMICS OF PDC BIT ON MULTI-LAYERED FORMATIONS USING ANSYS – EXPLICIT DYNAMICS / AUTODYN

by

KIRSANTH A/L INDRAN

15048

Dissertation submitted in partial fulfillment

of the requirements for the

Bachelor of Engineering (Hons)

(Petroleum)

JANUARY 2015

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

____

(Dr Dereje Engida Woldemichael)

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

Kirsanth A/L Indran

Abstract

This project focuses on the performance of Polycrystalline Diamond Compact (PDC) drill bit in multi-layered formations. Research papers conclude that PDC bit in market go through difficulties in order to penetrate multi-layered formations. The performance of PDC drill bit dropped when used in multi-layered formations, especially when hard formations are present. In order to investigate the performance of PDC bit, simulations will be carried out using computer aided software, since conducting experiment is much more difficult and expensive. Therefore, the purpose of this project is to model and simulate PDC bit using ANSYS. Parametric analyses were done in order to get a better understanding regarding the performance of the bit. Throughout this project, three types of simulation were done. Firstly, the project is started by constructing a preliminary model of bit, formation and fluid. Successful simulation of preliminary model proved that Audodyn can be indeed used as a solver for this simulation. Next, the reverse engineered model of PDC bit was used for the simulation. Finally, a single cutter model was used to carry out further simulations. The results of this project were obtained by varying the rake angle of the cutter, as well as using different formations such as limestone, sandstone and dolomite. From the simulations, it can be concluded that cutter with 0° rake angle gives better penetration in hard formation, whereas cutter with 10° rake angle gives better performance in soft formation. In future, Autodyn can be used to analyze the effect of drilling fluid on PDC bit performance.

ACKNOWLEDGEMENT

Firstly, I would like this opportunity to thank all parties who have contributed and helped me in completing my Final Year Project for the past two semesters. I would like to dedicate special thanks to my project supervisor, Dr Dereje Engida Woldemichael, for his guidance and motivation throughout the completion of this project. Moreover, I would like to extend my appreciation to those who may have taught me voluntarily or involuntarily during my simulation process.

I would like to thank all the Y-UTP team members for the valuable information that were provided by them. Last but not least, a heartfelt gratitude to Universiti Teknologi PETRONAS for providing the platform for this project to be carried out.

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Abbreviations and Nomenclatures

3D	*Three Dimensional*
FYP	*Final Year Project*
PDC	*Polycrystalline Diamond Compact*
ROP	*Rate of Penetration*
UTP	*Universiti Teknologi Petronas*

CHAPTER 1

INTRODUCTION

1.1 Background of Study

A new petroleum reserve is found and later on extracted by the process of drilling. A drilling engineer should have all the understanding of engineering aspects and tools required to drill a hole at the lowest cost. It is the responsibility of the drilling engineer to make the drilling operation successful and as profitable as possible. (J.J. Azar & Samuel, 2007).

Drill bit is a tool used to drill a well and the success of drilling operation partly depends on performance of the drill bit. There are several types of drill bits available in the market, and the selection of drill bit depends on type of formation to be drilled. Some formation are categorized as soft, some are categorized as hard formation, and some are in between these two, called medium hard formations. The most challenging formation to be drilled is when formations are interbedded with hard stringers. Around 98% of hydrocarbon production is from a type of rock called sedimentary rock (Bowers, Heavysege, Hamzah, and Passey, 2004). Examples of this type of rock are sandstone and limestone.

Drill bit selection is a crucial process because it has the most impact on the total cost to drill a new well. Generally, two types of drill bit are widely used in the industry. There are roller cone bit and fixed cutter bit. In this project, the author will be studying on the dynamics of Polycrystalline Diamond Compact (PDC) bit on multi-layered formation.

1.2 Problem Statement

The selection of the most suitable drill cutters and the establishment of optimum set drilling criterion are crucial in drilling engineering. Although the cost of a drill bit might be ranging 0.7% to 3% of the total drilling costs, their performance in drilling the formation influences directly usage of rig time which, in its turn, may reach up to 30% of the total cost (Azar et al., 2002). Therefore, a bit with poor quality will take a longer time for drilling, thus prolonging the need of rig for that particular drilling process.

Modern PDC bits series are proven to be effective in hard and abrasive formation. However, case history shows PDC bits might encounter problems in drilling a troublesome multi-layer formation. One of the biggest problem faced by any PDC manufacturer in the current time is optimizing the usage PDC bit in hard rock drillings (Clayton, Chen, & Lefort, 2005). As a result, operators consume more money to completely drill in multi-layered formations. To overcome this problem, few designs and features of PDC bits have been altered so that they can effectively drill interbedded formations.

The author will like to study the effect of shown by PDC bit by varying the main parameters that determines the performance of PDC bit, such as type of formation, cutter angle, as well as drilling fluid effect. The preferred solver for this simulation will be Autodyn. Simulation using Autodyn will be a trial and error, as this solver has not been used in any research before.

1.3 Objectives

The objectives to be achieved in this project are:

1. To model and simulate Polycrystalline Diamond Compact (PDC) bit design using ANSYS – Explicit Dynamics.
2. To study the effect of multi-layered formations, rake angle as well as drilling fluid on the performance of PDC bit using Autodyn.

1.4 Scope of Study

The scope of study of this project will be focusing on the interaction between single PDC bit cutter with different formations, such as dolomite, sandstone and limestone. The drilling fluid will be specified to water.

The author would like to analyze the velocity of the bit as well as the pressure profile of the system in detail in this project.

1.5 The Relevancy of the Project

The present project is relevant especially to *Y-UTP* team. This *Y-UTP* team is currently working on a project entitled "Bit Wear and Vibration Study to Aid Drilling Optimization". This team consists of five academic staffs from *UTP*, two research collaborators from *UniKL* and a few final year students. The author's effort on completing this project might help *Y-UTP* team to achieve certain limit.

The project is also relevant to the author since it's involves a very comprehensive study on theory and the application. The theory and calculations used comprises of general petroleum and mechanical knowledge which can be applied in the oil and gas industry.

1.6 Feasibility of the Project within the Scope and Time Frame

The project is within the capability of a final year student to be executed with the help and guidance from the supervisor and the lab instructor. Drilling Engineering course is one of the compulsory subjects for a Petroleum Engineering student. Therefore, the author has the knowledge that can be useful for this project. The time frame is also feasible and the project can be completed within the time allocated.

1.7 Overview of the Thesis

This paper consists of five chapters in total. Chapter 1 is basically an Introduction for this project, mainly stating the problem statement and objectives of this project. Chapter 2 is Literature Review, which has a critical analysis cited from research papers. Moving on, Chapter 3 is about Methodology. Here, all the research methods and project activities are stated.

Chapter 4, Results and Discussion will be presenting all the results and findings by carrying out the proposed methods and activities. Finally, Chapter 5 concludes the entire project with relevant to the objectives, and suggesting some recommendations in case of future work.

CHAPTER 2
LITERATURE REVIEW

2.1 Development of PDC Drill Bit

The first fixed cutter bits, or also known as drag bits were started to be used around 1900 in rotary drilling. Since these bits have poor wear resistance, they were used to drill in shallow and soft formations. In 1973, after years of researching and experimentation, General Electric introduced *PDC* cutters, which have lead to the development of *PDC* bits. Since its introduction, PDC cutters and bits have undergone tremendous technological advances to improvise their performances. On earlier years, 2% of all drilling process used PDC bits. This number has increased to 15% by late 1980s, 45% by late 1990s, 50% in 2003. By 2010, 65% of all footage drilled in oil fields is done using PDC bits (Che, Han, Guo, & Ehmann, 2012).

The polycrystalline diamond compact, or simply known as PDC bit consists of a layer of diamond particles bonded with each other, and on the outer it is coated with a thicker layer of a tungsten carbide (Gouda et al., 2011). A drilling bit has the highest influence on the cost factor in any drilling operations. Therefore, in order to minimize the cost, the same PDC bit will be used to drill a particular formation as long as the PDC cutters are in great conditions. PDC bits are widely known for performing in soft and medium-hard non-abrasive formations. Examples of these types of formations are sandstone, siltstone and shale.

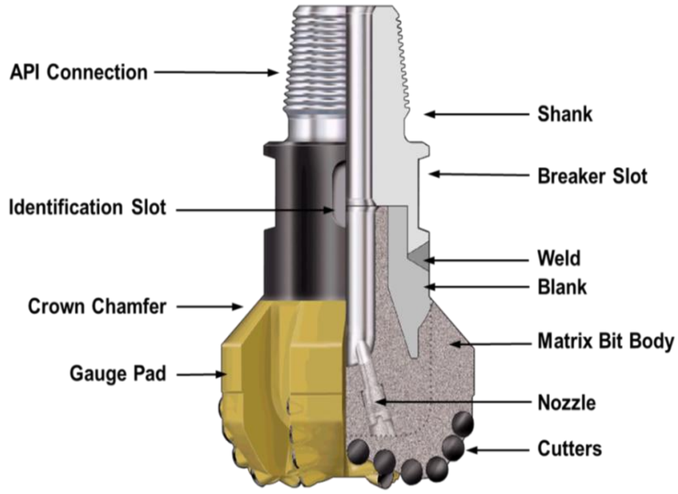

FIGURE 1. Component of PDC drill bits (Source from Schlumberger glossary)

2.2 PDC Bit in Multi-layer Formation

There are a few factors that affect the rate of penetration. One of them is the formation drilled. Different formations have their own type of strength and unconsolidated compressive strength value. In this research, simulation will be done on multi-layer formation. Multi-layer formation can be interpreted as formations interbedded with a different type of formation. An optimal bit type is required for different geological conditions, as this is one of the main factors that can increase technical and the economical drilling indicators (Kamatov, 2013). Extra caution has to be taken for multi-layer formations as these vary highly in mechanical properties such as strength and abrasivity. The problem will be magnified in cases when a soft formation is interbedded with hard formation. In Western South China Sea oilfields, interbedded stratums can be found abundantly in that area (Zhu et al., 2012). The stratums found here are mostly mudstones interbedded with shale and sandstone, with the unconsolidated compressive strength ranging from 50MPa to 120 MPa. In order to drill in a multi-layer formation, drilling companies have to use either roller cone or impregnated drill bits. These two types of bits provide compromised ROP and therefore increase the time as well as the drilling cost (Kamatov, 2013).

Drilling a multi-layer formation often involves few trips of pulling the bit out, and using a new bit to drill the well (Beaton et al., 2008). This happens because drill bits are easily worn out when penetrating a hard formation. Since the hard stringer are randomly scattered throughout the section, selecting the suitable bit to drill has become a difficult task for the drilling companies (Taylor et al., 1998). PDC bit might fail to perform well if its design and features are unsuitable to drill hard stringer. There are several factors that might contribute to catastrophic failure to the bit in hard stringers, such as the initial collision of the cutters as well as the increased vibration of the shoulder and also gauge cutters.

FIGURE 2. Condition of bit after drilling a multi-layer formation. Source from K., K. (2013, October). Hybrid Drill Bit For Horizontal Drilling In Highly Interbedded Formations Of Timano-Pechora Arctic Fields.

2.3 Drilling Fluids

The drilling fluid system, also known as the mud system, is the only component of well-construction process that remains in touch with the wellbore throughout the drilling operation. Due to differences in wellbore conditions, the fluids are designed in such way so that they can be used in any desired conditions.

These are some of the usage of a drilling fluid:

1. Pumps the cuttings to the surface, thus cleaning the wellbore.
2. Stabilizes formation pressures of wellbore in order to minimize the risk of issues such as kick.
3. Drilling fluid provides support to the wall of a well prior to casing and cementing.
4. Provides hydraulic horsepower to the bit to increase its impact force.

Drilling fluid is one of the factors that affect the rate of penetration (ROP). In drilling industry, ROP is defined as the speed at which the drill bit penetrates the formation or breaks the rock under it to increase the depth of borehole. By increasing the plastic viscosity of the drilling fluid, rate of penetration as well as the normalized rate of penetration is decreased (Paiaman et al., 2009). The penetration rate can be decreased by increasing the mud weight. Lower penetration rate is desired in any drilling process as it means less time is taken to drill, thus minimizing the usage of drill bit (Hemphill and Clark, 1994).

The type of drilling fluid used also showed effect on the ROP of drill bit. Increased ROP, together with reduction in torque and drag are observed when oil-emulsion mud is used as the drilling fluid. This happens because of the mud's lubricating properties. Apart from this, some experiments have shown that under hydraulically limited conditions, the effective bit hydraulics can be greatly enhanced by lowering the viscosity as well as the Reynolds number of the drilling fluid used (Beck and Alaska, 1995).

Due to the frictional force, the drill bits tend to get worn out after some time, thus increasing the time for drilling. Drill bits get affected from thermal wear and impact when drilling interbedded formations (Yahiaoui at al., 2012).

2.4 Finite Element Analysis (Explicit Dynamics)

Finite Element Analysis (FEA) is a computer model of a material or design that is analyzed to get specific results. It is used in existing or new product refinement. A company can verify a proposed design to meet client's specifications subject to manufacturing or construction. Modifying an existing product or structure is utilized to improve or qualify the product for a new service condition. If the model fails, FEA is very useful to help designer to modify back the design to meet the targeted condition. FEA help analyst to predict failure due to unknown stresses by showing problem areas on an object and giving chances for designers to see all of the theoretical stresses within. This method can help to reduce manufacturing costs and time rather than making and testing the real component (Szabo, 1991). Explicit Dynamics is one of the features in Finite Element Analysis. The ANSYS explicit dynamics product suite helps user to gain insight into the physics of short-duration events for products that undergo highly nonlinear, transient dynamic events.. With the ANSYS explicit dynamics products, the author can study how a structure responds when subjected to severe loadings.

2.5 ANSYS Autodyn

ANSYS Autodyn software is a versatile explicit analysis tool for modeling the nonlinear dynamics of solids, fluids, gases and their interactions. The product has been developed to provide advanced capabilities within a robust, easy-to-use software tool. Simulation projects can be completed with significantly less effort, less time and lower labor costs than with other explicit programs. This high productivity is a result of the easy-to-use, quick-to-learn, intuitive, interactive graphical interface implemented. Time and effort are saved in problem setup and analysis by automatic options to define contact, by coupling interfaces and by minimizing input requirements using safe logical defaults.

The solver technology in ANSYS Autodyn provides:

- Finite element solvers for computational structural dynamics (FE)
- Finite volume solvers for fast transient computational fluid dynamics (CFD)

- Mesh-free particle solvers for high velocities, large deformation and fragmentation (SPH)
- Multi-solver coupling for multiphysics solutions including coupling between FE, CFD and SPH
- A wide suite of material models incorporating constitutive response and coupled thermodynamics
- Serial and parallel computation on shared and distributed memory systems

2.6 Summary

PDC bit are the most used drill bit in the industry now. Although PDC bits have undergone several modifications since when they were introduced, their usage in multi-layered formation is still not satisfactory. Besides that, drilling fluid has an effect on the performance of PDC bit as well. Varying the properties of mud will have an effect on the rate of penetration of drill bit.

The next chapter will be discussing on the steps taken in this project to model and simulate PDC bit in different formations.

CHAPTER 3

METHODOLOGY

3.1 Project Flow Chart

The project is started by carrying out preliminary research on the topic from articles and research papers. As stated in literature review, the author focused researching on PDC bit itself first, followed by PDC bit performance in multi-layered formation, as well as drilling fluid. Once adequate amount of understanding is acquired regarding the topic, software will be used to carry out the rest of the project. A preliminary model with basic design of bit and formation will be constructed using Explicit dynamics. All the necessary parameters will be specified here. Once this is done, this model will be imported to another solver, called Autodyn. After that, simulations will be done using this model using Autodyn. The success of simulation using Autodyn will be crucial for this project, as this determines whether Autodyn will be a suitable solver for this project.

If simulation in Autodyn is proven successful, further simulations will be done to have a better understanding on the performance of PDC bit in multi-layered formation. For this purpose, a reverse engineered model of PDC bit will be used to run the simulation, replacing the preliminary model done earlier. Another parametric analysis will be simulating the PDC bit in the presence of drilling fluid. All these simulations will be solved using Autodyn. From here, the results for bit performances can be generated in order to be discussed later on.

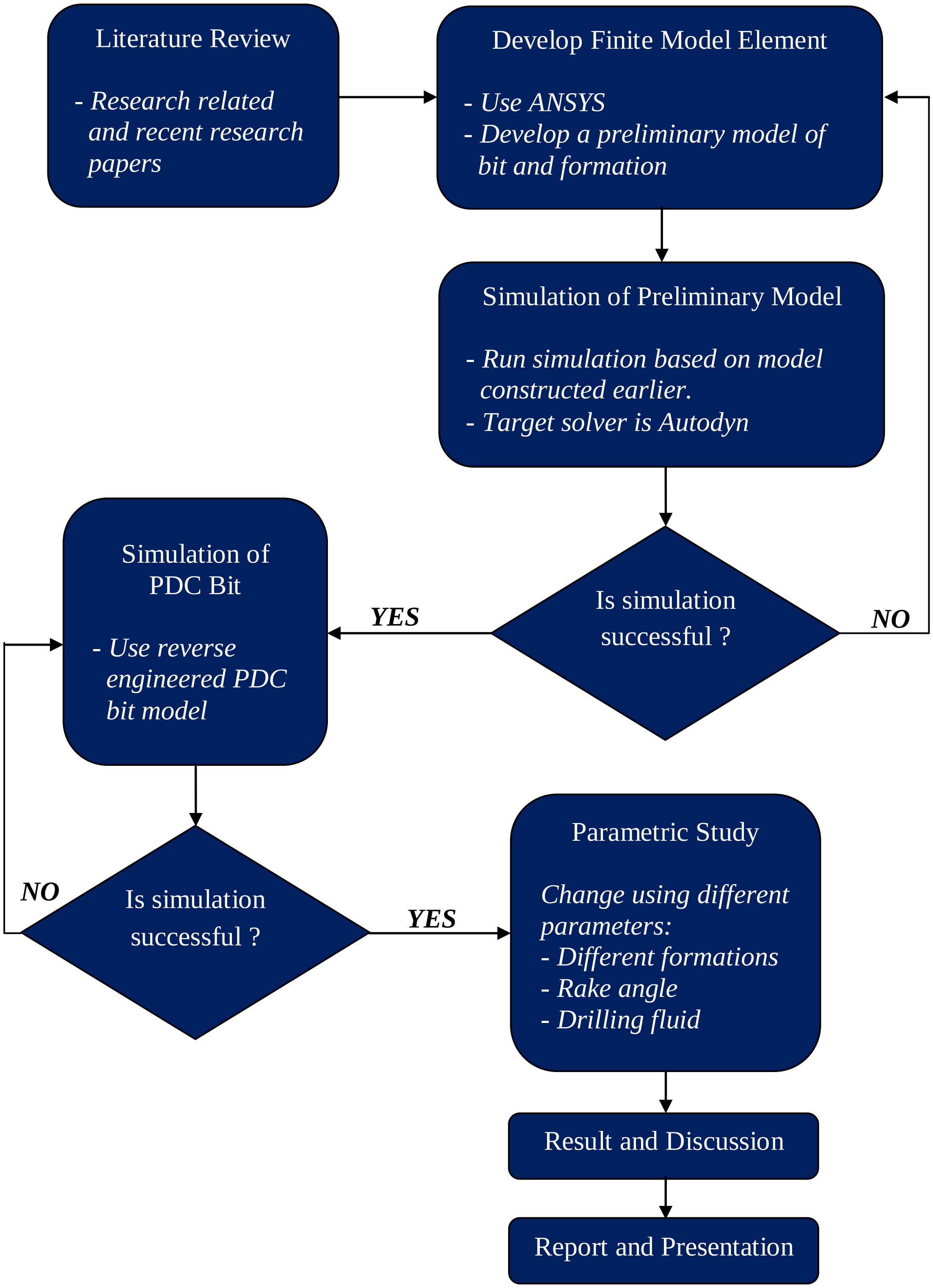

FIGURE 3. Project Flow Chart

3.2 Development of Model

3.2.1 Preliminary Model

In order to get familiarize with the software, a preliminary model is constructed, and later run for simulation. This preliminary model basically consists of just a cylinder, which represents a bit, and another slimmer cylinder which represents the formation itself. There are few steps involved in setting up the model, which are explained as follows.

Step 1: Setting up Engineering Data

Explicit Dynamics is usually used to study or simulate cases such as drop tests, impact between colliding objects and penetration. Here, the materials are selected and imported in order to fill in the parts later on.

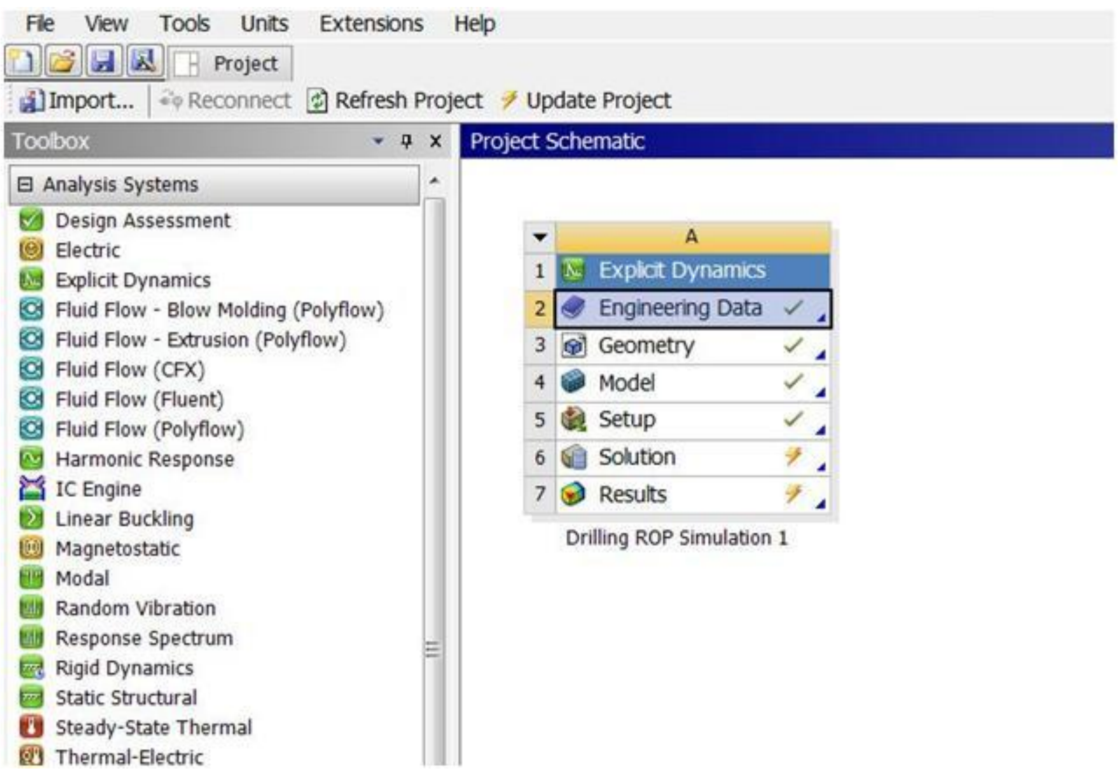

FIGURE 4. Explicit Dynamics component analysis

The materials and its properties for the component that are to be used in the analysis are defined in engineering data. The table shown below is the materials used and its properties for the purpose of this simulation.

TABLE 1. Material Properties

	Material	Properties
Cutter	Polycrystalline Diamond Compact	Density: 3250 kg m^-3 Young's Modulus: 1.5231E+08 Poisson's Ratio: 0.38462 Bulk Modulus: 2.2E+08 Shear Modulus: 5.5E+08
Bit body	Tungsten Carbide	Density: 19300 kg m^-3 Young's Modulus: 3.968E+11 Poisson's Ratio: 0.24 Bulk Modulus: 2.5436E+11 Shear Modulus: 1.6E+11
Rock formation 1	Limestone	Density: 1580kg m^-3 Young's Modulus: 3.2034E+09 Poisson's Ratio: 0.14407 Bulk Modulus: 1.5E+09 Shear Modulus: 1.4E+09
Rock formation 2	Sandstone	Density: 2650kg m^-3 Young's Modulus: 1.8456E+08 Poisson's Ratio: 0.2 Bulk Modulus: 1.0253E+08 Shear Modulus: 7.69E+07
Rock formation 3	Dolomite	Density: 2872 kg m^-3 Young's Modulus: 1.1657E+11 Poisson's Ratio: 0.29527 Bulk Modulus: 9.49E+10 Shear Modulus: 4.5E+10

Step 2: Importing Geometry from CATIA

All the drawings for this project are done in CATIA mechanical part design. These drawings will be saved to .stp file type so that they can be imported to ANSYS, as ANSYS only accepts drawings in this particular format. Next up, the material for each parts, coordinate systems, meshing, the initial conditions are defined in ANSYS Workbench Mechanical.

Step 3: Coordinate System

In this project, three coordinate systems were set-up under coordinates. These are Global coordinate system, Coordinate system 1 and Coordinate system 2. Global coordinate system has an ID of 0, and its coordinates are (0,0,0). These values cannot be changed by user. Coordinate system 1 is set for the cylindrical representing bit, or in further simulation the PDC bit itself. The Y-axis is set as rotating axis, in clockwise direction indicating positive rotation, while X-axis and Z-axis values are the same as global coordinate system. The final coordinate system, Coordinate system 2 is set at the point of load on top formation. Figure below depicts all the coordinate systems set on a simulation using PDC bit.

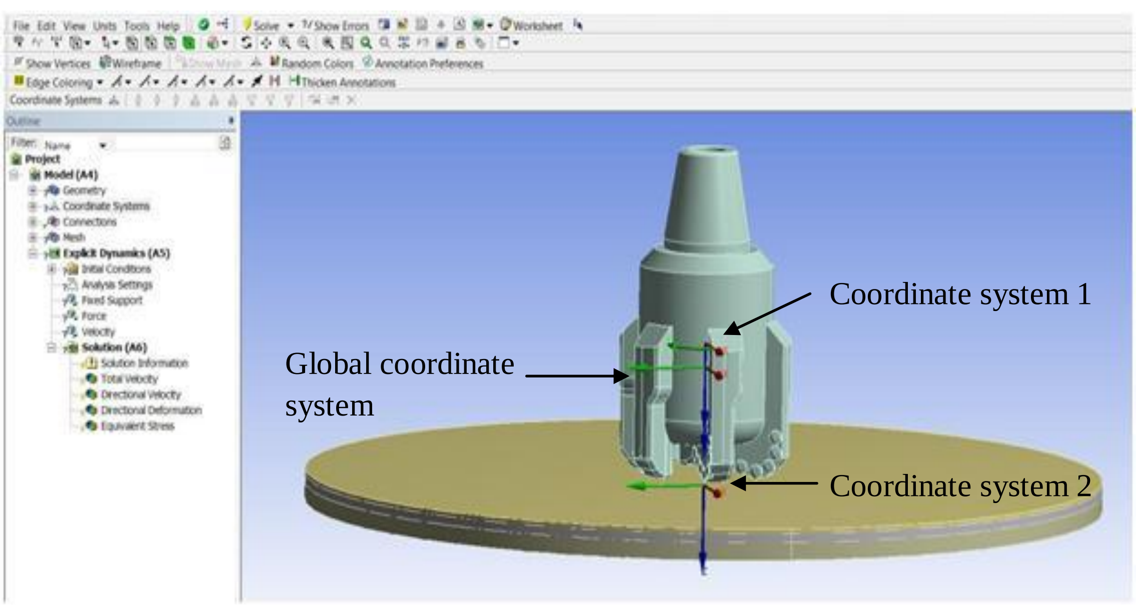

FIGURE 5. Coordinate systems

Step 4: Meshing

One of the crucial aspects in engineering simulation is meshing. Meshing is an integral part of the computer-aided engineering simulation process. Meshing has a huge influence on the simulation itself, such as the accuracy, convergence and also the duration of simulation. For this project, the meshing settings and pattern are shown below.

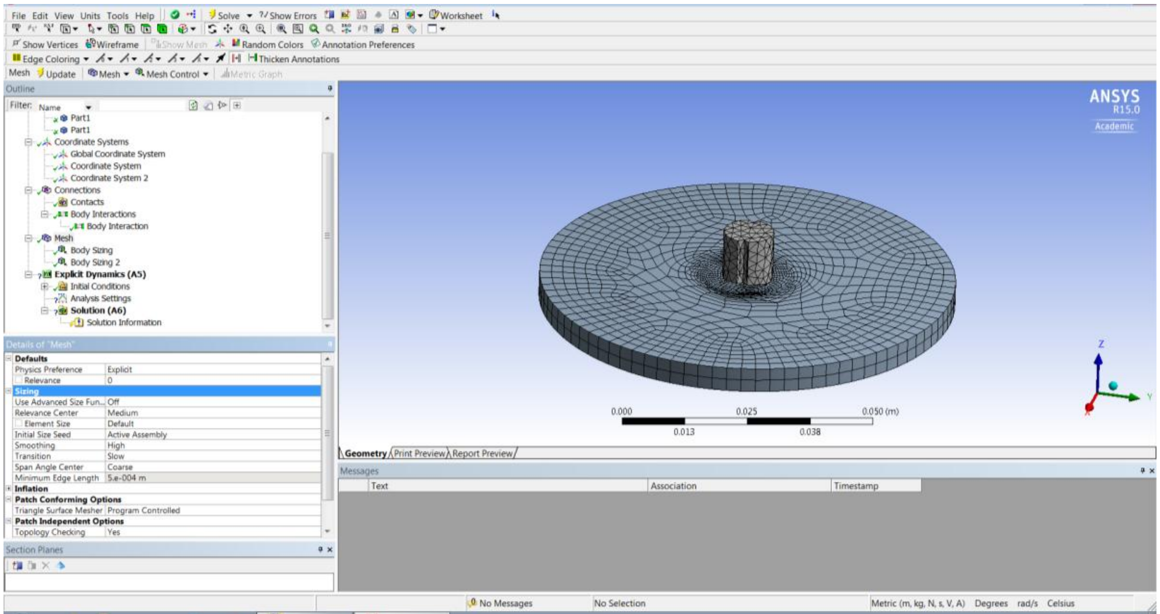

FIGURE 6. Preliminary Model meshing

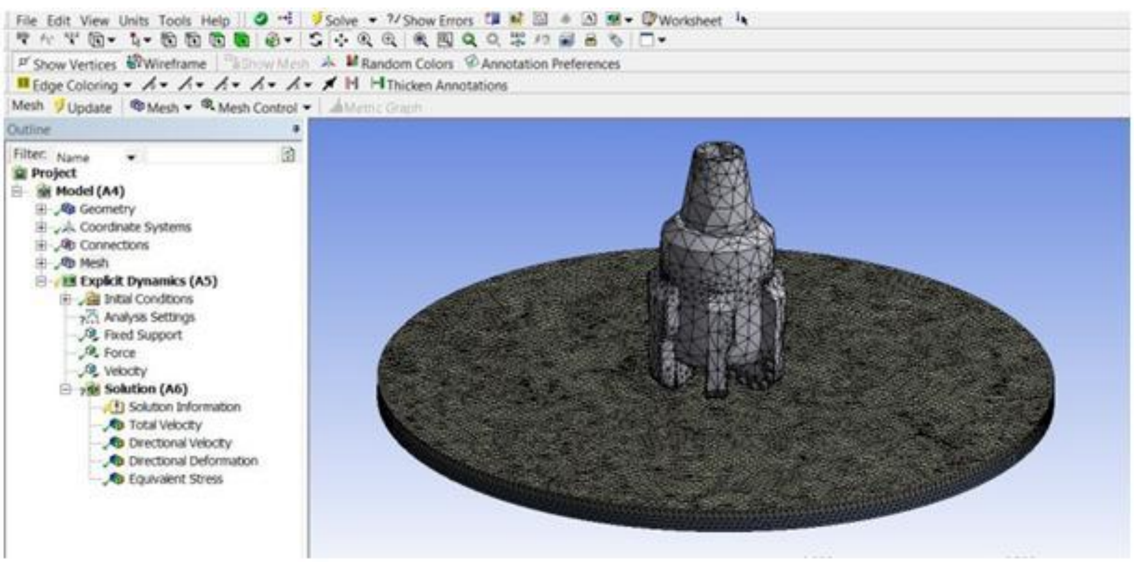

FIGURE 7. PDC Bit Model meshing

Step 5: Initial Conditioning

In order to solve this simulation in Autodyn, at least one initial condition has to be set up in Explicit dynamics. Basically, there are three initial conditions set for this preliminary model before importing the setup to Autodyn. The initial conditions are angular velocity, force and fixed support.

The angular velocity set here is basically the revolutions per minute (RPM) of the bit itself. All drilling bits have certain RPM that are set by the person in charge in order to drill a certain formation. In this project, the angular velocity is set at 100 RPM as an initial condition.

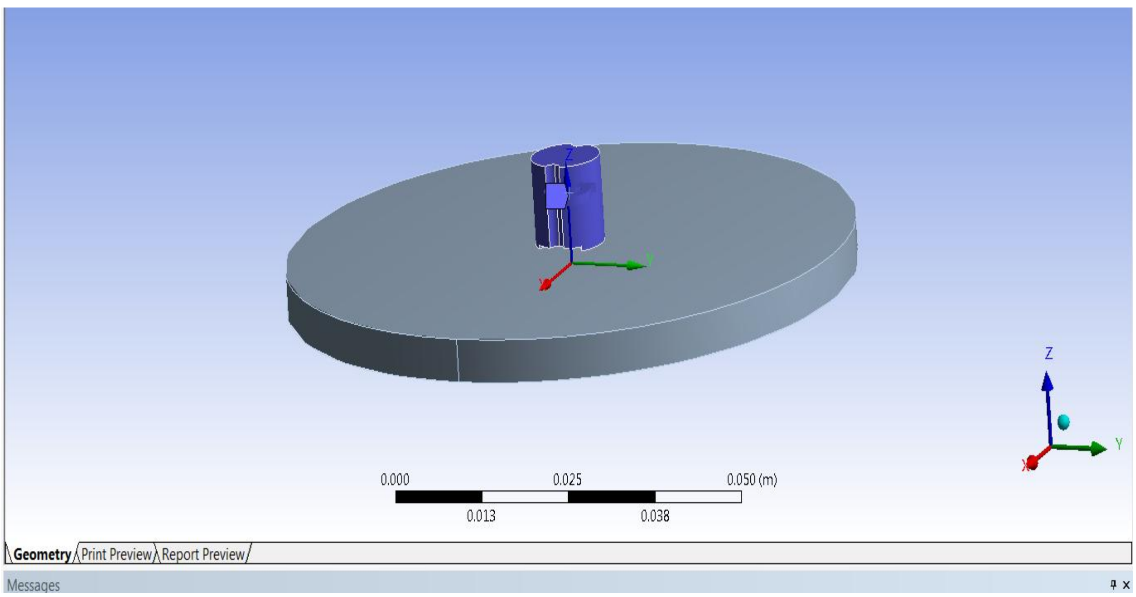

FIGURE 8. Angular Velocity on Preliminary Model

The second initial condition set on this model is Force. The Force here is actually the weight on bit (WOB) acting on the bit. In real drilling situation, WOB is actually the weight of the drill pipe up until the surface. This force helps the push the bit downwards in order to penetrate formations. In these simulations, the WOB is set as 100 000 N.

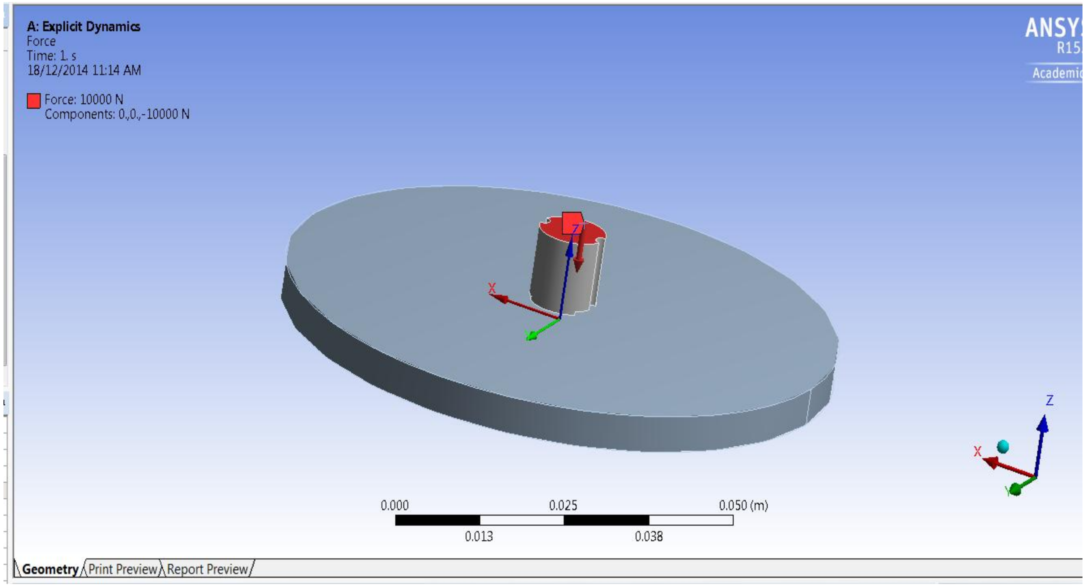

FIGURE 9. Force acting on Preliminary Model

The final initial condition set here is fixed support. Fixed support is set for the outer part of the formations. This is done so that the formations will not move in any direction when the impact is transferred from the bit to the formation.

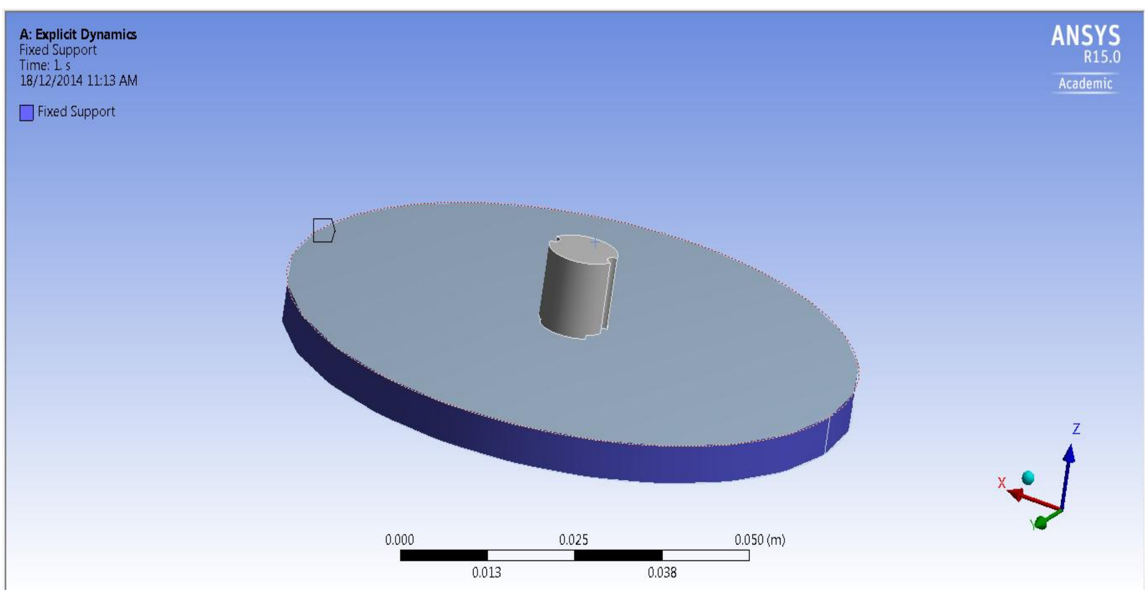

FIGURE 10. Fixed support on Preliminary Model

3.2.2 Simulation of Preliminary Model

After all the initial conditions have been set on Explicit dynamics, the setup is imported to Autodyn. It is in Autodyn where the simulation will be solved.

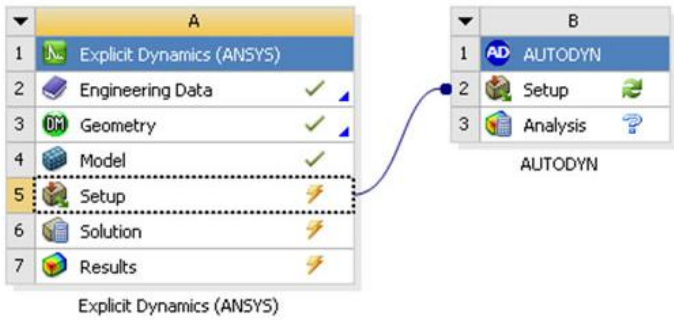

FIGURE 11. Audodyn Setup

Two different models are created under Preliminary phase; Case 1 and Case 2. Case 1 consists of only bit and formation, while Case 2 includes water as the drilling fluid, contained in the same cylinder as the bit. The setup model and the results are shown below.

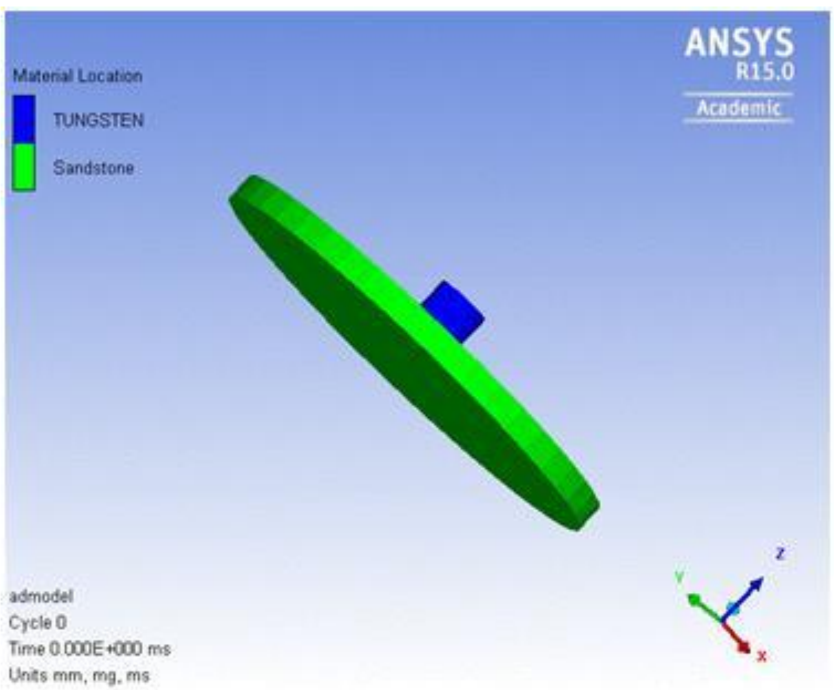

FIGURE 12. Preliminary Model – Case 1

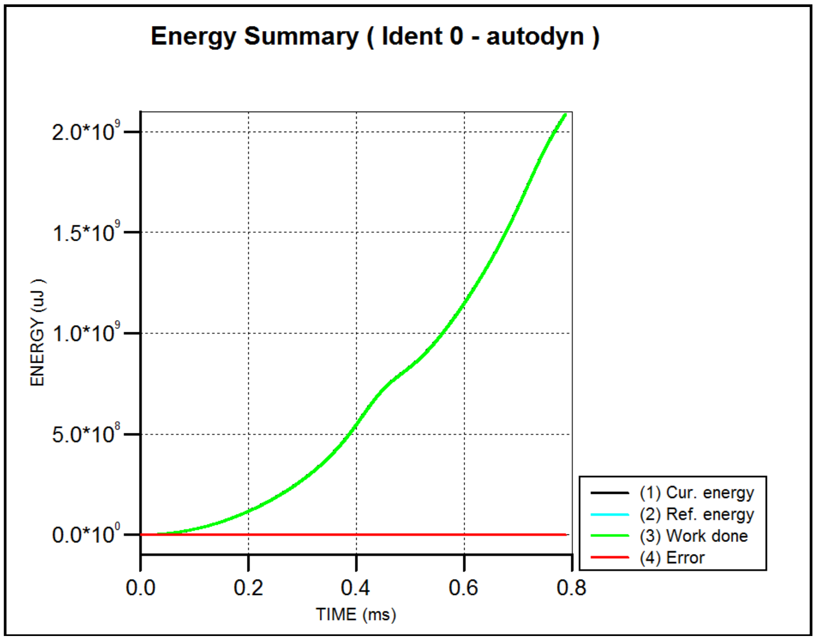

FIGURE 13. Energy Summary for Preliminary Model – Case 1

The main significant of this graph is to show the percentage of error in this simulation, as this indicates whether the simulation is successful or not. Based on the graph above, the error is 0, therefore this simulation is considered successful with no error.

The model setup and energy summary for Case 2 are displayed below.

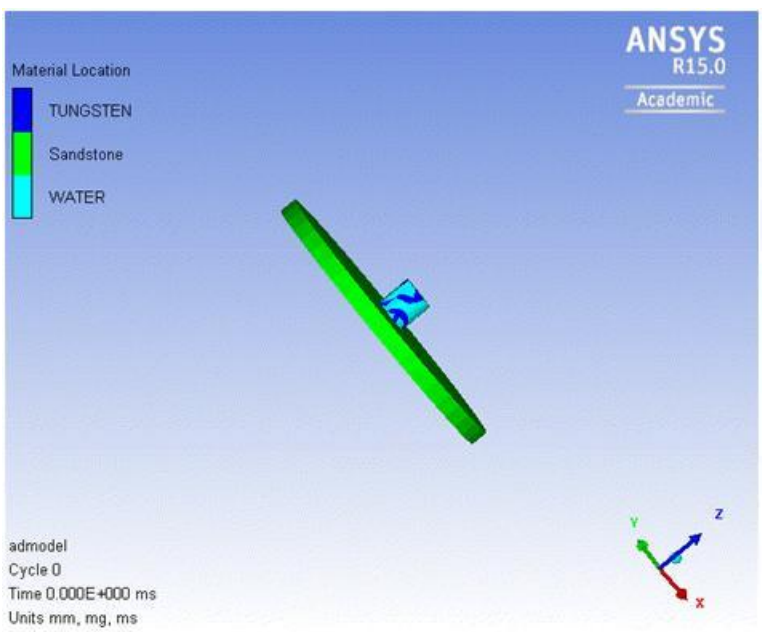

FIGURE 14. Preliminary Model – Case 2

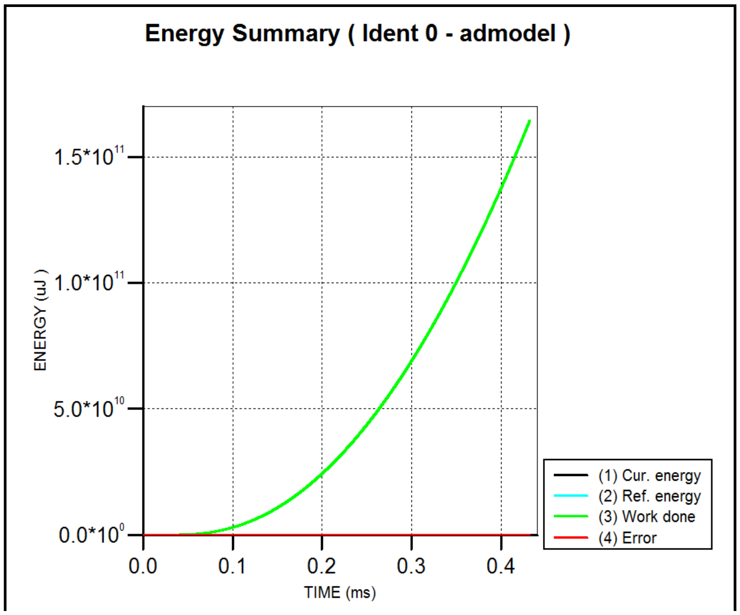

FIGURE 15. Energy Summary for Preliminary Model – Case 2

As shown in Figure 12, the model includes water, which is included in the bit itself. The same pattern of energy summary can be noticed for Case 2 too. The error in this simulation is 0 as well, confirming the simulation is successful. However, more energy is required when a fluid is introduced into the simulation.

The success of these two cases proves that Autodyn can be used in order to simulate two objects colliding, possibly with the involvement of fluid too. This basis is very important, as coming simulations will be more complicated than preliminary model.

3.2.3 Simulation of PDC Bit

For this simulation, the cylinder representing bit will be replaced with actual design of PDC bit. The design is obtained by reverse engineering a real PDC bit, and converting the model into a 3D model.

FIGURE 16. Model of PDC Bit in assembly design

Basically, the steps explained in Preliminary Model part (Step 1 to Step 5) are done again for this model. The only difference is the design of bit. Next, the setup will be transferred to Autodyn for simulation.

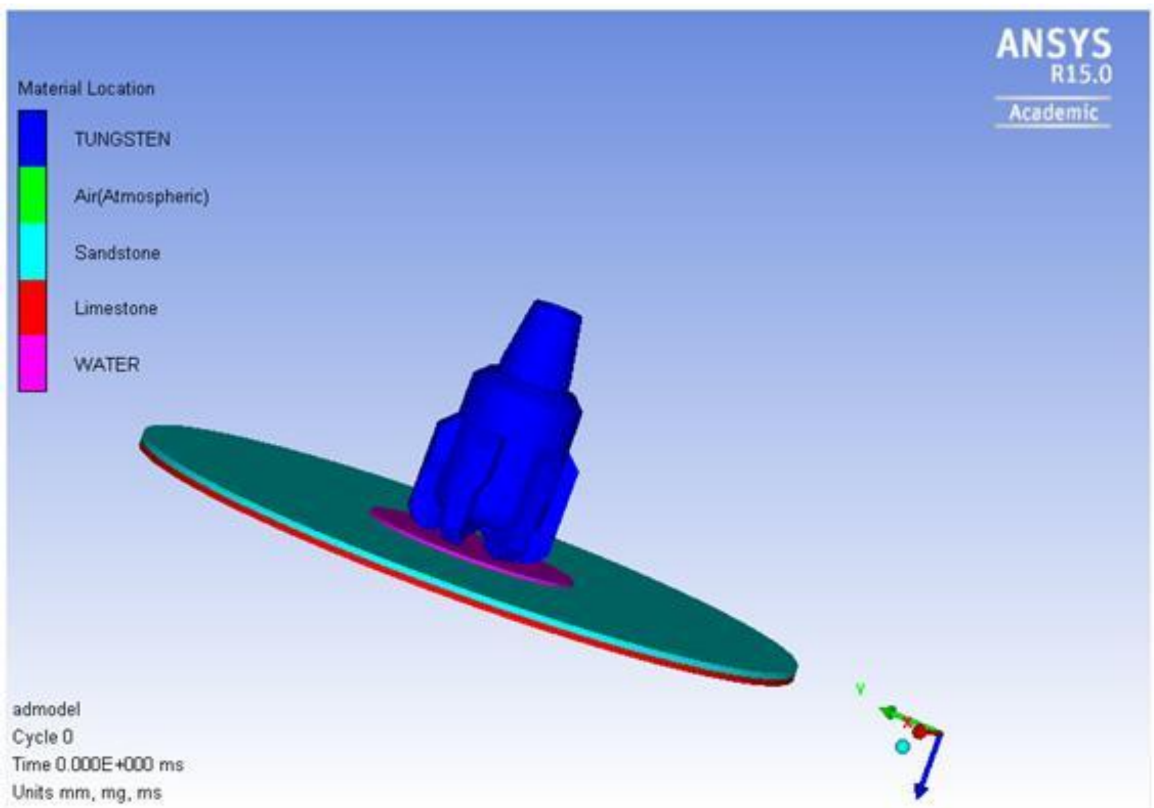

FIGURE 17. PDC Bit simulation

One example of simulation done using PDC bit is illustrated at Figure 15. In this simulation, the formations chosen are sandstone and limestone. Water is set in a static cylindrical form for this simulation. This is done in order to simplify the model itself. Simulating a flowing fluid will require more time, and are planned to done after the success of this simulation.

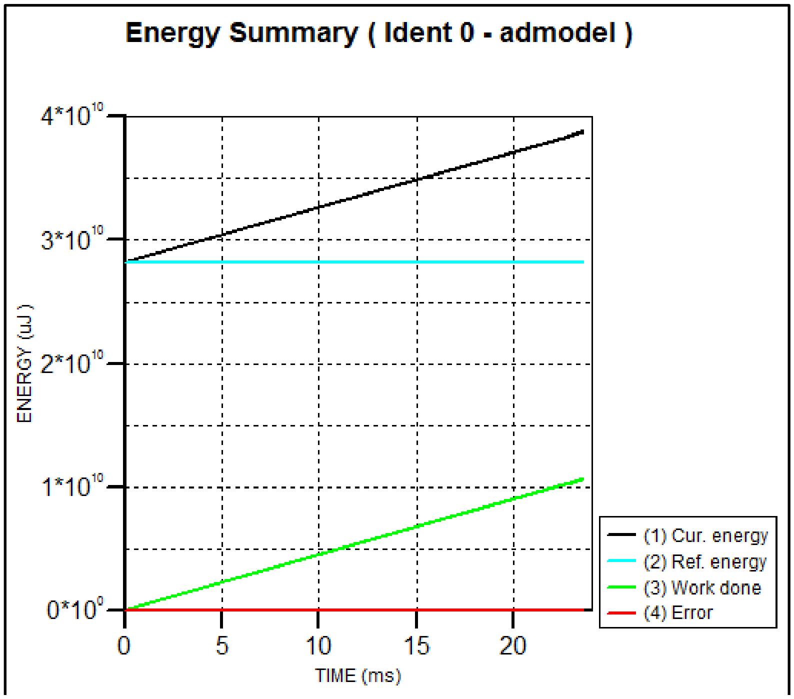

FIGURE 18. Energy summary for PDC Bit simulation

The graph above shows the energy summary for the above simulation. The error value is zero again, meaning the simulation is a success. However, a major drawback of this simulation is that it takes an extremely long duration to complete its simulation. One simulation has taken around two weeks to be completed. Therefore, in order to stick with the timeline given, the model has been simplified for further parametric analysis.

3.2.4 Simulation of Single Cutter

In this project, there are few criteria that have been chosen to investigate in order to further analyze the performance of PDC bit in multi-layered formation. Mainly, since the main objective of this project is to simulate the bit in multi-layered formation, all the formation used for simulations here after will be multi-layered, meaning containing two different types of formations. There are three sets of formations used in this simulation to illustrate the real pattern of formation. All the formations are classified as such based on its properties listed in Engineering Data section.

- Set 1: Limestone *(soft formation)* + Sandstone *(hard formation)*
- Set 2: Dolomite *(hard formation)* + Limestone *(soft formation)*
- Set 3: Sandstone *(hard formation)* + Dolomite *(hard formation)*

The next parameter that will be varied is the rake angle of the cutter. Rake angle can be defined as the amount that a cutter in a bit is tilted in the direction of bit rotation. This is one of the factors in determining the aggressiveness as well as the depth of cut. However, in this project, the effect of rake angle on different formations will be investigated generally, without any concern of depth of cut.

Since the reverse engineering PDC bit takes a long time to simulate, the PDC bit has been simplified to a simpler model to minimize the time usage for simulation. For these following cases, a basic cylindrical model similar to preliminary model is assumed as the bit, constructed with almost the same volume as PDC bit. However, one major change here will be the addition of a single cutter at the bottom of cylinder. This cutter will have either a rake angle of 0° or 10°.

Therefore, for each rake angle of cutter, there will be three sets of data, comprising the simulation done in three different multi-layer formations. The results will be discussed in the following chapter.

The figure below illustrate bit model with 0° and 10° rake angle.

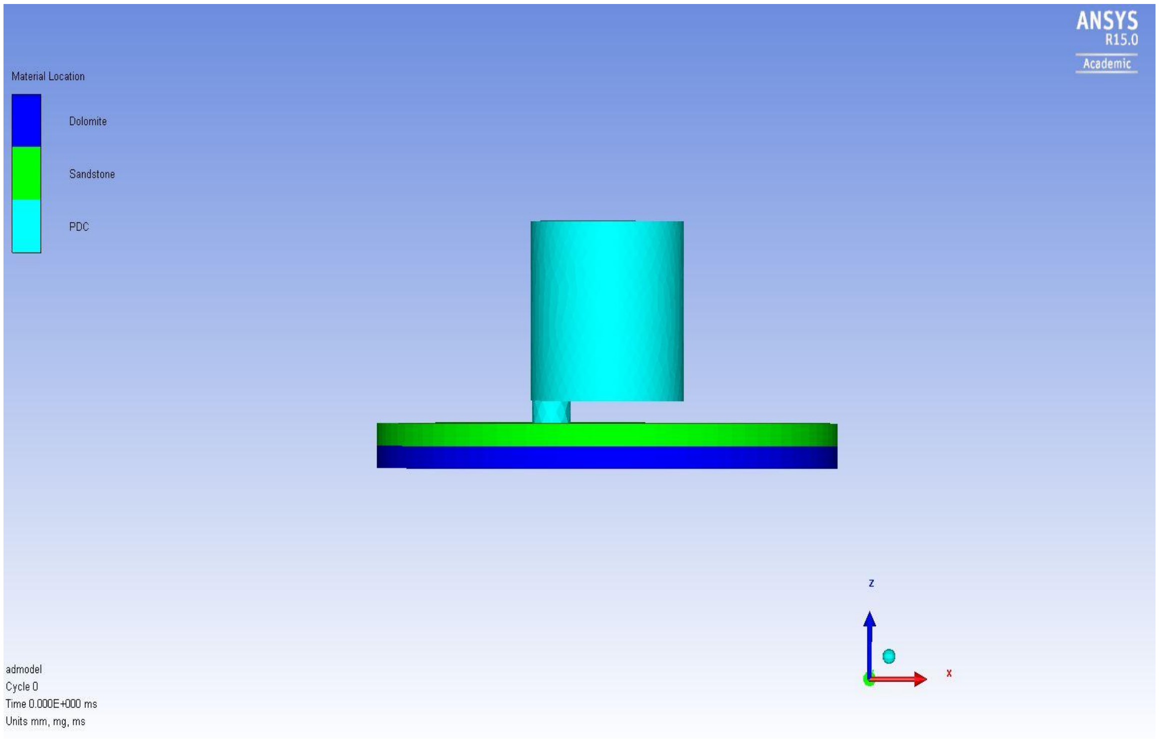

FIGURE 19. Cutter with 0° rake angle

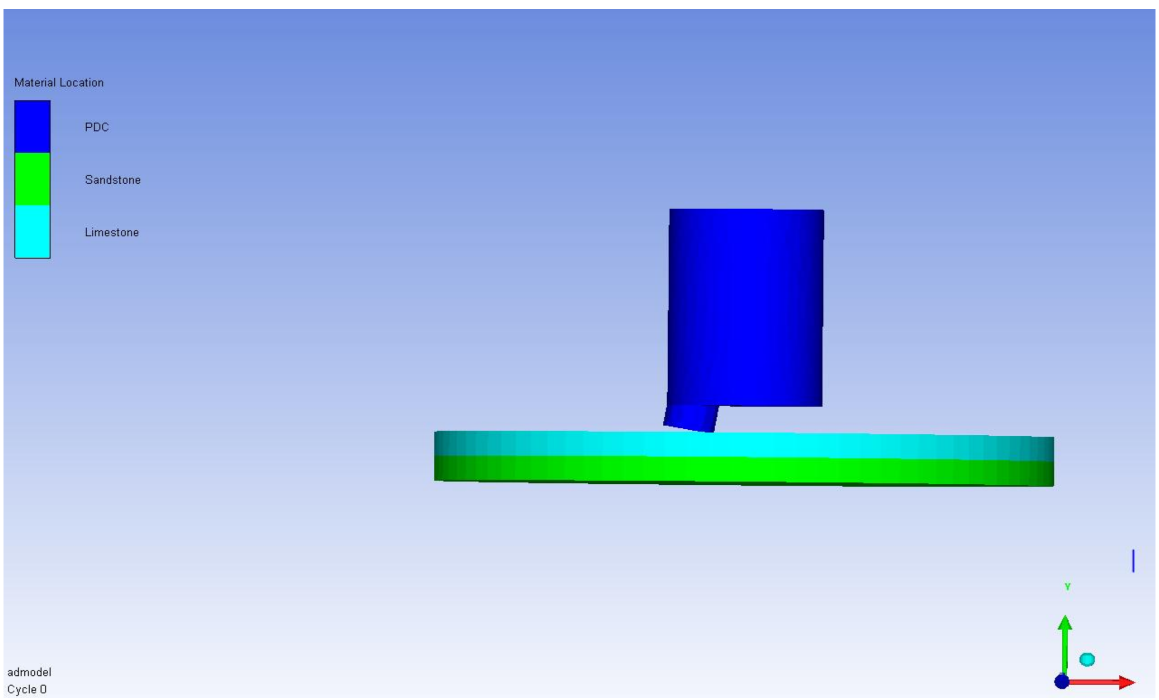

FIGURE 20. Cutter with 10° rake angle

Another parametric analysis that the author would like to try out in this project is the inclusion of drilling fluid in the drilling process as well. In real drilling situation, drilling fluid is present, and it plays an important role in drilling. Therefore, by adding a drilling fluid here, the results obtained will be much more reasonable for industrial purpose.

The procedure for the simulation setup will be the same as explained above. One extra thing that needs to be done is adding a fluid model in bit. Autodyn is used for this purpose. Autodyne has the capability of making a fluid flow simulation. There are few type of solvers that are available in Autodyn, however Euler method will be chosen here as Euler method is best used for flow of liquid or gas. The fluid flow is modeled at the centre of the bit, since there is a hole in the middle of the bit. For trial period, water will be chosen as the fluid here. The flow out of water will not be focused, as this will complicate the model even more.

Several conditions have to be set for the fluid flow. An Euler mesh first has to be constructed, in order for the simulation of fluid flow. Next, this water will be given a velocity of 10 m/s. This velocity must be lower than the bit so that water will not have greater effect on the penetration of formations. A boundary condition also has to be set to this fluid, so that water will flow continuously.

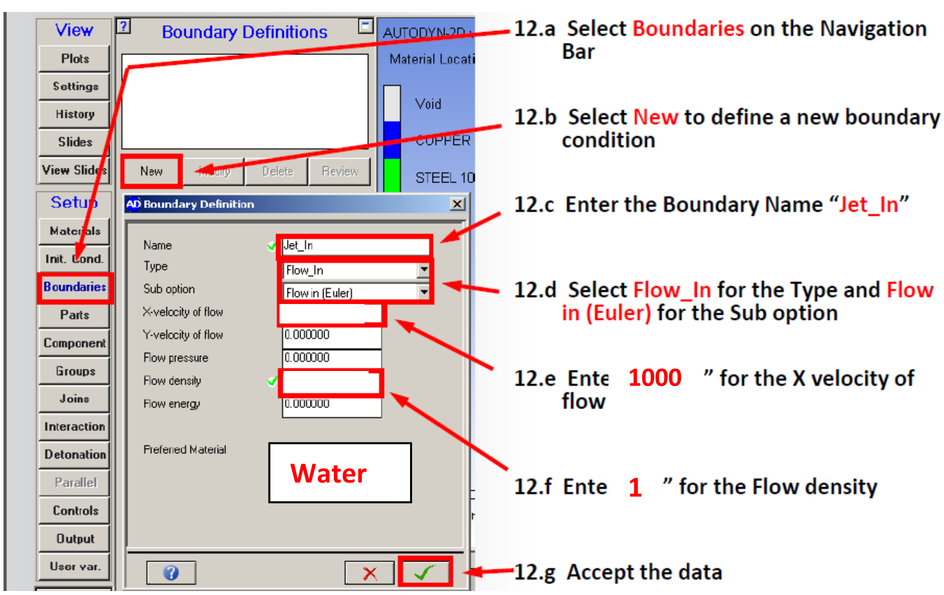

FIGURE 21. Defining boundary condition for Fluid flow

The model created for fluid flow is shown below.

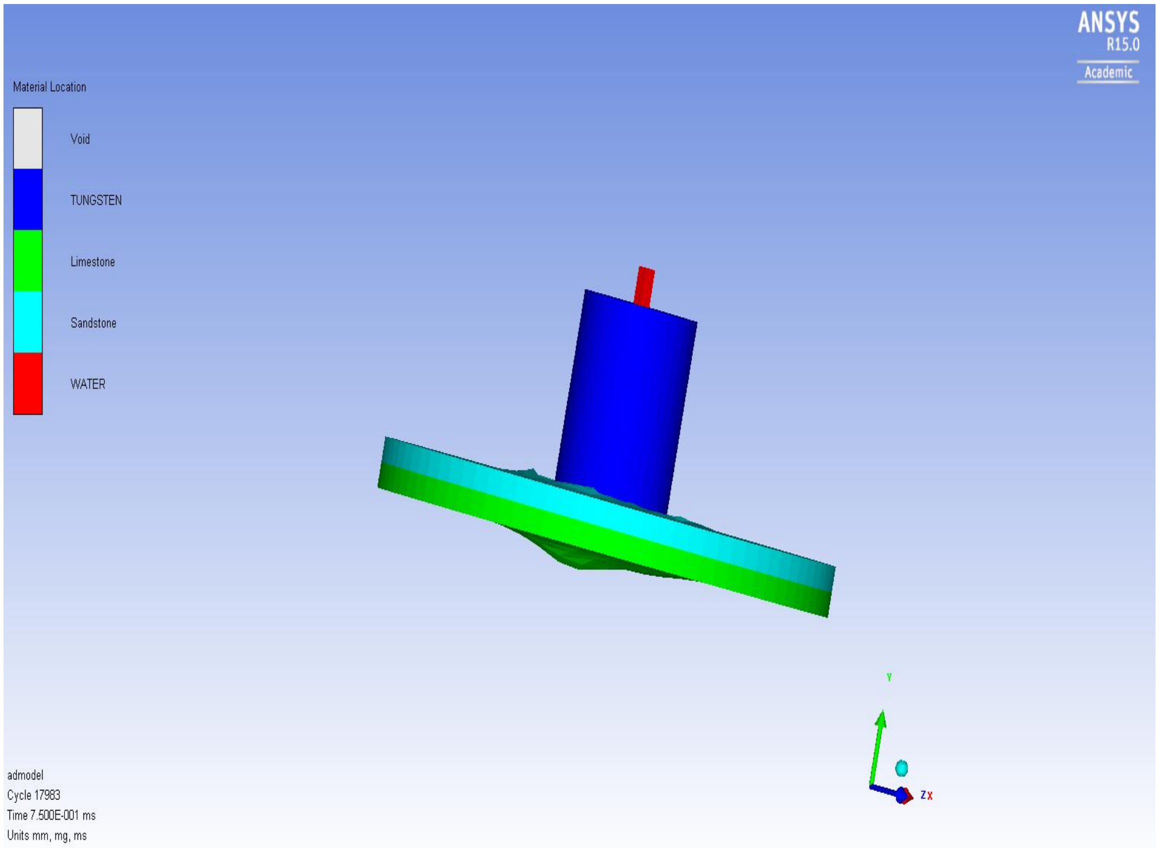

FIGURE 22. Simulation of Fluid flow

3.3 Gantt Chart and key milestone

No	Activities / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Literature Review														
2	Preliminary Research Work														
3	Preliminary model										1				
4	Field Visit to Kemaman Supply Base (KSB)														
5	Simulation using ANSYS (Explicit / Autodyn)														2

No	Activities / Week	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	Literature Review														
2	Simulation using PDC bit design					3									
3	Further simulation and parametric analysis												4		

TABLE 2. Gantt Chart for FYP 1 and FYP 2

Process Suggested Milestone

1	Key milestone 1: Completed a preliminary model
2	Key milestone 2: Completed simulation using the preliminary model created
3	Key milestone 3: Completed simulation using reverse engineered PDC Bit design
4	Key milestone 4: Completed parametric study and analysis on the simulation

TABLE 3. Key Milestone

3.4 Tools and Equipment

Tools and equipment used in this project are:

1) Computer-aided engineering simulation software, called ANSYS – Explicit dynamics/Autodyn

2) CATIA (Computer Aided Three-dimensional Interactive Application

3.5 Summary

This chapter highlighted in detail the activities done in order to get the desired results. Basically, three stages of simulations were done. First was with a preliminary model. Later on, the reverse engineered PDC bit was used to run the simulation. A static model of drilling fluid was included in that case. Due to complexity of the model, the simulation takes too long to complete, thus new model with single cutter is chosen to simulate.

The following chapter discusses all the results obtained by changing the parameters in the simulation with single cutter model.

CHAPTER 4

RESULTS AND DISCUSSION

Few sets of data were recorded from this simulation, such as directional velocity, pressure, effective strain and absolute velocity. However, in this part, focus will be given on directional velocity and pressure graphs.

4.1 Results for 0° Rake Angle

The table below represents the directional velocity of bit for three different sets of formations.

TABLE 4. Directional velocity for 0° Rake angle

Time (ms)	Directional velocity (m/s)		
	Limestone* + *Sandstone	***Dolomite* + *Limestone***	***Sandstone* + *Dolomite***
0.0	0	0	0
0.5	25	20	20
1.0	40	40	38
1.5	55	60	50
2.0	60	70	60
2.5	57	60	55
3.0	60	75	90
3.5	235	225	150

From these set of values, a graph is plotted to make a comparison on the performance of PDC bit on these different formations.

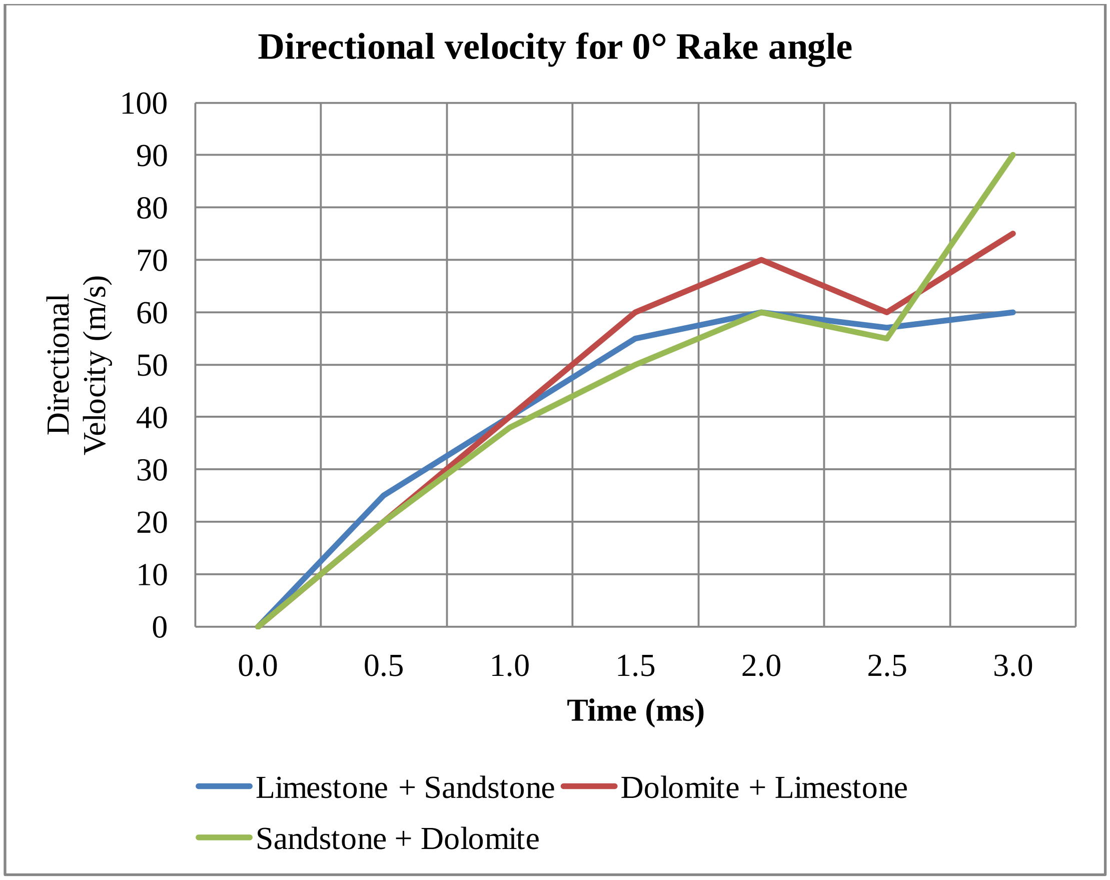

FIGURE 23. Directional Velocity for 0° Rake angle

Based on the graph above, it can be interpreted that bit with 0° rake angle works best in sandstone and dolomite formations. In the beginning of simulations, all sets of formation display similar pattern in directional velocity. Drastic changes can be observed by the time of 1.5 ms. In conclusion, the bit with this rake angle best penetrates in hard formation compared to soft formation.

Next observation will be on the pressure distribution. The pressure here is actually the pressure exerted by the bit when it hits and penetrates the formation. There are three graphs available, each for different sets of formation used during simulations. All these graphs show unstable reading due to fluctuation of pressure, as it goes high value to low value in a short period of time. Therefore, certain values could not be taken to plot new graphs, and the interpretations will be done based on the obtained graphs.

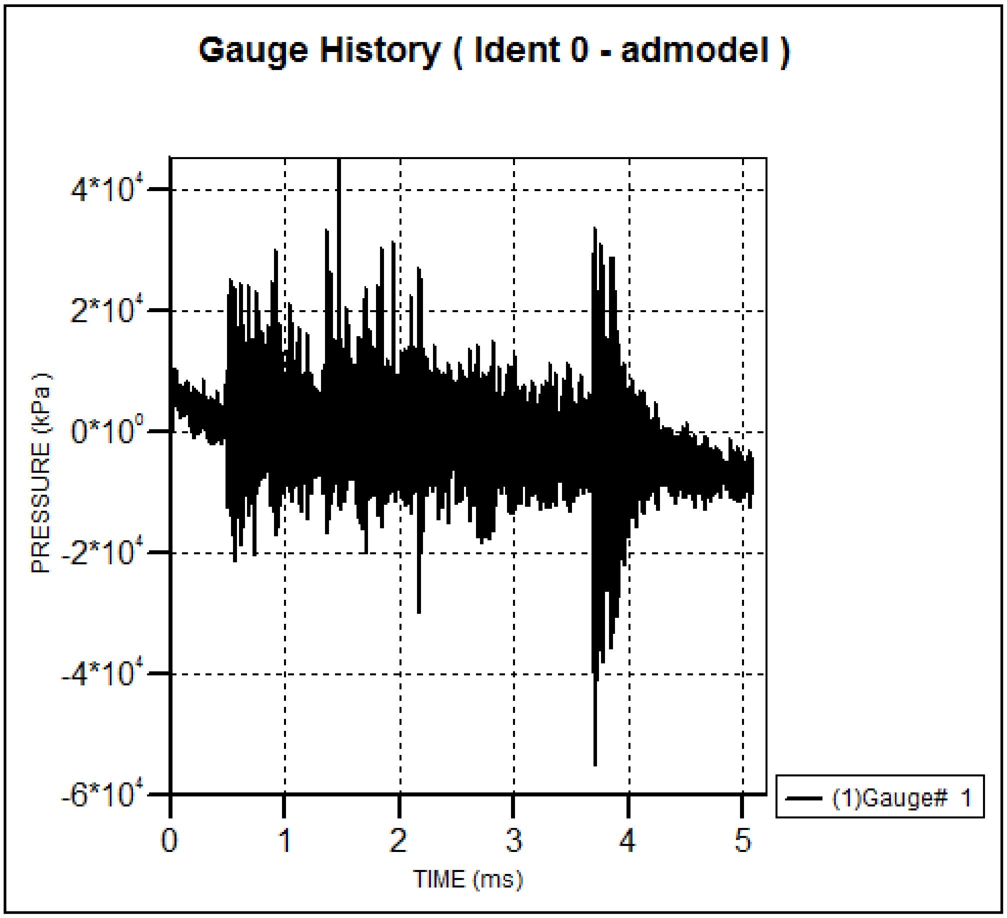

FIGURE 24. Pressure graph for Limestone & Sandstone (I)

Figure 24 shows pressure exerted in limestone and sandstone. At the beginning, a constant pressure was applied for the penetration for about 4 ms. Later, a huge pressure difference is observed, indicating the bit is now penetrating the harder formation, which in this case is sandstone. In order to drill a harder formation, the bit exerted a huge amount of pressure, estimated up until 3*10E+04 kPa. After that, less amount of pressure is observed as it was much easier for the bit to drill through the formation.

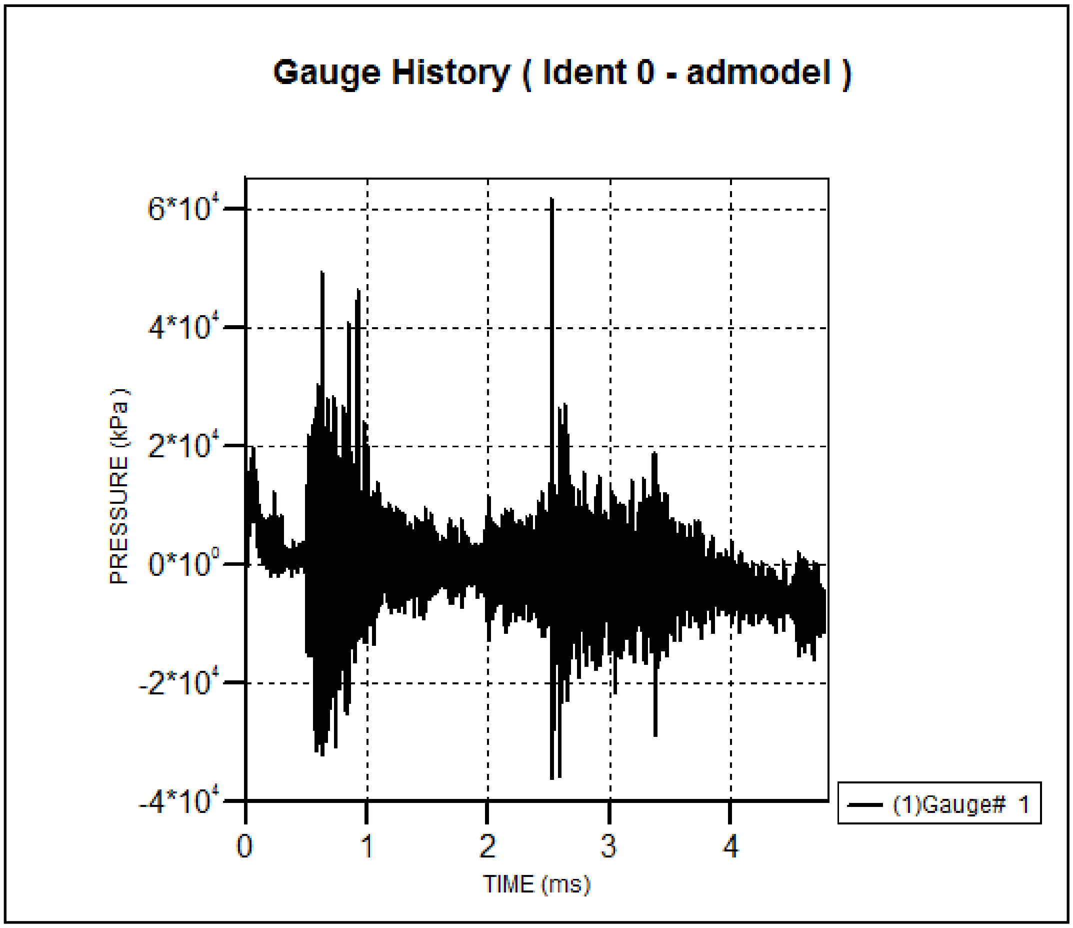

FIGURE 25. Pressure graph for Dolomite & Limestone (I)

Figure 25 displays the pressure exerted when dolomite and limestone were selected as the formation. In this simulation, dolomite represents the hard formation, while limestone represents the soft formation. At the beginning, a pressure up until 4*10E+04 kPa is required to penetrate dolomite. Although a higher pressure is observed here, the total time taken for the bit to drill through the formation is quite fast, which is around 2.5 ms. At this point, there is a rise in pressure exerted, in which can be interpreted as the bit is now drilling a new formation, which is limestone in this case. Since it is a softer formation compared to dolomite, less force is required to penetrate this formation.

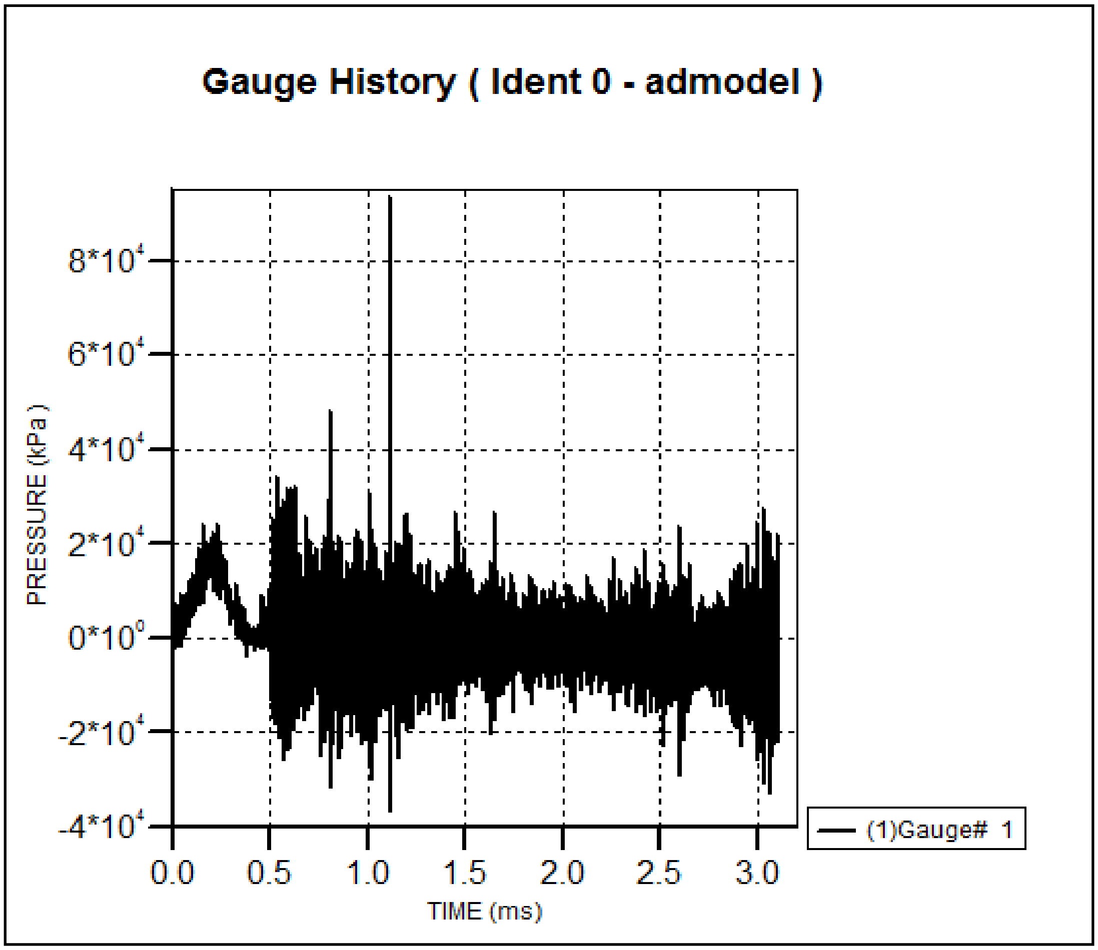

FIGURE 26. Pressure graph for Sandstone & Dolomite (I)

Figure 26 shows the result for pressure when bit with 0° is used to drill a hard layer interbedded with another hard formation, which are sandstone and dolomite in this simulation. The pressure graph does not show any point where the pressure increases or decreases tremendously in a certain point. This can be interpreted as the whole penetration process requires a constant high pressure, both for sandstone and dolomite.

Based on all the three pressure graphs above as well as the directional velocity graph, it can be generally concluded that bit with 0° rake angle basically is more efficient in hard formations, such as dolomite and sandstone, compared to soft formation.

4.2 Results for 10° Rake Angle

Another set of simulations are done, this time the parameter that was changed is rake angle. For previous case, the rake angle was 0°, meanwhile for this set a rake angle of 10° has been set for the bit. The directional velocity and pressure graph for this case will be discussed here.

The table below shows the directional velocity of the bit with 10° rake angle.

TABLE 5. Directional velocity for 10° Rake angle

Time (ms)	**Directional Velocity (m/s)**		
	Limestone + Sandstone	***Dolomite + Limestone***	***Sandstone + Dolomite***
0.0	0	0	0
0.5	10	15	15
1.0	25	25	25
1.5	40	35	35
2.0	50	50	50
2.5	65	59	55
3.0	77	55	50
3.5	90	37	35

From these set of values, a graph is again plotted to make a comparison on the performance of the bit on these different formations.

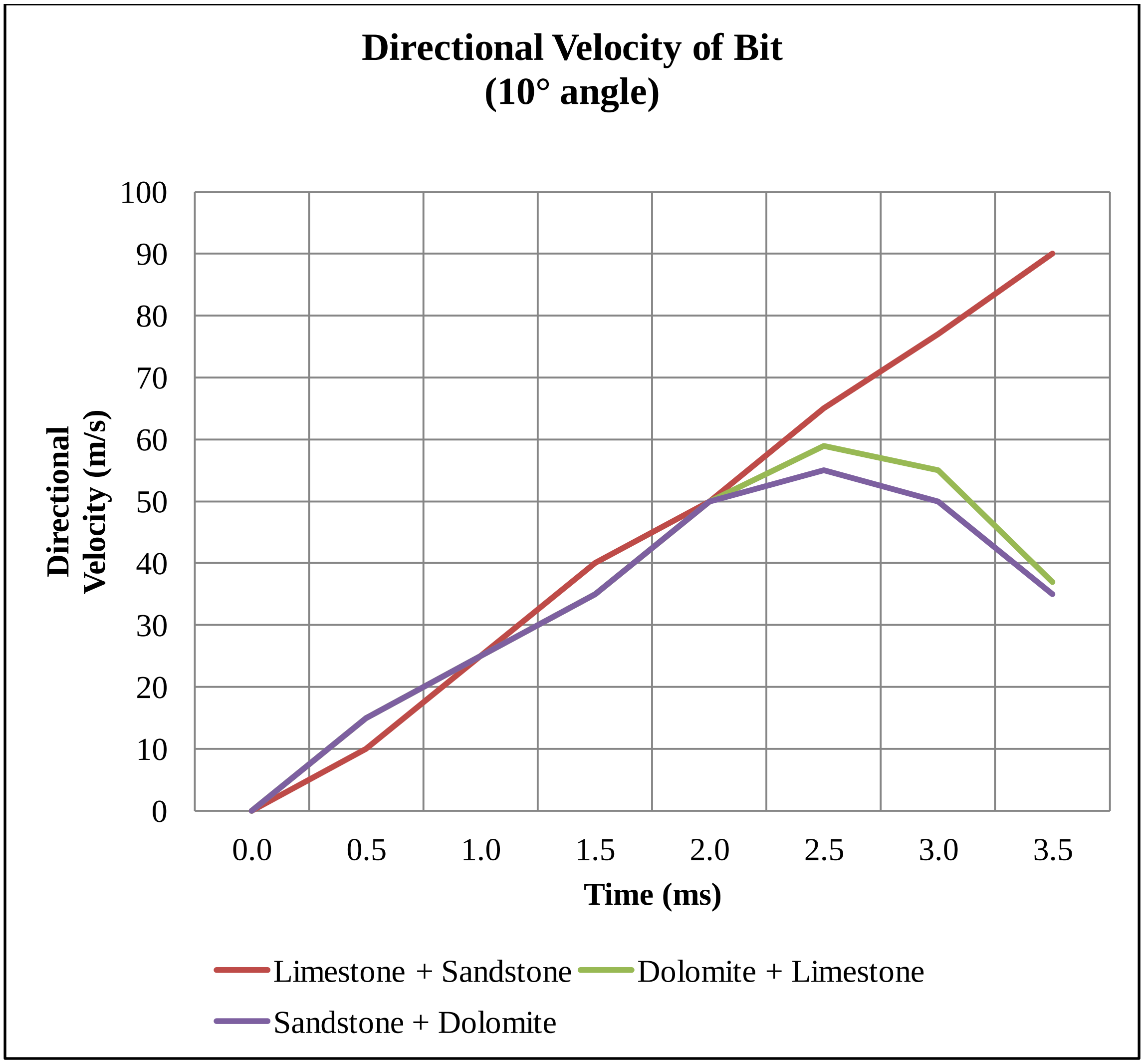

FIGURE 27. Directional Velocity for 10° Rake angle

Based on the graph above, the bit shows best directional velocity for when simulation is done using limestone and sandstone together. For this case, from the start until the end of simulation, almost a linear velocity can be observed for the bit.

Meanwhile, the graph shows similar pattern for two cases, both when the top formation is set as the harder formation. Initially, they have a high directional velocity, up until 2.5 ms. After this point, the graph shows a negative gradient, which indicates that the velocity of bit decreases when the bottom layer is about to be drilled, regardless of the strength of formations.

The pressure graphs for all these three cases are as below.

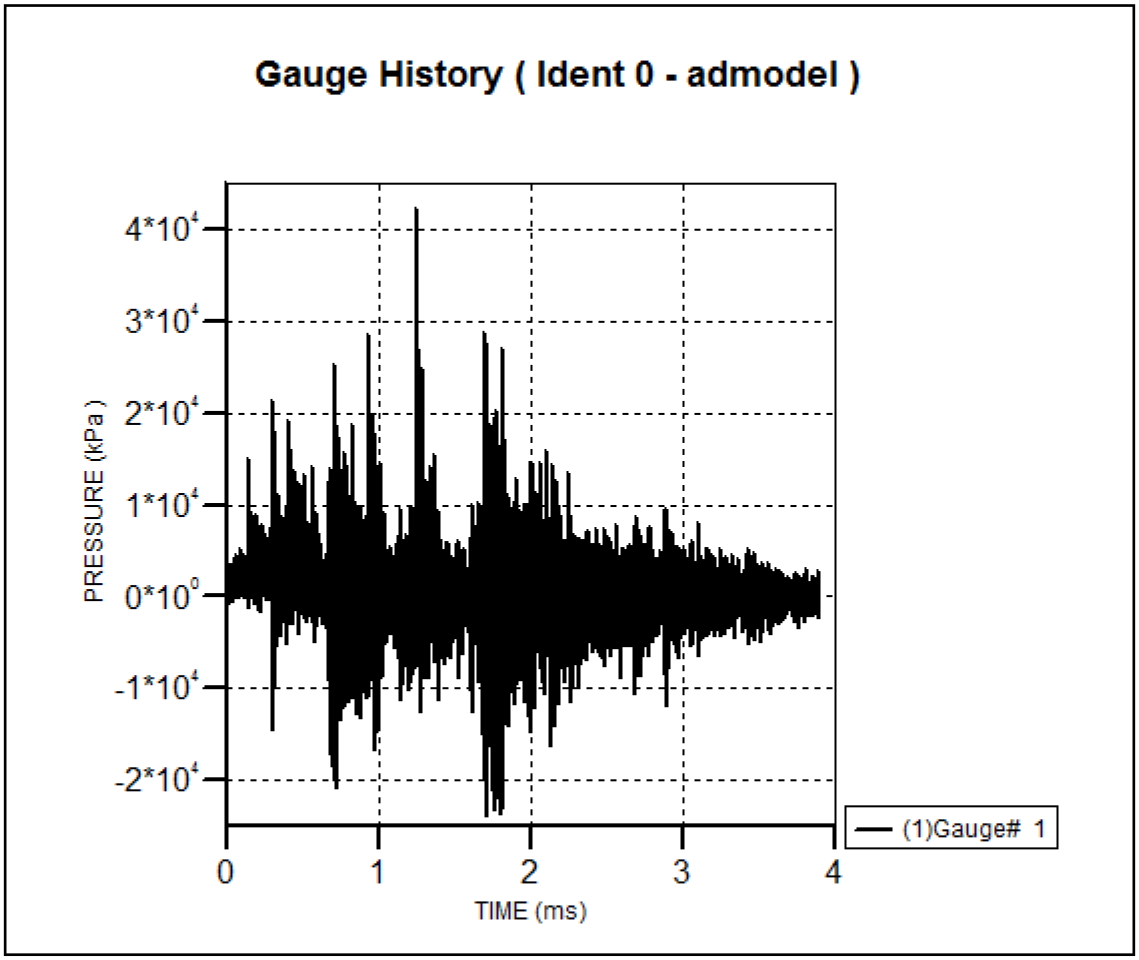

FIGURE 28. Pressure graph for Limestone & Sandstone (II)

Figure 28 shows the performance of bit when the formation consists of soft formation at the top, followed by a hard formation at the bottom. Low amount of pressure is recorded when the bit drills soft formation, and the drilling process was completed in a short period of time, which is less than 2 ms. A significant fluctuation of pressure is noted around 1.7 ms, meaning the bit started to penetrate sandstone at this time around. The pressure recorded for sandstone is less than 2*10E+04 kPa, meaning less force was required by the bit to drill through the bottom layer as well. Overall, this angle is suitable to drill a soft formation, followed by a harder formation.

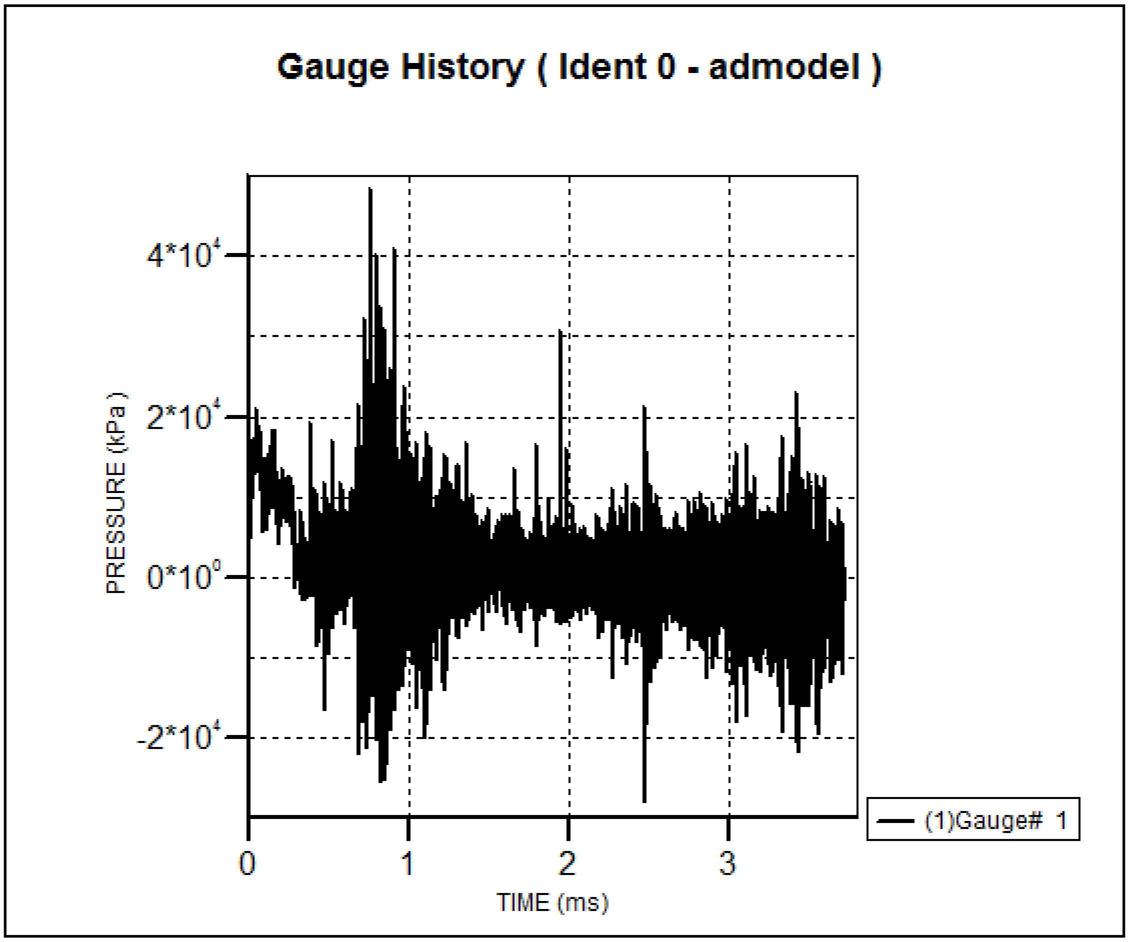

FIGURE 29. Pressure graph for Dolomite & Limestone (II)

The graph above depicts pressure distribution for dolomite and limestone formations. Unlike previous simulation, for this simulation the bit showed high pressure requirement in order to drill the hard formation first. Pressure up to 4*10E+04 was required by the bit in order to penetrate dolomite. For limestone penetration, the bit did not require much force for drilling process. This statement goes true for the earlier simulation, in which the bit drilled faster in soft formation. A constant pressure distribution is recorded through drilling the soft formation.

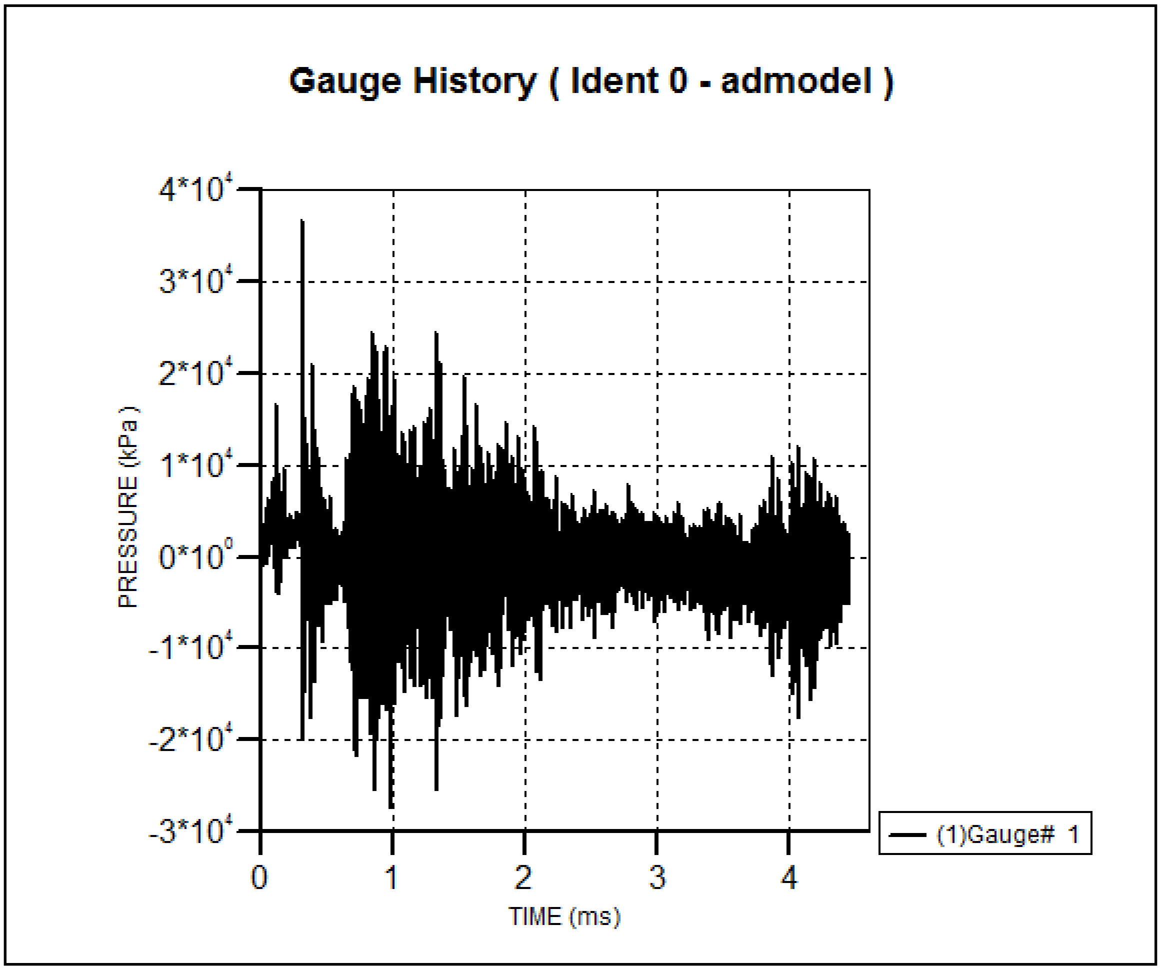

FIGURE 30. Pressure graph for Sandstone & Dolomite (II)

The last pressure graph displays the performance of bit with 10° rake angle when both the formations are hard formations. Initially, a high pressure profile can be observed, indicates that the bit exerted huge amount of force in order to penetrate dolomite. Since both the top and bottom layer are formation with hard characteristics, a constant high force was required to drill the top formation. Also, the time taken to drill through the first formation was longer compared to earlier simulations for the same condition. A rise in pressure is observed around 4 ms, meaning the second layer was drilled around this time.

Generally, when bit with 10° rake angle was used, the bit showed higher performance and efficiency when penetrating the softer formation, which is limestone. The bit showed more difficulty in hard formations.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This project has provided an insight on PDC bit performance in multi-layered formations. Some of the conclusions that can be drawn are:

1. Autodyn can be used as a solver in order to conduct parametric analysis on PDC bit on multi-layered formation.
2. Bit performance in drilling is highly influenced by the type of formation drilled. Different formations have different mechanical strength, therefore the efficiency of bit changes according to this. In this project, limestone is categorized as soft formation, whereas sandstone and dolomite are categorized as hard formations.
3. Rake angle of cutter has specific effect on the drillabillity of PDC bit.
   Cutter with 0° rake angle shows higher directional velocity in hard formations. The best penetration was observed in sandstone and dolomite formations. This cutter exerts a constant pressure at soft formation, thus it takes longer time to fully drill a hard formation, and start drilling the bottom formation. Meanwhile, in hard formation, the drilling time is very short.
   Cutter with 10° rake angle showed the best velocity trend when limestone and sandstone formations were used. A slightly high pressure is enough to penetrate the soft formation in a very short period of time. On the other hand, constant high pressure was needed to drill hard formations.

Thus, the objectives of this project have been achieved.

5.2 Recommendations

1. Use supercomputers in order to run simulation involving complex model. This is so that the simulation time can be reduced greatly.
2. Model the geometry in Autodyn, rather than exporting from Explicit dynamics.
3. Include the complete flow of drilling fluid in the system.

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